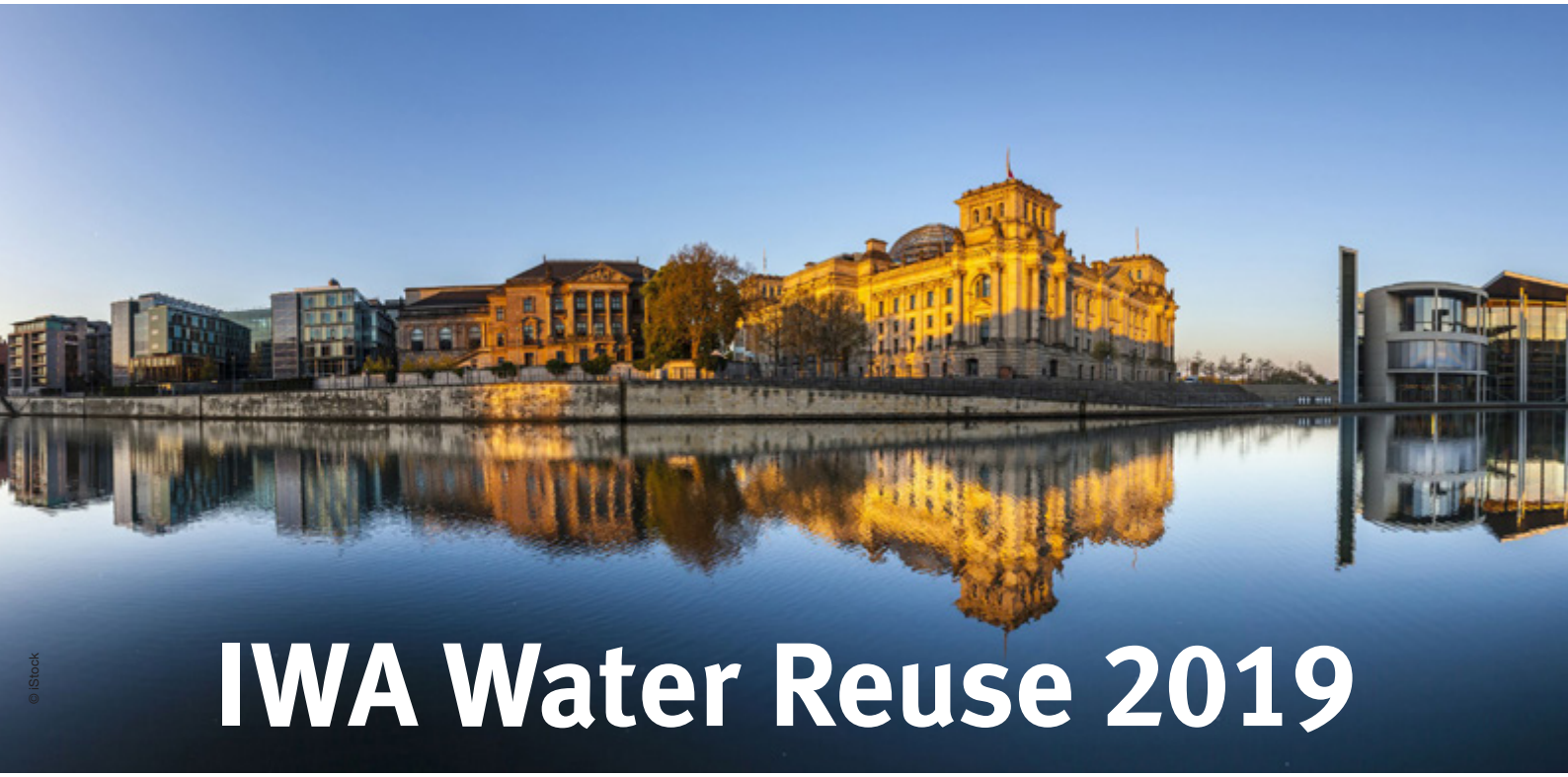
IWA WATER REUSE

the international water association



IWA Water Reuse 2019

12th IWA International Conference on Water Reclamation and Reuse

16 – 20 June 2019 · Berlin · Germany

Overcoming Water Stress by Water Reclamation and Reuse

Organizer

DECHEMA

Primary Support

DWA

Clear Concepts. Clean Environment.

Primary Sponsor

Federal Ministry of Education and Research

www.iwareuse2019.org

BOOK OF ABSTRACTS

CONTENT

Sunday, 16.06.2019

CONTENT

CONTENT

CONTENT

Monday, 17.06.2019

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

CONTENT

Lectures

Integrating Sanitation, Water Reuse and the Production of Food Crops – 6 Years of Experiences in Central Northern Namibia

Martin Zimmermann, Stefan Liehr, Thomas Kluge, ISOE – Institute for Social-Ecological Research, Frankfurt am Main, Germany; Peter Cornel, Technische Universität Darmstadt, Darmstadt, Germany

Abstract:

A sanitation and reuse system was implemented in Outapi, Namibia. It comprises the whole sanitation cycle, including provision of toilets, showers and laundry facilities, wastewater transport, treatment, reclamation and irrigation infrastructures for the production of fruits and vegetables. The system is running reliably six years after commissioning. This could only be made possible by the fact that technical implementation goes hand in hand with a demand-responsive approach. The key factors for the success of similar projects in the future are (1) the development of trust and confidence among all involved parties, (2) the combination of technological and social innovations, (3) the promotion of capacity development as well as (4) flexible project management.

Keywords: capacity development; demand-responsive approach; integrated systemic approach; irrigation agriculture; semi-arid climate; social innovations

Introduction

The goal of the CuveWaters project was to develop, implement and evaluate a sanitation system that responds to the water and sanitation challenges of peri-urban areas in central-northern Namibia. The semi-arid region is characterized by the occurrence of heavy rain and flood events as well as pronounced dry seasons and droughts, a flat topography, the absence of any receiving water bodies and dynamic population growth. Together with local stakeholders, the city of Outapi was chosen for implementation of the pilot project. The infrastructure comprises sanitation facilities in formal and informal settlements, along with a vacuum sewer system, a water reclamation plant and an agricultural irrigation site (Figure 1). The system had to cope with the local environmental, socioeconomic and legal conditions. It needed to assure safe transport of excreta without contamination of the environment during the rainy season. It had to be flexible enough to take dynamic population developments into account. Water and nutrients had to be reused in agricultural irrigation as valuable resources. Organics contained in the wastewater and residues

from the agricultural irrigation site were used for energy production, while stabilized bio-solids were applied as soil conditioner. The revenues of the agricultural reuse should subsidize operation and maintenance costs of the whole reuse system to a certain extent. The aim of this paper is to evaluate the process of implementing the project in retrospect and to derive lessons learnt from it.

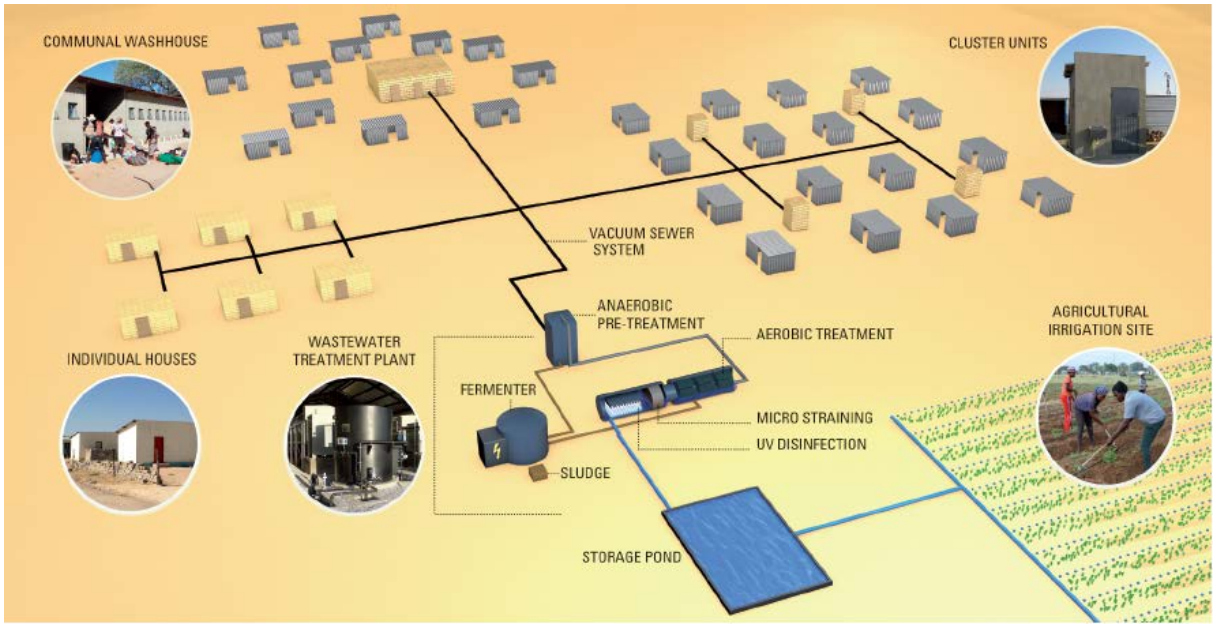


Figure 1: Overview of the sanitation and water reuse concept (CuveWaters 2015; Layout: tvt.film+vfx, 2013 – modified)

Material and Methods

An integrated systemic approach was applied which considers the entire water cycle including water supply, sanitation and water reuse for irrigation purposes (Liehr et al. 2018). In this regard, water is used several times for different purposes: for personal hygiene, as a carrier medium for the transport of excreta and as a resource for the reclamation of water, nutrients, bio-solids and energy. Planning and implementation of the project started with a community-based situation assessment. Political, institutional, social and economic aspects were of very high relevance in this process. Technical planning had to consider the design of the sanitation facilities, possible options for the collection and transport of sewage, wastewater treatment technologies, sludge treatment and energetic utilization, disinfection and removal of parasites, water storage and irrigation infrastructure. A demand-responsive approach was used to integrate the needs of the future users and the operator into planning and construction of the sanitation facilities (Kramm and Deffner 2018). This approach

is considered appropriate for adapting the design of the infrastructure and in developing management structures after commissioning.

Results and Discussion

Three types of sanitation facilities were implemented in different areas of Outapi comprising up to 1,500 residents (Müller et al. 2018). A shared sanitation facility (communal wash-house) offers flush toilets, showers, hand washing basins and laundry washing sinks. Furthermore, 30 so-called cluster units are shared by three to five families. Finally, 66 households in an area with brick houses are individually equipped with tap water and sewer connections. Vacuum sewers were used for sewage transport. Such a system provides advantages when installed in seasonal flooded flat terrain with low population density and sandy soils as it is the case in Outapi. Proper construction and sufficient training of the operators ensured long-term operation.

The wastewater is pre-treated in UASB reactors (upflow anaerobic sludge blanket) before it is processed with RBCs (rotating biological contactors) and solids are removed by a lamella clarifier (Müller et al. 2018). Organic compounds are oxidized and most of the nutrients are intentionally left in the water for later use as fertilizer. Solids and helminth eggs are removed from the secondary effluent by a micro-screen (15 µm mesh width). Finally, the effluent is disinfected by UV radiation before being stored in a pond. One drawback was that energy recovery from sewage sludge and crop residues was difficult to implement due to low quantities of organic matter contained in the sewage and agricultural residues, amongst other things.

After retention in the storage pond, the reclaimed water serves to irrigate and fertilize agricultural fields by drip irrigation in order to produce crops for human consumption (Zimmermann et al. 2018). The cultivable land covers a net area of approx. 3 ha in total due to the reclamation plant's capacity of approx. 90 m^3 per day. The drip irrigation prevents fruits or vegetables from direct contact with irrigation water as long as no crops growing in or on the ground are used. Hence, the crop scheme mainly comprised crops such as tomatoes, green peppers, maize, water melons, sweet melons, spinach, butternut squashes and cabbage.

Since the start of operation in 2013 and more than three years after the plant was handed over to the town in 2015, the sanitation facilities are in regular use since then and are being well maintained. The number of users in the washhouse is strongly

influenced by the tariff levels and how billing is carried out. The vacuum sewer system and wastewater treatment (i.e. UASB, RBC, UV) function reliably. The reuse of nutrient-rich water for irrigation provides a lot of potential. Crops for human consumption are being produced and several full-time and part-time jobs were created. However, the responsible farmer needs professional experience as well as sound agricultural knowledge and business skills in order to carry out the farming activities. Key factors for a successful replication of the reuse concept in institutional and organizational terms are a clear allocation of responsibilities between the operator or municipality and the farmer along with effective controlling by the operator. Table 1 summarizes the achievements and challenges of the sanitation and reuse system.

Table 1: Overview of achievements and challenges during implementation of the sanitation and reuse system (Müller et al. 2018)

Achievements:
• The sanitation facilities were well accepted and properly maintained
• The vacuum sewer system and water reclamation plant worked reliably
• Irrigation water quality objectives were met
• Profitable crop yields were obtained
• Jobs were created
• The demand-responsive approach facilitated well-adapted implementation
• Users responded positively towards the contribution of the project
• Operator skills were sufficient to carry out operation and maintenance tasks
• The system results in benefits of an ecological and social nature
• The Outapi Town Council (OTC) demonstrated a high level of commitment throughout the project period
Challenges:
• Thorough supervision was required throughout the construction phase
• Energy recovery from sewage sludge and biomass could not be fully implemented
• Problematic material (most notably stones of the Eembe fruit, Berchemia discolor) contained in wastewater needs to be removed
• There is a need for further improvement to the skills of the farmer and OTC management
• Ongoing participation of the users and OTC needs to be maintained
• Funding is required to cover the cost of investment and any financial deficits with regard to operation and maintenance
• It is important to correctly estimate future utilization and the water quantities

needed

From the residents' perspective, the technical and societal measures carried out during the project reduced open defecation and improved hygienic conditions in the settlements as well as the inhabitants' health status. The incidence of diarrhea in surveyed households decreased considerably in all settlements. Furthermore, the water reuse considerably improved the efficiency of water use in a water-scarce region and avoids spills of water in the environment.

The early involvement of stakeholders and the establishment of community health clubs turned out to be important in developing and implementing the tariff and management system that fitted the requirements and capacities of Outapi's administration. On the whole, the staff operating the vacuum sewers, water reclamation plant and irrigation site carried out their tasks autonomously after corresponding training. Future capacity development needs to focus on the operator's management skills and the transfer of business expertise to the farmer.

An important lesson learnt was that the future number of users and water quantities to be treated were overestimated due to unpredictable population dynamics. This led to oversized sanitation facilities, sewers and water treatment facilities as well as less water and nutrients for irrigation. Lower amounts of wastewater sludge and agricultural residues for energy purposes resulted also in lower energy savings.

The experiences with this project provide a basis for improved planning in order to fully utilize the capacity of the water reuse plant. Although funding of investments remains a major challenge, ecological and social benefits such as reduced health costs and improved food security have to be highlighted at this point from a regional economic perspective.

Conclusions

On the whole, this pilot project provides a tailor-made solution to sanitation challenges in water-scarce, urban and peri-urban areas in semi-arid developing countries. It comprises the whole sanitation cycle, including provision of toilets, showers and laundry facilities, wastewater transport, treatment, reclamation and irrigation infrastructures. This however is only successful if technical implementation goes hand in hand with a demand-responsive approach. The key factors for the success of similar projects in the future are (1) the development of trust and confidence among all involved parties, (2) the combination of technological and

social innovations, (3) the promotion of capacity development and multiplication of the proposed technologies as well as (4) flexible thinking which is not attached to linear planning (Liehr and Kluge 2018).

The project experiences show that trust and confidence are crucial for the project's success. Factors contributing to this comprise for instance a continuous communication flow that has to be maintained between the consortium and the partners in the target country, a strong emphasis on the demands of local and regional stakeholders, obtaining follow-up funding for the project, addressing all technical and social challenges occurring during the project and finally personal engagement of the project team members throughout various activities.

Technological innovations also involve the introduction of social innovations with various challenges such as a lack of knowledge as well as of practice and institutions for successful implementation in everyday routines. The activities needed for such kind of social innovations can only partially be planned from the start such as capacity development, institutionalization around operation and maintenance of the pilot plant, monitoring and knowledge management.

Bridging the gap between research and practice requires properly adapted and effective capacity development. This is the basis for the operation and maintenance of technological innovations and functioning institutions behind them. It paves the way for economic viability and dissemination of the solutions. Capacity development for institutions also promotes openness towards new technological opportunities.

Finally, a project that strives for implementation in practice addresses also problem resolution as well as conflict and crisis management in addition to scientific challenges. Research under such circumstances cannot be planned and conducted in a linear manner. Flexibility is necessary on the part of the researchers but also on the part of the funding institution and all project partners. There is a considerable need for resources and competences for dealing with the re-planning of processes, ad hoc reactions and temporary intensification of communication processes.

References

CuveWaters (2015): Omeya ogo omwenyo – Water is Life. CuveWaters Report

Kramm J. and Deffner J. (2018): Social aspects of new sanitation infrastructure. In: Integrated Water Resources Management in Water-scarce Regions. Water Harvesting, Groundwater Desalination and Water Reuse in Namibia, Liehr S., Kramm J., Jokisch A. and Müller K. (Edts.), IWA Publishing, London, pp. 52-59

Liehr S. and Kluge T. (2018): Challenges of transdisciplinary research and lessons learnt. In: Integrated Water Resources Management in Water-scarce Regions. Water Harvesting, Groundwater Desalination and Water Reuse in Namibia, Liehr S., Kramm J., Jokisch A. and Müller K. (Edts.), IWA Publishing, London, pp. 235-240

Liehr S., Kramm J., Jokisch A. and Müller K. (Edts.) (2018): Integrated Water Resources Management in Water-scarce Regions. Water Harvesting, Groundwater Desalination and Water Reuse in Namibia. IWA Publishing, London.

Müller K., Cornel P. and Gerlach M. (2018): Collection, transport and treatment. In: Integrated Water Resources Management in Water-scarce Regions. Water Harvesting, Groundwater Desalination and Water Reuse in Namibia, Liehr S., Kramm J., Jokisch A. and Müller K. (Edts.), IWA Publishing, London, pp. 32-41

Müller K., Cornel P. and Kluge T. (2018): Conclusions. In: Integrated Water Resources Management in Water-scarce Regions. Water Harvesting, Groundwater Desalination and Water Reuse in Namibia, Liehr S., Kramm J., Jokisch A. and Müller K. (Edts.), IWA Publishing, London, pp. 81-83

Müller K., Cornel P. and Kluge T. (2018): Integrated systemic approach. In: Integrated Water Resources Management in Water-scarce Regions. Water Harvesting, Groundwater Desalination and Water Reuse in Namibia, Liehr S., Kramm J., Jokisch A. and Müller K. (Edts.), IWA Publishing, London, pp. 28-31

Zimmermann M., Woltersdorf L., Felmeden J. and Müller K. (2018): Water reuse for agricultural irrigation. In: Integrated Water Resources Management in Water-scarce Regions. Water Harvesting, Groundwater Desalination and Water Reuse in Namibia, Liehr S., Kramm J., Jokisch A. and Müller K. (Edts.), IWA Publishing, London, pp. 42-51

Waste stabilization ponds with pre-treatment provide irrigation water – a case study in Namibia.

Sinn, J., Technische Universität Darmstadt, Institute IWAR, Darmstadt, Germany;
Cornel, P. Technische Universität Darmstadt, Institute IWAR, Darmstadt, Germany;
Lackner, S., Technische Universität Darmstadt, Institute IWAR, Darmstadt, Germany;
j.sinn@iwar.tu-darmstadt.de

Abstract:

This research presents the implementation of pre-treatment technologies to reduce the load to a full scale waste stabilization pond in Namibia. Often these systems are too small and produce insufficient effluent quality for reuse. Here, we investigated the effect of anaerobic biological (by an upstream anaerobic sludge blanket (UASB) reactor) and mechanical (by a micro-screen) pre-treatment to reduce solid and organic loads. Little data is available so far, which technology to choose, and what these technologies are able to achieve. First results revealed that both technologies are able to reduce COD and solids, with better results for the micro screen so far. However, stable operation of the micro-screen remains challenging and more difficult in comparison.

Keywords: Developing country, Fodder production, Improvement of existing wastewater treatment systems, Nutrient recovery, Water reuse

Introduction

The importance of water reuse is constantly increasing, especially in Africa, where climate change affects farmers by variable rainfall or their complete outage. At the same time, towns with sewer systems treat wastewater in waste stabilization ponds (WSP). However, many of these regions lack receiving water bodies, leaving evaporation of the treated wastewater as the only choice. Additionally, these systems are often too small and overloaded due to the steady rise in population numbers. Typical enhancement is realized through new ponds and an increase of the area of the plant.

The need for reuse of treated municipal wastewater from WSP in water scarce areas is increasing (Mara, 2009). Many of the pond systems were originally designed only for evaporation due to the lack of receiving water bodies. With extended drought periods due to climate change, evaporation may not be a sustainable option for the future any longer. With the focus now shifting more and more towards water reuse,

e.g. for irrigation, WSP face new challenges. With the increase in population and need for more water, WSP now have to accommodate to (a) fast population growth, (b) reuse of water resources, (c) reuse of nutrients, (d) production of crops and (e) reduction of greenhouse gas emissions (Hernandez-Paniagua et al., 2014, Shelef and Azov, 2000).

One way of accomplishing these goals can be the purposeful upgrade of the existing WSP with other technologies. This project aims at comparing an upstream anaerobic sludge blanket (UASB) reactor to a micro-screen as pre-treatment technologies in order to reduce COD_{tot} and TSS, targeting values of 40-70 % and 20-75 %, respectively (Lazarova and Bahri, 2005). The results are especially important for fast growing communities in warm climates with the need of water reuse for irrigation and for regions without perennial streams (Buttler et al., 2017). Therefore, one line of an existing WSP system in Northern Namibia was improved with such a pre-treatment to investigate the effect on performance and effluent quality.

Material and Methods

The study was carried out in the city of Outapi in Northern Namibia (Figure 1). In 2011, Outapi had a total population of 6,437 persons (NSA, 2011). In its informal settlements, simplest sanitary facilities are used or open defecation is practiced. In town districts, that are better developed, flush toilets are used. The only wastewater infrastructure in Outapi at that time was a gravity sewer system in the developed parts of town and the WSP that were constructed in 2004. Back then, Outapi had a population of about 3,000, with 2,500 having access to sewerage services.

The WSP system has two parallel lines (line A and line B) with four ponds each: one primary facultative pond (1) followed by three maturation ponds (ponds 2 – 4). All eight ponds have a total water surface area of 40,000 m^2 and a total volume of 55,000 m^3. The final evaporation pond has a surface area of 41,000 m^2 and a volume of 20,000 m^3. The original design employed an alternating feed rhythm between the two lines.

Improvements were installed in line A, whilst line B remained in its original stage to act as a comparison for gauging the effect of the modifications. At the inflow of the plant a pre-treatment consisting of an UASB reactor with 42 m^3 volume, 3-4 m^3/h inflow, 10-14h hydraulic retention time and a micro-screen (Noggerath Rotary Drum Screen Mircro Giant®) with a 250 *µm* mesh were installed in parallel to reduce the organic

load to line A. Additionally, baffles were installed in the first pond of line A to optimize flow conditions by getting closer to a plug flow reactor rather than the current uncontrolled mixed reactor.

Wastewater quantities were measured with inductive flow meters and water quality was monitored in-situ with WTW probes (pH, dissolved oxygen, conductivity). Grab samples were analyzed regularly with Hach Lange LCK cuvette tests for COD, ammonium, nitrite, nitrate and phosphate. Indicator bacteria were examined with IDEXX Colilert-18 and Quanti-Tray/2000 (see www.idexx.de).

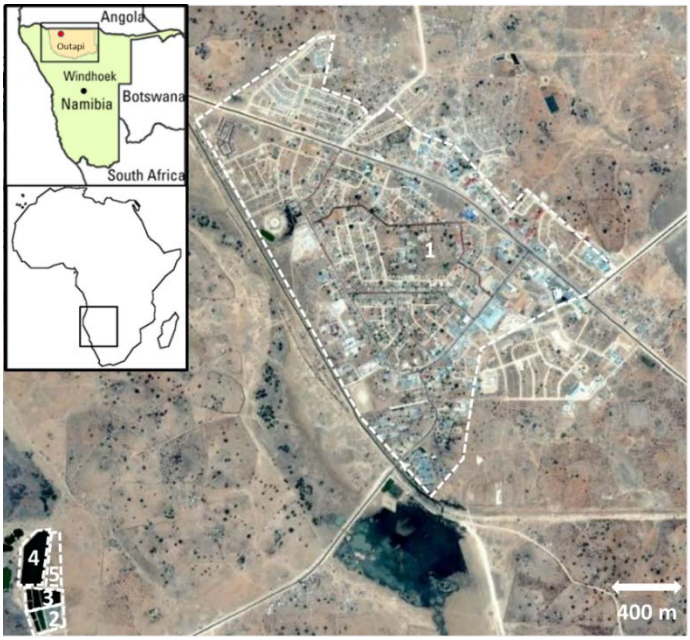


Figure 1: Location of wastewater components in Outapi: gravity sewer with pump stations (1) and wastewater stablisation ponds with improved line A (2), original line B (3), evaporation pond (4) and irrigation site (5) (Google Earth (Version 7.1.8.3036) 2016, Price and Hegnauer 2017, modified).

Results and Discussion

According to the Namibian code of practice (DWA, 2008) all effluents from wastewater treatment ponds have to evaporate and are not to be discharged into the environment. Evaporation ponds, however, are in danger of overflowing, also the one in Outapi, which has been overflowing several times, due to the high population growth, continuous extension of the gravity sewer system and infiltrating water during the rainy season. Especially during this period, the surrounding ephemeral surface waters are at risk of contaminations caused by the low treatment efficiency and overflows.

The population growth presents a big challenge for the Outapi Town Council, which is operating and maintaining the WSP. Until 2018 the population increased to around 11,000 people with 6,500 connected to the gravity sewers (Mwinga et al., 2018). The original WSP did not allow for the required retention time of 40 days (DWA, 2012). Therefore, the water quality targets for water reuse have not been met so far. The effluent quality of the WSP before the improvements are presented in Table 1.

These values underline, that especially the concentration of the total COD (COD_{tot}) remained relatively high in the effluent with 275 mg/l and a reduction of 65 % from the influent to the effluent of B4. Most of the reduction of the chemical parameters took place in B1, and only a further reduction of 5 – 15 % occurred from pond B2 to the effluent of B4 for these parameters (in Table 1). Extensive nutrient removal might, however, not be necessary, if the water is used for irrigation and the nutrients can be used for fertilization.

Table 1: Water quality parameters of the WSP before enhancement (Mar-May 2017)

Parameter	Influent WSP (mg/l)	Effluent B1 (mg/l)	Effluent B4 (mg/l)
COD_{tot}	780	400	275
COD_{filt}	250	85	75
P_{tot}	9.6	7.1	6.9
N_{tot}	77	54	44
NH_4-N	57	27	24
TSS	322	197	89

A different picture presented itself for the microbial parameters. The concentrations of *Escherichia Coli* are shown exemplarily in Figure 2. The concentration of *E.coli* reduced in each pond reaching minimum values of approximately 7E+03 MPN/100ml with a reduction of 99.95%. Threshold values for *E.coli* are between 1E+03 – 1E+04 depending on the guidelines (WHO or Namibian Code of Practice for Water Reuse, DWA, 2008). Therefore, a further reduction of pathogens is desirable for save water reuse.

The setup of the existing two-line WSP system (Figure 3) allowed to improve line A with pre-treatment, guiding walls (and post-treatment) whilst line B remained in its original unimproved configuration for comparison. These improvements should help to overcome disadvantages of WSP such as large land requirements, high evaporation losses, high methane emissions and high COD and TSS concentrations in the effluent.

From July until December 2018, the average total inflow was 753 m³/d with a peak of 1267 m³/d after the first rains in November. During the commissioning phase (July-mid September) the daily inflow to the pre-treatment (line A) was about 1/3 (242 m³/d) of the total inflow (735 m³/d). The inflow further increased during the next phase (September-October 2018), to up to half (384 m³/d) the total inflow (774 m³/d). The average feed to the UASB was 50 m³/d, and 418 m³/d to the micro-screen during this phase. The difference of 84 m³/d accounts for the spray water which was circled back to reduce floating sludge in the buffer tank.

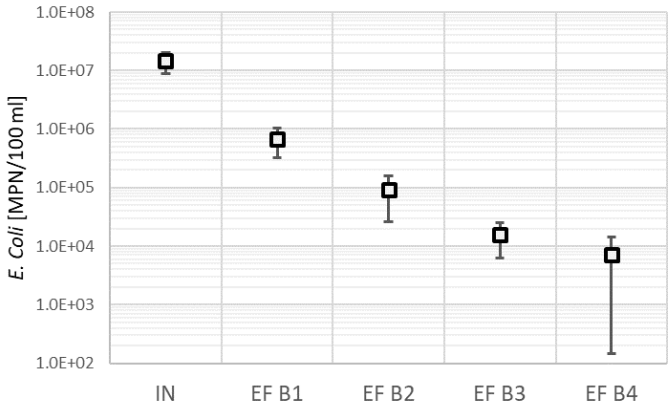


Figure 2: Course of Escherichia Coli concentrations throughout line B from the influent (IN) over the effluent of pond B1 (EF B1) down to the effluent of ponds B2 – B4 (EF B2 - EF B4); MPN – most probable number

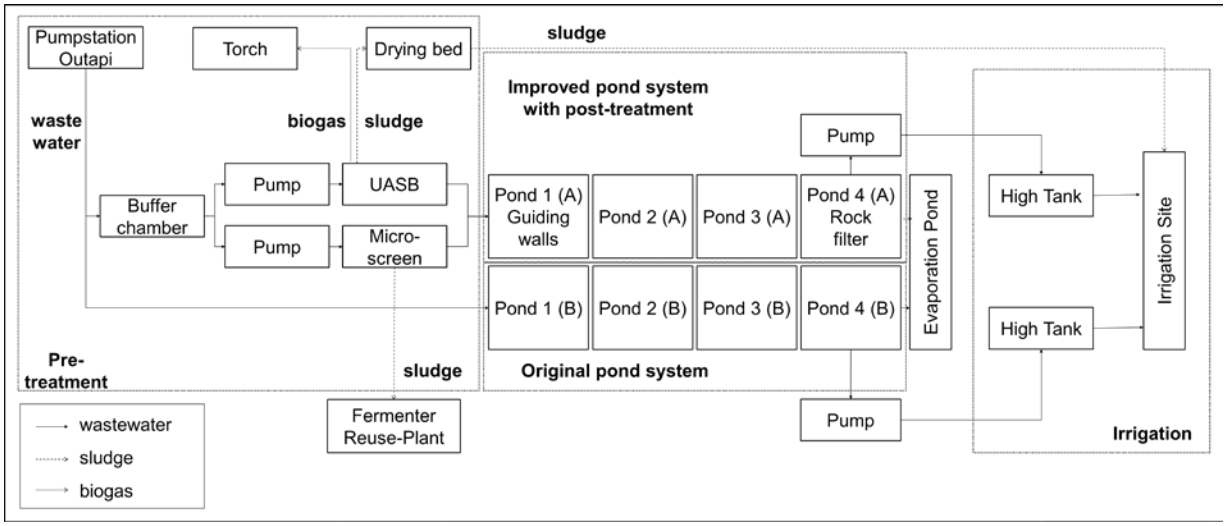


Figure 3: Flowchart of the improved waste stabilisation pond system

The volumetric loading rates of the UASB were about 1260 g/(m³·d) and 550 g/(m³·d) of COD_{tot} and TSS, respectively. COD_{tot} and TSS were reduced through sedimentation and anaerobic digestion, and the UASB reached initial reductions of 15

– 20%. A further development of the anaerobic sludge bed within the coming weeks and months is expected to further improve the performance of the UASB.

During an intensive testing phase of the micro-screen, different flows and operation parameters were examined (Table 2). At first, the inflow was increased from 28 m³/h to 60 m³/h (maximum capacity of feed pump: 67 m³/h). Secondly, the impounding depth was increased from 10 to 18 cm. In the third step, the drum was cleaned with a 2% potassium hydroxide solution at 60°C.

The change of impounding depth had a positive effect on the spray water consumption in relation to the inflow, and decreased to 3.7%. At the same time, the elimination of the total and particulate COD slightly improved from 16 % to 17 % and 25 % to 27 %, respectively. The cleaning of the screens had no significant effect on the spray water consumption. It only slightly increased, but this might have also been a result of the change in inflow rate. The elimination rates of COD_{tot} and COD_{part} further improved to 18 % and 29 %, respectively.

Table 2: Elimination rates of micro screen

Mode	Operation details	Spray water (m³/h)	Spray water / inflow (%)	COD_{tot} elimination (%)	COD_{part} elimination (%)
1	Inflow between 28 m³/h and 61 m³/h	2.2	4.9	16	25
2	Increased impounding depth (10 to 18 cm) (inflow: 29-60 m³/h)	1.7	3.7	17	27
3	Chemical cleaning (18 cm impounding, inflow: 29-67 m³/h)	2.3	3.9	18	29

These first observations suggest, that the micro-screen in Outapi achieves elimination rates which are at the lower range compared to others, e.g. the 15-25 % reduction of COD_{tot} reported by Lazarova and Bahri (2005). The elimination of the TSS was also estimated to be at the lower level with 20-35 %.

The sieving residue from the micro-screen (1.5 m³/week) was collected and transported to a fermenter at another wastewater treatment reuse plant (CuveWaters) in town on a weekly base. There it was co-digested and the produced biogas was transformed to energy with a combined heat and power unit. Thereby, the pre-treatment can reduce methane emissions by 70-160 m³/d. Methane emissions with their 28 times higher global warming potential (GWP_{100}) than CO_2, are thus also reduced. Nitrogen and phosphorus mostly remain in the water and can thus be used

as fertiliser for later irrigation purposes. The digested sludge is also dried and later used as fertiliser on the agricultural fields.

Conclusions

A UASB and a micro-screen were compared for their ability to serve as pre-treatment stages to improve WSP. Both technologies can be viable installations as pre-treatment of WSP in warm climates, especially, if there is only limited space available for extensions. However, power supply and increased maintenance for pumps and machinery, become necessary. As these technologies mainly reduce the COD and solids in the wastewater, the nutrients nitrogen and phosphorus are only partially taken up by algae, and therefore, remain in the water as valuable nutrients for the further irrigation purposes. Further research is necessary on the long term performance and operation stability of the UASB and micro-screen to compare their reduction capacities within the local context.

Acknowledgements

This research is conducted within the joint research project EPoNa (grant number 02WAV1401A-F), which is funded by the German Federal Ministry of Education and Research under the funding measure Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination - WavE.

References

Buttler, E., Hung, Y.-T., Al Ahmad, M.S., Yeh, R.Y.-L., Liu, R.L.-H. and Fu, Y.-P. (2017). Oxidation pond for municipal wastewater treatment. Applied Water Science, 7(1), 31-51.

DWA (2008). Code of practice: Volume 2 Pond Systems, General Guidelines, July 2008, Department of Water Affairs and Forestry, Ministry of Agriculture, Water and Forestry, Windhoek.

DWA (2012). Code of practice: Volume 6 Wastewater Reuse, July 2012, Department of Water Affairs and Forestry, Ministry of Agriculture, Water and Forestry, Windhoek.

Hernandez-Paniagua, I.Y., Ramirez-Vargas, R., Ramos-Gomez, M.S., Dendooven, L., Avelar-Gonzales, F.J., Thalasso, F. (2014). Greenhouse gas emissions from stabilization ponds in subtropical climates. Environ Technol, 35(5-8), 727-734.

Lazarova, V. and Bahri, A. (2005). Water Reuse for Irrigation – Agriculture, Landscapes, and Turf Grass, Boca Raton, FL: CRC Press.

Mara, D.D. (2009). Waste stabilization ponds: Past, present and future. Desalination and Water Treatment, 4(2009), 85-88.

Mwinga, M., Siboleka, M., Kavezuva, C. (2018). Economy Profile for Outapi. Windhoek: First Capital Namibia.

Shelef, G. and Azov, Y. (2000). Meeting stringent environmental and reuse requirements with an integrated pond system for the twenty-first century. Water Science and Technology, 42(10), 299-305.

Wastewater disinfection for agricultural reuse using solar radiation in a Developing Country: field observations

Tamires Lima da Silva1, Department of Rural Engineering, Agronomic Science Faculty- São Paulo State University, Botucatu-SP, Brazil, Rodrigo Máximo Sánchez Román, Department of Rural Engineering, Agronomic Science Faculty- São Paulo State University, Botucatu-SP, Brazil; João Gabriel Thomaz Queluz, Institute of Geosciences and Exact Sciences- São Paulo State University, Rio Claro-SP, Brazil, email: tamireslsilva@gmail.com

Abstract:

The aim of this study was to determine the feasibility of using solar radiation to disinfect reclaimed urban wastewater for agricultural reuse. The solar disinfection system (SODIS) used in the experiment presents a concrete base and shape of an inverted truncated cone. Fixed depths of wastewater (0.10; 0.15 e 0.20 m) were exposed to solar radiation for a period of 10 hours (from 08:00 a.m. to 6:00 p.m.). The efficiency of the SODIS process was studied for the inactivation of *E. coli*. Results show that SODIS can reached inactivation values of 4.0 log reduction. SODIS was effective in reducing *E. coli* in the three wastewater depths tested at the more rigorous standard recommendation for agricultural reuse proposed by World Health Organization after six hours exposures to direct sunlight.

Keywords: Solar disinfection, wastewater reuse, *E-coli,* irrigation; Brazil.

Introduction

The World Water Assement Program-WWAP Report (2017) addresses the importance of proper wastewater management for reuse purposes. Wastewater can be a source of energy, nutrients, organic matter and other useful, cost-effective and sustainable products. The potential benefits of extracting such wastewater resources go far beyond human and environmental health, with implications for food and energy security, as well as mitigation of climate change.

Among the positive aspects of the reuse of wastewater in agriculture can be distinguished the fact that treated wastewater could be an uninterrupted water resource throughout the year since it is independent of precipitation variability along the seasons. This aspect might allow the increase of irrigated areas and annual food

production (Keraita et al., 2008). However, there is public heath risk associated with the use of wastewater in agriculture due to the presence of pathogens (bacteria, viruses, protozoa and helminths). These pathogenic microorganisms can contaminate soils and crops, posing a health risk to both workers and consumers of food produced in wastewater irrigated areas (Scheierling et al., 2010).

The term Solar Disinfection (SODIS) describes the process of inactivation of pathogens in water through the direct effects of solar irradiation. SODIS has been used for the disinfection of drinking water in 33 countries presenting economic cost–benefit project ratio amounts to about 1:49. (Meierhofer and Landolt, 2009). Hence, the SODIS efficiency for drinking water disinfection, researchers started to evaluate the efficiency of the same technique in the disinfection of wastewater, seeking an effluent with quality for agricultural reuse (Bichai, Polo-López and Fernández Ibañez, 2012; Queluz and Sánchez-Román, 2014).

According to the Department Water and Sanitation in Developing Countries- Sandec (2002), SODIS can be a suitable solution in regions between latitudes 35º N and 35º S, where the great majority of Developing Countries are located. Therefore, SODIS could be one of the most adequate technologies for water and wastewater treatment in Developing Countries areas with high-irradiance conditions where access to electricity and/or chemical supplies might be either limited or unavailable.

This study aims to determine the feasibility of using solar radiation to treat urban wastewater for agricultural reuse, and to develop a model to simulate pathogen mortality using the solar disinfection process.

Material and Methods

The pilot study was conducted at Faculty of Agronomic Sciences-UNESP, Botucatu-SP, Brazil (22º 51’ 12” S and 48º 25’ 45” W). The effluent from Botucatu City Wastewater Treatment Plant (WWTP) was used as supply; this wastewater passed through biological filters bed (BFB’s) before being directed to solar disinfection system (SODIS). The BFB’s consist of four rectangular fiberglass water boxes (100 x 35 x 31 cm) filled with gravel (size range 4.8 mm-9.5 mm) connected in series by 50 mm PVC pipe, with a difference of 2 cm between each BFB’s (Figure 1). The BFB’s present an average value of 65% of porosity. The hydraulic retention time (HRT) of the BFB’s was approximately 1.5 day.

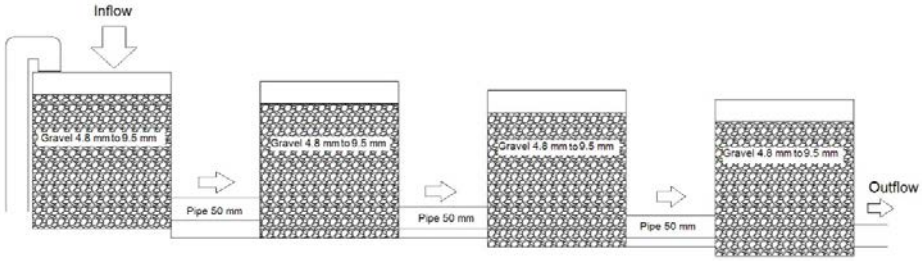


Figure 1 Cross section of the biological filters bed design

The solar disinfection system (SODIS) used presents a concrete base and shape of an inverted truncated cone with the following measures: 1.00 meter for larger radius, 0.25 meters for smaller radius and 0.30 meters height (Figure 2). This structural form was adopted to ensure that the walls of the reactor do not produce shadows on the effluent surface for the longest time possible.

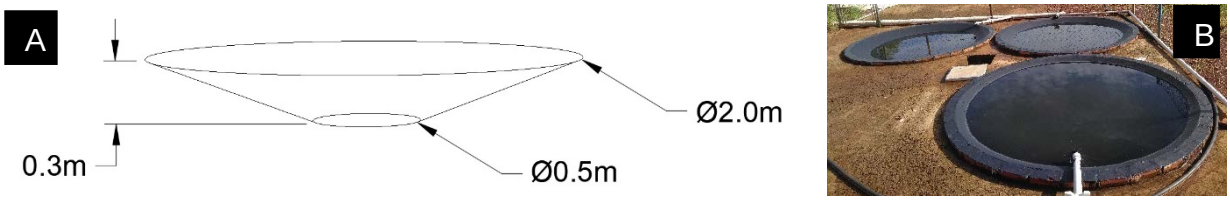


Figure 2 A) SODIS design B) SODIS photograph

Fixed depths of wastewater (0.10; 0.15 e 0.20 m) were tested considering different time of exposure to solar radiation from May to July 2018. The three fixed wastewater depths were exposed to solar radiation for a period of 10 hours (from 08:00 a.m. to 6:00 p.m.). Samples were collected and analyzed according to Standard Method for the Examination of Water and Wastewater (APHA, 2012). The collection of wastewater sample for *E-Coli* analysis was performed every two hours. In addition, the parameters of chemical oxygen demand (COD), total suspended solids (TSS), pH, turbidity, temperature and solar radiation were measured (Table 1).

Table 1 Parameters analyzed and the denomination of the adopted methods

Parameter	Method
E. coli (MPN100 mL^{-1})	Enzyme Substrate Coliform Test
TSS (mgL^{-1})	Total Suspended Solids Dried at 103º-105º membrane filter
COD (mgL^{-1})	Closed Reflux, Colorimetric Method
Turbidity (NTU)	Nephelometric Method (Turbidimeter)
Temperature (ºC)	Thermo-hygrometer
pH	Electrometric Method (pH meter)
Solar Radiation (Wm^{-2})	Pyranometer sensor (spectral range of 310-2800 nm)

Results for bacteria (*E-coli*) population inactivation were analyzed by nonlinear regression using the statistical software Statgraphics. The model used to fit the data was S-shaped function recommended by Crawley (2002). The viability for agricultural reuse was determined by using the recommended quality standards for the use of wastewater in irrigation as defined by the World Health Organization (WHO, 2006).

Results and Discussion

Table 2 shows the patterns evaluated of the effluent used in the solar disinfection process. After passing through the BFB's, the wastewater from the WWTP presents mean values of 2.6 x 10^4 MPN 100 mL^{-1} for *E- Coli,* 9.25 mg L^{-1} for total suspended solids (TSS), 28.17 mg L^{-1} for chemical oxygen demand (COD), and 7.60 for pH. Sandec (2002) estimated that for turbidity level ≤ 1 the remaining UV-A radiation can be 75% for 0.10 m water depth, 72% for 0.15 m water depth, and 70% for 0.20 m water depth. The mean turbidity value found in this study was 1.63 NTU.

Table 2 Characteristics of the effluent from the biological filters bed

Parameter	Units	Mean Value	Standard Deviation	Minimum Value	Maximum Value
E-coli	MPN100 mL^{-1}	2.6 x 10^4	3.85 x 10^4	200	1.05 x 10^5
TSS	mgL^{-1}	9.25	4.40	4.33	17.00
COD	mgL^{-1}	28.17	5.77	23.00	40.67
Turbidity	NTU	1.63	0.57	0.87	2.66
pH		7.60	0.18	7.43	8.00

The temperature differences of the wastewater depths tested were very small (<0.12). The maximum and minimum value of 34.7 ºC and 15.46, respectively, were obtained for the depth of 0.10 m (Figure 3).

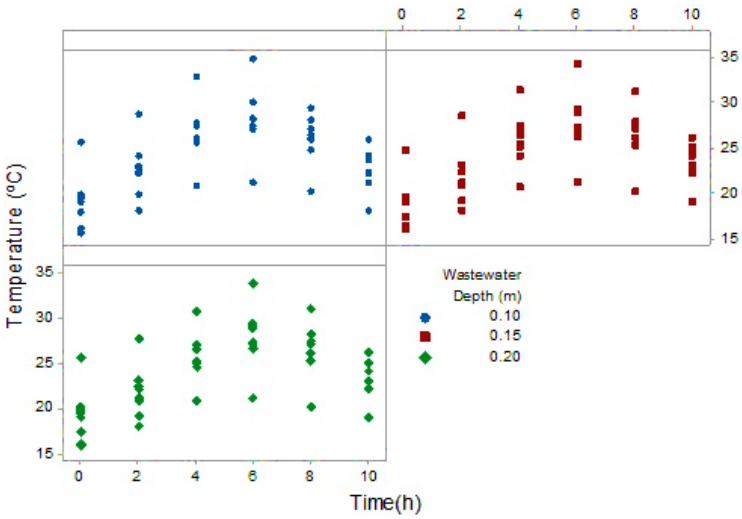


Figure 3 Temperature variation for the wastewater depths of 0.10, 0.15 and 0.20m.

Results of inactivation assays showed that SODIS can bring down *E-coli* concentrations of 10^4 MPN 100 mL^{-1} in urban wastewater to < 3 MPN 100 ml^{-1}. *E-coli* was more effectively disinfected by SODIS with 0.10 m wastewater depth, exhibiting logarithms reduction values ranging between 2 $\log_{10}$ (99%) to 4.3 $\log_{10}$ (99.99%) than by the depths of wastewater of 0.15 m (1.2 $\log_{10}$ to 3.8 $\log_{10}$) and 0.20 m (1.0 $\log_{10}$ to 3.9 $\log_{10}$) (Figure 4). Nevertheless, statistical analysis of variance (ANOVA) did not show a significant difference (p=0.9701) for *E-coli* inactivation between the wastewater depths tested.

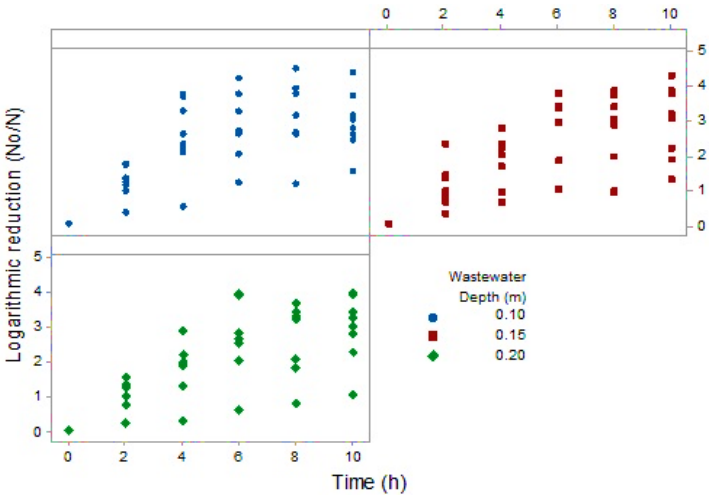
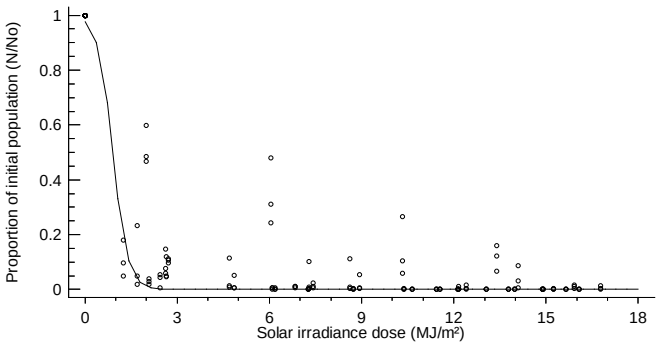


Figure 4 Logarithmic reduction for *E-coli* over the exposure time.

A model was developed to estimate the remaining population of fecal coliforms (*E-coli)* in the wastewater after being exposed to SODIS, knowing its initial *E-coli* population (N_o), the *E-coli* population present in the wastewater after exposed to solar radiation (N), and solar energy received (Eq. 1 and Figure 5). The R-squared statistic indicates that the model, thus adjusted, explains 92.20% of the variability in the remaining fraction of *E-coli* population in the wastewater.



$$y = \frac{exp(3.67676 - 4.05289 * D)}{(1 + (exp(3.67676 - 4.05289 * D))}$$

Eq.1:

where:
y= remaining fraction of *E-coli* population in the effluent ($\frac{N}{No}$)
D= solar irradiance dose (MJ m^{-2})

Figure 5 Experimental and estimated data with nonlinear regression model (equation 1) for the three wastewater depths tested.

Conclusions

Comparisons of the three wastewater depths tested (0.10, 0.15 and 0.20 m) leads to conclude that independent of the wastewater depth adopted, the SODIS tested can achieve levels of disinfection that fulfill the World Health Organization's more rigorous guidance for unrestricted irrigation (≤200 MPN/100 mL of *E-coli*) after six hours exposure to direct sunlight proving to be a suitable solution for Developing Countries.

Acknowledgement

This study was supported financially by São Paulo Research Foundation (FAPESP), grant nº 2017/14729-3.

References

American Public Heath Association – APHA (2012). 22 th. ed. Standard Methods for the Examination of Water and Wastewater. Washington DC, USA.

Bichai, F.; Polo-López, M. I.; Fernández Ibañez, P. (2012). Solar disinfection of wastewater to reduce contamination of lettuce crops by Escherichia coli in reclaimed water irrigation. Water Research, Elsevier, 46(18), 6040-6050.

Crawley, M. J. (2002). Statistical Computing. An Introduction to Data Analysis using S-Plus. John Wiley & Sons, Ltd. West Sussex, England,761 pp.

Department Water and Sanitation in Developing Countries- SANDEC. (2016). SODIS Manual**:** Guidance on Solar water disinfection. Dübendorf, Switzerland.

Keraita, B.; Drechsel, P.; Konradsen, F. (2008). Perceptions of farmers on health risks and risk reduction measures in wastewater-irrigated urban vegetable farming in Ghana. Journal of Risk Research, 11(8), 1047-1061.

Meierhofer, R.; Landolt, G. (2009). Factors supporting the sustained use of solar water disinfection: Experiences from a global promotion and dissemination programme. Desalination, 248(1-3), 144-151.

Queluz, J.G.; Sánchez-Román, R.M. (2014) Efficiency of domestic wastewater solar disinfection in reactors with different colors. Water Utility Journal, 7,35-44.

Scheierling, S. M., et al (2010). Improving Wastewater Use in Agriculture: An Emerging Priority. Water Anchor Energy, Transport, and Water Department, The World Bank.

United Nations World Water Assessment Programme (WWAP). (2017). Wastewater: The Untapped Resource. Paris, France. UNESCO.

World Health Organization (WHO) (2006). Guidelines for the Safe Use of Wastewater, Excreta and Greywater: Wastewater use in agriculture. 2. ed. Switzerland.

On-farm wastewater treatment using biochar from local agroresidues promotes safer irrigation water for food production and enhanced crop yields in West Africa

Korbinian Kaetzl[1,2], Manfred Lübken[1], Bernd Marschner[3], George Nyarko[4], Gordana Kranjac-Berisavljevic[4], Kathrin Stenchly[5] and Marc Wichern[1]

[1]Instiute of Urban Water Management and Environmental Engineering, Ruhr-Universität Bochum, Universitätsstraße 150, 44780 Bochum

[2]Grassland Science and Renewable Plant Resources, Universität Kassel, Steinstraße 19, 37213 Witzenhausen

[3] Institute of Geography, Department for Soil Science and Soil Ecology, Ruhr-Universität Bochum

[4]Faculty of Agriculture, University for Development Studies (UDS), Tamale Box, TL 1882, Ghana

[5]Organic Plant production and Agroecosystems research in the Tropics and Subtropics, Universität Kassel, Steinstraße 19, 37213 Witzenhausen

Introduction

Untreated wastewater is frequently the only available water source for urban and peri-urban farmers in West Africa to irrigate their crops during the long-lasting dry season. The aim of this study was to develop and implement a multi-stage wastewater filtration plant in the city of Tamale (northern Ghana) for the production of safer irrigation water using locally available resources.

Material and Methods

An anaerobic pre-filter (AF) with corn cob biochar was used to reduce suspended solids, turbidity and chemical oxygen demand (COD) of the raw wastewater to a suitable level, so that the following biological filter (BF) was operated under optimal conditions. To further reduce not only COD and turbidity, but also primarily pathogens, the filtered water was additionally treated with a downstream gravity BF that contained rice husk biochar as filter material. Filters were operated for six months under saturated conditions, with raw wastewater coming from military barracks open drain in the northern part of the city and with a hydraulic loading rate of 0.05 $m \cdot h^{-1}$. Samples of influent and effluent were taken periodically and analyzed for the fecal indicator bacteria (FIB) *Escherichia coli* and enterococci, using the most probable number method (MPN). Additionally, physico-chemical parameters (e.g. turbidity, COD, total nitrogen (N_{tot}), phosphorous (P_{tot}) and iron (Fe)) were measured.

On the field, both treated and raw wastewater was used by farmers for irrigation and the pathogen load of vegetable crop (FIB).Yield and nutrient uptake was compared to plants that were irrigated with potable water with and without fertilizer. .

Results and Discussion

The concentration of *E. coli* within the raw wastewater was around $5 \cdot 10^6$ MPN·100 mL^{-1}. An average COD of 202 ± 60 $mg \cdot L^{-1}$ found for the raw sewage indicated a low-strength wastewater. Thus, the AF received a mean organic loading of 128 $g_{COD} \cdot m^{-3} \cdot d^{-1}$. The raw sewage was further characterized by a mean turbidity of 73 ± 57 FNU, N_{tot} of 46 ± 17 $mg \cdot L^{-1}$, P_{tot} of 4.9 ± 1.3 $mg \cdot L^{-1}$ and Fe of 1.3 ± 0.5 $mg \cdot L^{-1}$. Over the entire experiment a FIB reduction of up to 3 log_{10}-units was observed. Additionally, biochar filters were able to eliminate 89 % COD, 92 % turbidity and 62 % Fe. Due to anaerobic conditions no significant removal of P_{tot} and N_{tot} was determined. Mean *E. coli* contamination on leaves of the cultivated jute mallow (*Corchorus* spp.) irrigated with the treated wastewater was below the detection limit of $1.9 \cdot 10^2$ MPN·100·g_{FW} (tap water: $3.98 \cdot 10^2$ MPN·100·g_{FW}) and significantly lower than on plants irrigated with raw wastewater ($8.28 \cdot 10^4$ MPN·100·$g_{Fresh\ weight}$; Figure 1a). We further found that fields irrigated with treated wastewater showed a significantly higher dry matter yield (up to 30%) compared to fields irrigated with raw wastewater or tap water with fertilizers (up to 100% higher yields; Figure 1b).

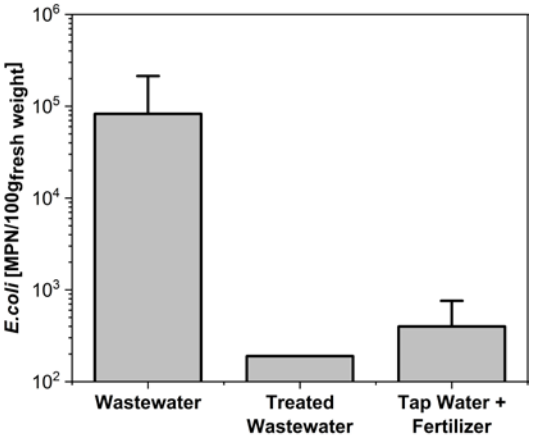


Figure 1a. *E. coli* contamination of jute mallow (*Corchorus* spp.) irrigated with raw wastewater, treated wastewater and tap water with fertilizer application in Tamale, Ghana.

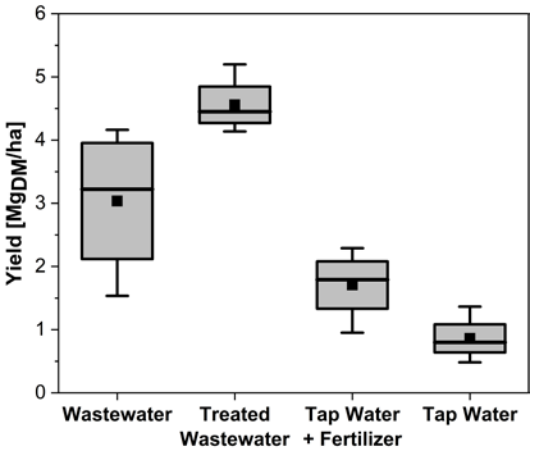


Figure 1b. Dry matter yield of jute mallow (*Corchorus* spp.) irrigated with raw wastewater, treated wastewater, tap water and tap water with fertilizer application in Tamale, Ghana.

Remove of antibiotic-resistant bacteria from greywater

Zeev Ronen, Ge Guodong, and Amit Gross

Zuckerberg Institute for Water Research, Jacob Blaustein Institutes for Desert Research and Ben-Gurion University of the Negev, Israel

Body Text Arial 12 pt., justified, 1.5-spaced

Introduction

Greywater (GW), household effluents that excludes wastewater from toilet flushing, is often contaminated with pathogens and require treatment before it can be safely reused for landscape irrigation. A recirculating vertical flow constructed wetland (RVFCW), is a useful treatment technology for GW (Gross et al. 2007). An emerging source of adverse environmental impact associated with wastewater reuse is the spread of antibiotic-resistant bacteria (ARBs).

Interestingly, there is very little information concerning the presence of ARBs in GW. While GW does not contain elevated levels of antibiotics, they do include a considerable amount of organic micropollutants such as healthcare products, biocides, surfactants and detergents that can be the evolutionary drive for antibiotic resistance development. Thus, the present study aimed to investigate the presence of ARB in GW and then to evaluate the efficacy of RVFCW to reduce ARB in the treated effluents.

Materials and Methods

Freshwater (FW) Raw and RVFCW-treated GW from three households were routinely examined for ARBs as well as respective irrigated soils. Moreover, Freshwater (FW) and freshwater irrigated soil samples from nearby plots were also tested for ARBs. The numbers of ARB, for three different classes of antibiotics (Beta-lactam, Aminoglycoside, and fluoroquinolone), in the various samples were counted on PTYG media containing 20 mg/l of each antibiotic. Plates were enumerated under the magnifying glass after incubation at 25°C for 24-48h.

Results and Discussion

No ARB were detected from all freshwater samples. In all systems and all sampling points, we identified ARB's for the three tested antibiotics. Amoxicillin ARB's were

most abundant followed by kanamycin and ciprofloxacin ARB (Fig.1). The RVFCW treatment reduced all ARB's by 99% (Fig. 1). No significant differences were observed between ARB loads in soil irrigated with GW or FW. These results agree with earlier observations on RVFCW effectivity in removing bacteria from GW. When the microbial community in the GW was challenged with different concentrations of antibiotics, no complete growth inhibition was found confirming the presence of ARB. The susceptibility of mixed bacteria from the water source and soil was lowest to amoxicillin and highest to ciprofloxacin. This result confirmed the higher abundances of amoxicillin ARB (Fig 1) and may be the result of the more frequent use of this antibiotic in the different households. Interestingly, at the same concentration of antibiotics, the inhibitory effect was much lower for biofilms from the upper tank of the RVFCW and bacteria in soil. For biofilm, this reduced susceptibility is caused by a combination of different factors, namely: (i) a poor antibiotic penetration into the polysaccharide matrix; (ii) the arbitrary presence of cells showing a resistant phenotype (known as “persisters”); and (iii) the presence of either non-growing cells or cells that triggered stress responses under unfavorable chemical conditions within the biofilm matrix.

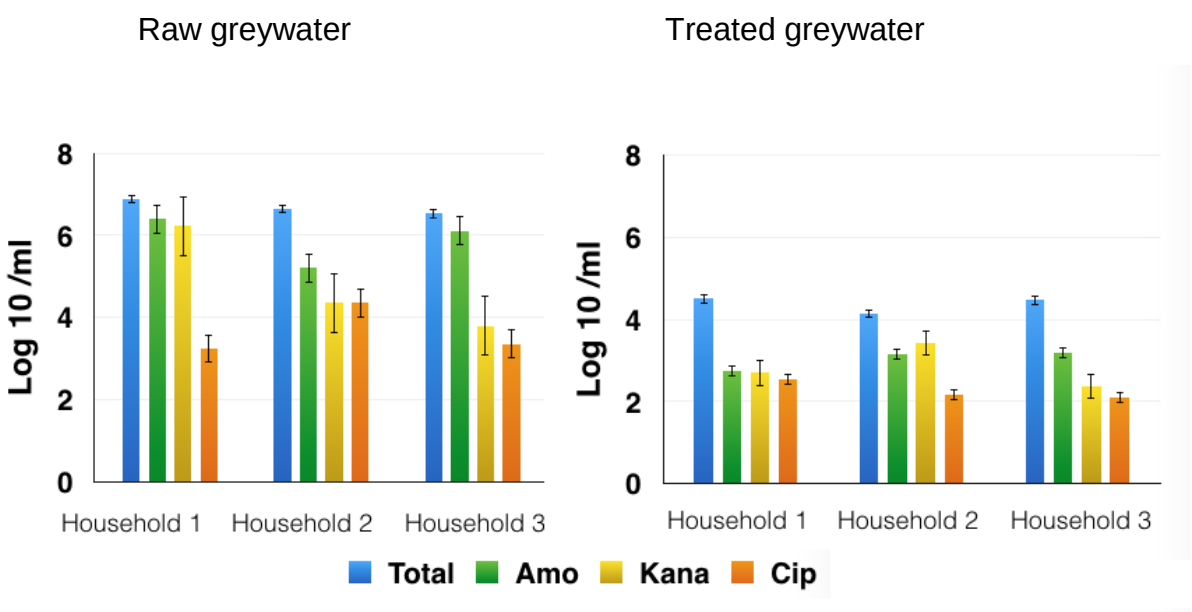


Figure 1: Abundances of ARB in raw and RCFVCW-treated GW (left-right respectively). Each household was sampled two times. Amo- Amoxicillin, Kana- Kanamycin, Cip- Ciprofloxacin).

From the different locations, we isolated 27 strains with resistance for the different antibiotics. No gram-positive bacteria were found during the experiment. Five of the ARBs were opportunist pathogen. Flavobacterium occupied 36% of ARB isolated from water source and soil. One of them, identified as Elizabethkingia meningoseptica, was highly resistant to Ciprofloxacin. Thus, we tested its sensitivity for TGW chlorination. Even at 0.3 mg/l chlorine in the TGW, ARB was eliminated to below detection limits after 2h. Thus, as suggested earlier (Ronen et al. 2010), disinfection of the TGW should be used before irrigation.

Conclusions

This study is the first to reveal that GW contains the significant population of ARB for the tested antibiotics. We suggest that the ARB may originate from external surfaces of human bodies in the bath water or contaminated laundry or food. Pathogens resistances were not detected because the treatment has eliminated them. Thus, upon adequate treatment, ARBs are not expected to accumulate in soils because of GW irrigation.

References

Benami, M., A., Gross, M., Herzberg, E., Orlofsky, A., Vonshak, & O., Gillor, (2013). Assessment of pathogenic bacteria in treated greywater and irrigated soils. Sci. Tot. Enviro., 458, 298-302.

Gross, A., O., Shmueli, Z., Ronen, & E., Raveh. 2007. Recycled vertical flow constructed wetland (RVFCW)—a novel method of recycling greywater for irrigation in small communities and households. Chemosphere, 66, (5), 916-923.

Ronen, Z., A., Guerrero, & A., Gross, (2010). Greywater disinfection with the environmentally friendly Hydrogen Peroxide Plus (HPP). Chemosphere, 78(1), 61-65.

The view from Australia

Stuart Wilson, Water Services Association of Australia, Sydney, Australia; Adam Lovell, Water Services Association of Australia, Sydney, Australia; Danielle Francis, Water Services Association of Australia, Sydney, Australia

Abstract:

Australia is far away, but faces many core water industry challenges – climate change, urbanisation, waterway health, political leadership changes, cost of living pressure – which impact the ability to supply basic services, and build trusting relationships with customers and community.

Australia's most important annual water industry conference was recently held in Melbourne, called OzWater, and one of the most popular sessions was *'Is Australia ready to drink recycled water?'*. This address will look at potable reuse in Australia and highlight what appear to be the key opportunities and challenges, and propose some practical suggestions about how best to approach community engagement on drinking water reuse.

Keywords: reuse; engagement; community; potable; trust

Introduction

In May I attended Australia's most important annual water industry conference, OzWater, in Melbourne. The theme this year was *'Transforming our World'* and one of the most popular sessions was *'Is Australia ready to drink recycled water'.*

This is a topic that my organisation, the Water Services Association of Australia, considers extremely important, and one where we are taking leadership on behalf of our members (the large and small urban water utilities across the country). This leadership takes the form of understanding learnings from the past – successes and failures – both in Australia and all over the world. And also, putting those learnings to good use going forward, as reuse inevitably emerges again for consideration to supply our growing population, amid drought, climate change and urbanisation. I emphasise that there have not been any decisions made to pursue potable reuse, but being open to all options is good water industry planning.

This address will highlight what appear to be the key opportunities and challenges for Australia, and outline some practical suggestions about how best to approach community engagement on drinking water reuse, whether in Australia or beyond. In the water industry, what we have in common tends to be far greater than our differences.

Non-drinking reuse applications are common and well documented in Australia, and are not the subject of this address.

Material and Methods

This is an informal overview of recent consideration of drinking water reuse in Australia. The address will also propose practical suggestions on how to approach community engagement on drinking water reuse, that may be relevant to any country considering it.

Results and Discussion

Drinking water reuse has had an interesting history in Australia. Given our dry climate, it is only natural that various cities have considered it. In fact, many would consider Australia to be a very likely candidate to rely on drinking water reuse, as water stress is a very real issue for both urban and rural parts of the country. However, it was only seriously looked at in the last 15 years – decades after it was introduced in parts of America and Namibia.

The two main places where it has been considered are South East Queensland, on the East Coast – in the middle of a serious drought, ie around 2005-2010. Then a couple of years later, in Perth, over on our West Coast.

The results were very different. The first town to consider it in South East Queensland, Toowoomba, put the issue to a referendum and it was defeated, amid very emotional and sensational media coverage. A year or so later, with drought conditions persisting plus a clear need for new long term water supply sources, a

much larger scheme was proposed in the same region. The media controversy continued, but dam levels were dropping so rapidly that government leadership was necessary, and the Premier of the day rose to the challenge. A huge grid was built very quickly, including advanced water treatment plants for surface water augmentation. Early plans for a referendum were abandoned – the leaders explained that there simply was not enough time to debate whether drinking water reuse was acceptable to the community or not. They would build the scheme, and it would be used.

However, with ironic and dramatic timing, drought-breaking rain came only months after the scheme was built. The Premier who had advocated so strongly for the scheme had retired. His replacement, facing an upcoming election with continued critical media coverage, made the decision to downgrade the scheme to an emergency response, for use only if dams dropped low again. The new scheme was switched off and largely unused, despite the significant investment.

The situation was somewhat different in Perth. The drivers were similar - climate resilience was a key driver, as Perth now expects very little of its water supply from rainfall and runoff, instead it relies heavily on groundwater and desalination.

However, the conversations with stakeholders, the government and the community took place over years; and drinking water reuse was not a drought strategy, but rather a long term water supply approach. With rainfall inflows dwindling the need was no less real, but the timeframes involved less panic. Plus the move towards reuse was incremental; small steps taken in consultation with the community, led to the ultimate outcome of reuse. There was not a perception of a fait accompli, or a decision already made to adopt a particular water supply solution.

The scheme itself was also different – groundwater replenishment, which at the time was estimated to not actually enter the drinking water supply for several decades.

After several years of planning and engagement, the scheme was supported by the community and the government, and was built. Perth now estimates that in ten years the water in the recharged aquifers will move into the drinking water supply.

If we fast forward to today, the drivers in Australia have changed little. The world knows that Australia is very dry, but we are seeing new extremes all the time. This

summer just ended was the hottest on record, the third hottest ever for Sydney, and we are seeing a record drought emerge on the East Coast – less than a decade after the last drought, that we already called ‘the Millennium drought’. In fact this may not be drought at all, but ‘the new normal’.

In that context, Australian cities are recognising the importance of building climate resilience into their water supply planning. Reuse may well have a part to play. This is not directly drought related – in fact potable reuse tends to be part of long term supply planning rather than drought. However, the current dry conditions in Australia mean the community is focused on water, which can make it an opportune time for conversations about long term supply options.

Given the very controversial media and community debate around introducing potable reuse in Queensland (Toowoomba and Western Corridor), many people doubted that potable reuse could happen in Australia – or that the community would agree to it. But it has, through Water Corporation’s comprehensive, long-term grass roots outreach program.

On the East Coast, we’ve seen a different sort of breakthrough too, with a regional town called Orange implementing the first stormwater-to-potable reuse scheme in the state of New South Wales. With both Perth and Orange, as in many overseas cities, there wasn’t a lot of regulatory framework precedents in place to work from – so plenty of time was needed to effectively ‘write the rule book’.

Conclusions

At the Water Services Association of Australia, we emphasise that no single water supply solution is the most important; rather, diversification itself is critical. But all options need to be ‘on the table’ for consideration, including potable reuse alongside desalination, water conservation, dams and recycling. Even though potable reuse has had a difficult history in our country, other cities like San Diego show that opposition to potable reuse can be overcome, through patient, careful, education and public outreach.

In Australia we hope we may be able to benefit from the lessons that others have learned about drinking water reuse. In particular, we take an interest in understanding what approach other cities around the world have taken to achieve community acceptance – it is an essential element, and probably the most challenging.

During this address to the conference we will identify what we believe to be key elements that help enable potable reuse to be accepted by communities. While no single method guarantees community support, there do appear to be some elements that are helpful. Elements like trust and transparency; allowing a long time; very careful use of language and imagery, and the construction of a demonstration facility, seem to help increase the chance of community acceptance.

Another useful tactic would be to make drinking water reuse seem more familiar – by highlighting that it is quite common around the world, probably moreso than many people realise.

For example, many members of the water industry, if asked where drinking water reuse takes place, will probably name Singapore, Namibia, and perhaps Orange County, or California generally. It may surprise people to learn that there are around 40 cities with drinking water reuse schemes, many in North America. For example, most visitors to Disneyland in Anaheim would likely have drunk recycled water. Around a dozen more cities are considering it or undertaking studies. And these figures do not take into account the many, many schemes all over the world where ‘unacknowledged’ reuse occurs, i.e. communities discharge treated effluent to rivers and water sources, that form part of the drinking water supply of other communities downstream.

It’s also crucial to have good media and political engagement. Of course that’s important for any issue, but for one that can be controversial, a lot of harm can be done very quickly through media coverage – including social media, which moves incredibly fast.

Another important element is customer centricity. Because the water industry in Australia tends to be highly regulated, and often includes state-owned corporations in more-or-less monopoly environments, customer centricity has developed more

slowly. Some interesting ways of putting decision-making back in the hands of the community have arisen, for example, Yarra Valley Water in Melbourne has formed a ‘citizens jury’ process.

It’s encouraging to note that in many cities that have successfully introduced drinking water reuse, it has been grass roots education and engagement, rather than high profile media campaigns, that have been effective.

The next ten years will be critical times for the water industry in Australia, and we are learning all we can from others that have gone before. We look forward to sharing some Australian observations and perspectives at the conference.

Development of Regulatory Criteria for Direct Potable Reuse in the United States

Jeffrey J. Mosher, Carollo Engineers, Los Angeles, California (USA); Julie Minton, The Water Research Foundation, Alexandria, Virginia (USA), Gina Vartanian, National Water Research Institute (retired), Foundation Valley, California (USA); Andrew Salveson, Carollo Engineers, Inc., Walnut Creek, California (USA)

Direct Potable Reuse (DPR), which involves the introduction of advanced treated recycled water into the raw water supply upstream of a drinking water treatment facility or directly into a drinking water distribution system, is an emerging strategy gaining increased interest in the United States (U.S.) as a reliable water supply alternative. Federal regulations do not exist in the U.S. for potable reuse and regulations are developed on a state-by-state basis.

Although Texas has permitted DPR on a case-by-case basis (i.e., in Big Spring, TX and Wichita Falls, TX), several states have embarked on the development of formal state DPR regulations, including California, Arizona, Colorado, and Florida. The development of DPR regulations in these states have involved organized efforts to develop guidance or regulatory frameworks in California (NWRI, 2016 and Olivieri, et. al.; 2016), Arizona (Mosher and Vartanian, 2018), Colorado (WateReuse Colorado, 2018), and Florida (PRC, in development). These guidance and/or framework reports have several common elements: protection of public health as an overarching objective; strong water utility interest due to water scarcity and other drivers; strong involvement of regulators; and reliance on existing potable reuse experience and extensive research.

In addition, an essential component of these state efforts has been the use of stakeholder engagement processes to develop the regulatory frameworks and to raise awareness and support for DPR. In California, the State Water Resources Control Board used both an Expert Panel and an Advisory Group of stakeholders to inform its decision to develop DPR regulations. In Arizona, WateReuse Arizona and AZ Water, both non-profit water industry associations, sponsored a stakeholder process to develop an Arizona DPR Guidance Framework to support the state in developing DPR regulations. In Colorado, WateReuse Colorado spearheaded a

stakeholder process to kick start the development of DPR regulations in the state. In Florida, a Potable Reuse Commission (PRC) was established by WateReuse Florida, Florida Section of AWWA, and the Florida Water Environment Association to advance potable reuse in Florida, including DPR. The Florida PRC is a stakeholder driven process to develop recommendations that reflect the input from water, wastewater, agricultural, environmental, and academic representatives. In each of these states, the goal of the regulatory frameworks is to support the development of state regulations for DPR.

In the four states, the framework and guidance documents included specific recommendations regarding the development of DPR regulations that were specific for each state. In general, recommendations provided in the frameworks and guidance documents were made to ensure protection of public health based on available technical and scientific information. The information and recommendations presented in the documents addressed various facets of DPR, including: source control; treatment performance; pathogen control; chemical control; monitoring; operations; water quality; and other related areas.

In the reports, several best practices for implementing DPR were identified. These practices are based on the recognition that potable reuse projects involve not just regulatory criteria, but a range of components that support the implementation of DPR projects by utilities. For a potable reuse program to be successful regulatory, technical, and public engagement components need to be evaluated and addressed.

The authors have been integrally involved in each of these state DPR efforts. This presentation will focus on two themes: 1) the use of stakeholder processes in these four states to develop technically and scientifically sound DPR regulatory frameworks; and 2) a review of the specific criteria and related elements underlying the regulatory frameworks, including pathogen and chemical criteria, treatment processes, monitoring, operations, and other areas.

References

Mosher, J.J., and G.M. Vartanian (2017). Guidance Framework for Arizona Potable Reuse. Prepared for WateReuse Arizona and AZ Water Association, Prepared by National Water Research Institute, Fountain Valley, CA.

NWRI, 2016. Recommendations of the Advisory Group on the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse. Convened by the State Water Resources Control Board. Prepared by the National Water Research Institute, Fountain Valley, CA.

Olivieri, A.W., J. Crook, M.A. Anderson, R.J. Bull, J.E. Drewes, C.N. Haas, W. Jakubowski, P.L. McCarty, K.L. Nelson, J.B. Rose, D.L. Sedlak, and T.J. Wade (2016). Expert Panel Final Report: Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse. Prepared August 2016 by the National Water Research Institute for the State Water Resources Control Board, Sacramento, CA.

PRC (in development). Advancing Potable Reuse in Florida: A Regulatory Framework. Prepared by the Florida Potable Reuse Commission. Published by the WateReuse Association, Alexandria, VA.

WateReuse Colorado (2018). Advancing Direct Potable Reuse to Optimize Water Supplies and Meet Future Demands. Executive Summary. Prepared by Carollo Engineers, Inc, September 2018.

Potable Water Reuse in California–
Update on Recent Developments, Regulations and Research Topics (USA)

A.W. Olivieri, EOA, Inc., Oakland CA, USA, J..E. Drewes, Technical University of Munich, Garching, Germany, B. Pecson, Trussell Technologies, Oakland CA, USA, K.A. Maruya, Southern California Coastal Water Research Project, Costa Mesa CA, USA; J. Crook, Environmental Engineering Consultant, Mattapoisett MA, USA, B. Bernados, California Water Board, San Diego CA, USA, J. Minton, The Water Research Foundation, Alexandria VA, USA.

Abstract:

In 2017, the California State Water Resources Control Board (SWB) formed an Expert Panel to review surface water augmentation for potable reuse regulations and to consider the feasibility of developing uniform regulations for direct potable reuse (DPR). The SWA regulations were adopted in 2017 (Waterboards, 2017) and an in-depth review of the feasibility of developing uniform DPR regulations was completed in 2016 and found development of uniform regulations feasible as well as identified six areas for further investigation (Olivieri, et al. 2016).

The goal of the paper is to provide a summary update on the current potable reuse regulations in California and the status of the priority research topics as they relate to assisting the State of California develop DPR regulations by 2023.

Key Words: Potable reuse; surface water augmentation; microbial pathogens of concern; treatment system performance and reliability; environmental buffer

Introduction

The California legislature required the SWB to investigate public health issues and scientific and technical matters regarding the development of uniform water recycling criteria for indirect potable reuse through surface water augmentation and investigation of the feasibility of developing uniform water recycling criteria for direct potable reuse (DPR). (CWC, 2016). An independent Expert Panel, appointed by the SWB, reviewed the following topics: public health surveillance tools and methods to quantify and mitigate risks; analytical approaches for measuring chemical water quality; application of bioanalytical tools (i.e., bioassays) to water analyses; traditional and molecular methods for assessing microbial water quality; antibiotic resistant bacteria and antibiotic resistance genes; performance of direct potable reuse (DPR) systems; potable reuse regulatory feasibility analysis comparing an example DPR system

against an existing potable water supply in California that is protective of public health; and management controls.

In terms of public health protection, waterborne microbial pathogens – including bacteria, viruses, and protozoan parasites – are acknowledged as the most critical constituents to regulate in recycled water due to the potential impacts to human health resulting from short-term exposure (most effects arise shortly after exposure, although chronic sequelae of acute infection are known to occur). Among the large number of chemicals that can be present in recycled water, some are of concern due to their potential adverse health effects associated with both short- and long-term exposures. Determining which constituents to regulate can be challenging, but has been done for planned groundwater recharge and surface water augmentation projects (a form of indirect potable reuse, or IPR) (Anderson et al., 2010; Drewes, 2013 and 2018, and CCR, 2015). The possibility of doing the same for DPR is considered in the Expert Panel report (Olivieri et al., 2016).

The Expert Panel found that it is feasible to develop uniform water recycling criteria for DPR that would incorporate a level of public health protection as good as or better than what is currently provided in California by conventional drinking water supplies, IPR systems using groundwater replenishment, and proposed IPR projects using surface water augmentation. Several additional research topics were identified by the Panel to address some data gaps and assist the SWB during development of DPR criteria.

Potable Reuse in California

Public water supplies in California come from a variety of sources (i.e., groundwater and surface water), but factors like population growth and extended droughts are stressing these supplies. Over the next few decades, supplies are likely to diminish and alternative sources of water are needed to help meet current and future water demands as well develop more sustainable water supplies. One such alternative is planned potable reuse, in which treated wastewater (or “recycled water”) is used to augment public drinking water supplies.

Planned potable reuse criteria for groundwater recharge (GWR)- Planned potable reuse has been practiced in the form of indirect potable reuse (IPR) via groundwater recharge (GWR) for over 50 years in California. The Los Angeles County Sanitation District (LACSD) began groundwater recharge through spreading basins in the early 1960’s followed by the Orange County Water District’s (OCWD) groundwater recharge program through injection wells some 15 years later. Thus, a key element of these groundwater recharge projects (previously known as IPR) is the reliance on an *environmental buffer* which, through storage,

allows for some level of water quality equalization and time to respond to any process failures or out-of-compliance water quality monitoring results. However, for some groundwater replenishment projects, the soil (particularly in the vadose zone) can provide additional treatment to reduce levels of both chemical and microbial constituents in the recharged water. The longstanding operational experience with the LACSD and OCWD projects allowed the State to develop groundwater recharge regulations, which were adopted in 2014. The criteria for groundwater recharge reflect a cautious approach toward potential short- and long-term health concerns. The criteria rely on a combination of controls intended to maintain a microbiologically and chemically public health protective groundwater recharge operation and protect current and future potable groundwater supplies. The criteria specify the need for enhanced source control (program that go beyond standard pretreatment), wastewater treatment processes (including multiple barriers) water quality, recharge methods (i.e., surface spreading versus direct injection), dilution, monitoring locations and frequencies, and extraction well location(s). GWR relying on direct injection also requires full advanced treatment (i.e., unit processes including microfiltration or ultrafiltration, reverse osmosis, and advanced oxidation (see CCR Title 22, section 60320.201).

The State Water Board (SWB) also requires monitoring of additional constituents for unregulated chemicals (e.g., chromium-6, diazinon, 1,4-dioxane, N-nitrosodimethylamine (NDMA), and 1,2,3-trichloropropane) using approved drinking water analytical methods, where available and practicable, and will specify other methods where necessary (e.g., for certain endocrine disrupting chemicals, pharmaceuticals, personal care products).

For GWR projects, four indicator compounds based on their toxicological relevance (i.e., N-nitrosodimethylamine, 17β-estradiol, caffeine, and triclosan) were included in the State Water Board Recycled Water Policy (SWB, 2013) based on the 2010 Panel report (Anderson et al., 2010). In addition, four additional CECs (N,N-diethyl-meta-toluamide (DEET), gemfibrozil, iopromide and sucralose) were identified for surface spreading and direct injection operations as viable performance indicator compounds along with certain surrogate parameters (e.g., ammonia, dissolved organic carbon, conductivity), which differ by the type of reuse practice. The Panel emphasized that the compounds identified represented an initial list based on the limited data that were available at that time and several qualifying assumptions.

Planned potable reuse criteria for surface water augmentation (SWA) – In 2017 the State Water Board adopted surface water augmentation regulations as part of California Code of

Regulations Title 22 (SWB, 2017b). The SWA regulations establish *minimum* uniform water recycling criteria for the purpose of adequately protecting public health with respect to the planned placement of recycled water into a surface water reservoir that is used as a source of domestic drinking water supply. The criteria require an advanced water treatment facility to meet a minimum of the 8-$\log_{10}$ enteric virus, 7-$\log_{10}$ *Giardia* cyst, and 8-$\log_{10}$ *Cryptosporidium* oocyst reduction to produce a new source of water for placement into a surface water reservoir used as a source of domestic drinking water. The reservoir water is also required to receive additional treatment consistent with the California drinking water regulations.
The benefits of the reservoir as an environmental buffer lie primarily in the form of contaminant attenuation to mitigate the potential consequences of the production of off-spec water and or a failure of the advanced treatment facility. As a result, the attenuation is not considered part of the treatment train and may not be used as credit to meet the other proposed regulatory requirements associated with contaminant control and removal for SWA projects. To ensure the reservoir provides a meaningful environmental buffer, two types of criteria associated with the robustness of a reservoir are included in the regulation.

- Theoretical Residence Time (Tr) – Operational Criteria: for a reservoir to be used as part of a SWA project, the reservoir must initially be able to provide a Tr of at least 180 days (monthly basis). The criteria allow the operating agency the option of submitting an application for a reduced minimum Tr of no less than 60 days. However, if Tr is less than 120 days, an additional $\log_{10}$ reduction for all three categories of pathogens is required.
- Dilution – Performance-Based Criteria: The SWA criteria require a 100:1 dilution in the reservoir with the minimum pathogen reduction of 8, 7 and 8 $\log_{10}$ reductions for enteric virus, *Giardia* and *Cryptosporidium*, respectively, and an allowance for 10:1 dilution but requiring an additional $\log_{10}$ reduction for all three categories of pathogens.

Planned potable reuse criteria – Direct Potable Reuse (DPR) – DPR essentially involves turning wastewater into drinking water without relying on a significant and effective environmental/natural buffer such as a groundwater basin or reservoir. Thus, DPR in California has been defined as the planned introduction of recycled water either directly into a public water system or into a raw water supply immediately upstream of a water treatment plant. The California legislature has required the SWB to adopt regulations by December 31, 2023.

While the SWB independent panel determined that is was feasible to develop uniform criteria for DPR that adequately protect public health, the panel identified six areas of additional investigation that would enhance the SWB efforts to develop DPR criteria and regulations. The six priority research topics pertain to the control of contaminants, both microbial pathogens and toxic chemicals. The pathogen topics include developing additional information on the concentrations of pathogens present in raw wastewater (under both typical and outbreak conditions), as well as the use of quantitative microbial risk assessment (QMRA) to understand microbial risks and how treatment can be used to control those risks. For chemical risks, the SWB identified three topics of concern for DPR: (1) the need for enhanced source control, (2) an evaluation of strategies to define and control peaks of chemical contaminants, and (3) the need to evaluate the feasibility and use of non-targeted analysis to identify unknown contaminants or those more likely to pass through advanced treatment (low molecular weight compounds).

DPR Priority Research Projects and Approach

The Expert Panel recommended that the SWB investigate the following topics to further ensure the protectiveness of DPR. All of the projects, with the exception of the source control project, are being managed through the Water Research Foundation and are planned to be complete by March 2021.

Develop a targeted monitoring program for source control and final water quality - proactively monitor the literature on the potential health risks that could present serious harm to health over short durations of exposure to compounds likely to be present in recycled water. Of specific concern are chemicals that adversely affect the development of fetuses and children. A formal process should be established by the SWB that includes: (1) an internal process to monitor the literature and (2) an external peer review process to address the results of the internal efforts to maintain a high level of awareness of these issues. This project is currently underway with the National Water Research Institute leading the efforts of a panel of experts.

Adopt the use of probabilistic quantitative microbial risk assessment (QMRA) - QMRA offers a unique opportunity to understand the reliability of DPR systems. It provides a tool assess and compare the public health protection anticipated by various treatment trains. It provides a metric to evaluate the necessary LRVs of viruses, *Cryptosporidium,* and *Giardia* needed to maintain a risk of infection equal to or less than10^{-4} per person per year. In particular, it provides a tractable metric for evaluating overall treatment plant reliability

including treatment process redundancy and robustness (multiple barriers). This project is underway and is being conducted by a technical workgroup composed of: Drs Brian Pecson (chair), Nick Ashbolt, Chuck Haas, Teri Slifko, Edmund Seto and Dan Gerrity.

Conduct pathogen monitoring in raw wastewater - To better inform decisions associated with updating LRVs, as well as conducting probabilistic-based QMRA and plant performance modeling, the SWB should conduct monitoring in the raw (untreated) wastewater feeding a DPR system to provide more complete information on concentrations and variability of various waterborne pathogens and indicators. The technical workgroup overseeing this effort includes the following individuals: Drs. Teri Slifko (Chair), Kara Nelson, Channah Rock, Menu Leddy, Rick Danielson, George DeGiovanni and Brian Pecson. Improvements to current methods are currently being evaluated for Virus **-** Enterovirus (*culture* and *molecular*), Adenovirus (*culture* and *molecular*), Norovirus (*molecular*), and Bacteriophage (*culture* and *molecular*), and for Protozoa **-** *Giardia* (*microscopy* and *molecular*) and *Cryptosporidium* (*microscopy* and *molecular*).The monitoring plan is designed to collect 24 samples over roughly an 18 month period (capture two winter seasons, if possible) from five facilities in California and is planned start September 2019.

Investigate feasibility of collecting pathogen data during an outbreak - investigate the feasibility of collecting pathogen concentration data for raw wastewater associated with community outbreaks of disease. This project is planned to start during the fall of 2019.

Control of chemical peaks - Investigate and identify suitable options (i.e., treatment, monitoring, operations, and source control) that can provide some “averaging” with respect to potential chemical peaks (in particular, for chemicals that have the potential to persist through advanced water treatment). In addition, defining a chemical peak is a key component of the project. The technical workgroup conducting this effort includes the following individuals: Drs. Jean Debroux (Chair), Shane Trussell, Megan Plumlee, Steve Timko, and Aleks Pisarenko.

Non-Targeted analysis and low molecular weight compounds (LMW) – this project focuses on evaluating potential analytical methods, including but not limited to non-targeted analysis (NTA), to identify contaminants not presently detected by current monitoring approaches, particularly LMW compounds that may occur in wastewater and recycled water and that may not be removed by advanced water treatment processes. The effort will build upon the recent results and recommendations from the SWB 2018 CEC report (Drewes, et.al, 2018) . This project will develop a white paper on recommendations for the use and

interpretation of analytical results to identify unknown contaminants. Dr. Keith Maurya is the lead investigator and Drs. Eunha Hoh, Lee Ferguson and Shane Synder are peer reviewers.

References

Anderson, P., Denslow, N., Drewes, J.E., Olivieri, A.W., Schlenk, D., Snyder, S.A. (2010) "Monitoring Strategies for Chemicals of Emerging Concern (CECs) in Recycled Water," Recommendations of Science Advisory Panel, Report to California State Water Resources Control Board, June 25, 2010.

CCR (2015). *Water Recycling Criteria*, Title 22, Division 4, Chapter 3, California Code of Regulations: Sacramento, CA. https://govt.westlaw.com/calregs/Browse/Home/California/CaliforniaCodeofRegulations?guid=IE8ADB4F0D4B911DE8879F88E8B0DAAAE&originationContext=documenttoc&transitionType=Default&contextData=(sc.Default)

CWC (2016). California Water Code, Division 7. Water Quality, Chapter 7.3, Section 13561, Sacramento, CA http://www.waterboards.ca.gov/laws_regulations/docs/portercologne.pdf

Drewes, J.E., Anderson, P., Denslow, N., Olivieri, A., Schlenk, D., Snyder, S.A., Maruya, K.A. (2013) Designing monitoring programs for chemicals of emerging concern in potable reuse - What to include and what not to include? Water Sci Technol 67: 433-439. Drewes, J.E.,

Anderson, P., Denslow, N., Olivieri, A.W., Schlenk, D., Snyder, S.A (2018) "Monitoring Strategies for Chemicals of Emerging Concern (CECs) in Recycled Water," Recommendations of Science Advisory Panel, Report to California State Water Resources Control Board, SCCWRP Technical Report 1032, April 2018.

Olivieri, A., Crook, J., Anderson, M., Bull, R., Drewes, J.E., Haas, C., Jakubowski, W., McCarty, P., Nelson, K., Rose, J., Sedlak, D., Wade, T. (2016). Expert Panel Final Report: Evaluations on the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse. State Water Resources Control Board, Division of Drinking Water, Sacramento, California, USA https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/rw_dpr_criteria/app_a_ep_rpt.pdf

Pecson, B., S. Triolo, R., Olivieri, S., Chen, E., Pisarenko, A.N., Yang, C., Olivieri, A.W., Haas, C.N., Trussell, R.S., and Trussell, R. (2017). Reliability of Pathogen Control in Direct Potable Reuse: Performance Evaluation and QMRA of a 1 MGD Advanced Treatment Train, *Water Research, 122, 258-268.*

SWB (2013) California State Water Resources Control Board. Water Quality Control Policy for Recycled Water, Resolution No. 2013-003, Sacramento, California. USA https://www.waterboards.ca.gov/water_issues/programs/water_recycling_policy/

SWB (2017b) California State Water Resources Control Board. SBDDW-16-02 Surface Water Augmentation (SWA) Regulation, Sacramento, California. USA. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/swa/apregtext.pdf

Emerging contaminants in wastewater treated for direct potable re-use: the human health risk priorities in South Africa

CD Swartz [(1)], B Genthe [(2)], JG Menge [(3)] and CJ Coomans [(1)]

(1) Chris Swartz Water Utilization Engineers, Cape Town, South Africa; cswartz@mweb.co.za

(2) CSIR, Stellenbosch, South Africa

(3) InReWaSol, Windhoek, Namibia

Abstract

A research project, funded by the South African Water Research Commission (WRC), was undertaken to identify the emerging contaminants of concern in reclaimed potable water in South Africa, their source and pathways, potential risk from exposure to these chemicals, and indicative removal potential of these micro-pollutants by treatment plants.

A total of 20 chemicals were identified for the first local priority list of contaminants of emerging concern (CECs) for assessing water quality for direct potable reuse. A number of CECs were present in the final water from the direct potable reuse plants, although at levels considerably lower than that considered to be safe. The results of tests have shown the bio-assays to be of value to monitor the water quality in direct potable reuse schemes.

Introduction

If not treated properly, reclaimed water can act as a possible exposure pathway to a high number of emerging contaminants and their metabolites. Many of these compounds may pass through conventional wastewater treatment systems without removal and accumulate in potable water supplies.

The project aimed at compiling a first priority list of emerging contaminants of concern in reclaimed potable water for Southern Africa, which included identification of the sources, pathways and receptors by which these compounds enter drinking water systems. The indicative removal potential of these chemicals by water reclamation and wastewater treatment plants was investigated, and a risk assessment conducted to determine possible health impacts as a result of human exposure to the identified priority chemicals of concern.

Material and Methods

a. Identification of priority compounds, their sources and pathways

To determine a priority CEC list for monitoring reclaimed water in South Africa, the local context needed to be established. The following criteria was therefore considered:

- compounds detected in South African potable waters
- compounds which are persistent and are not removed by conventional water treatment processes
- pharmaceuticals prescribed in the largest volumes in South Africa
- pesticides identified as high-risk priority pesticides in South Africa
- chemicals representing each of the groups of CECs
- chemicals prevalent in South African waters (e.g. antiretroviral drugs)
- potential for human exposure
- analytical ability to detect.

The health and environmental risk for individual contaminants of emerging concern was assessed to prioritise chemicals which should be included in monitoring programs.

b. Potential risk from exposure to these chemicals

A battery of bio-assays was included in the study to illustrate their use in assessing water quality. This provides a broad indication of effluent quality and is often recommended as screening tests for wastewater reuse. These included the Ames mutagenicity test, the Daphnia acute toxicity test. Daphnia (freshwater fleas), and Daphnia magna specifically, are prescribed in the Organisation for Economic Co-operation and Development Guidelines for the Testing of Chemicals (OECD, 2004). The YES (yeast estrogen screen) test is used to test for oestrogenic activity. The YES test is included in the Global Water Research Coalition overview of sources and biological methods for measuring EDC (GWRC, 2003). It is based on measuring oestrogenic activity relative to the most potent oestrogenic compound, namely 17ß-oestradiol.

Indicative removal potential of the chemicals by wastewater treatment and water reclamation plants

Two water reclamation plants (WRPs), three wastewater treatment plants (WWTPs) and one water treatment plant (WTP) were sampled during three sampling programmes, representing different times of the year. The purpose and design of the sampling

programmes were to determine the indicative removal capabilities under certain conditions of certain treatment processes for the priority parameters that were identified.

The analyses performed on the samples included the following for the three sampling campaigns:

- Priority CECs: Bisphenol A (BPA), triclosan, 17α ethinyl estradiol (EE2), acetaminophen, atrazine, imidacloprid, carbamazepine, lamivudine, simazine, sulfametoxazole, terbuthylazine and cinchonidine.
- Perfluorinated compounds (PFCs): Perfluoroheptanoic acid (PFHPA), perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA), perfluorooctanesulfonate (PFOS), perfluorodecanoic acid (PFDA) and perfluoroundecanoic acid (PFUnDA).
- Ammonia, nitrate plus nitrite, DOC, TOC, EC, pH, COD, turbidity and UV_{254} absorbance.

c. Risk assessment

A qualitative chemical risk assessment was carried out using the risk matrix approach. This method provided a relatively simple way of analysing the likelihood of potential hazards or events of taking place, and what the consequence would be should it take place. To evaluate risks, the “As Low as Reasonable Practicable” principle was used (Lindhe, 2010). The risks were then determined to be either unacceptable, acceptable or in the ALARP region, which means that they are acceptable if it is unreasonable due to technical or economic constraints to reduce them.

Results and Discussion

a. Priority list of CECs

Table 1 shows the recommended list of priority CECs that was compiled for assessing water quality in direct potable reuse.

Table 1: Recommended first priority list for CECs for water reuse in South Africa

GROUP	TYPE	CHEMICALS
Industrial chemicals	Flame retardants	TDCPP and TCEP
	X-ray contrast fluid	Iopromide
	PAH	Benzo(a)pyrene
Pesticides, biocides and herbicides	Herbicide	Atrazine
	Herbicide	Terbuthylazine
	Insecticide	Imidacloprid
	Pesticide	Simazine
Natural chemicals	Stimulant	Caffeine
	Hormone	17-beta estradiol
Pharmaceuticals and metabolites	Antiretroviral drugs	Lamivudine Stavudine
	Anti-epileptic drugs	Carbamazepine
	Anti-malarial drugs	Cinchonidine Cinchonine
	Analgesic	Paracetamol
	Antibiotic	Sulfamethoxazole
Personal care products	Anti-microbial	Triclosan
Household chemicals	Plasticiser	Bisphenol-A
Transformation products	By-product	N-Nitrosodimethylamine (NDMA)

Developing the priority list for CECs included chemicals representing each of the main groupings of CECs, and specifically pesticides identified as high-risk priority pesticides in South Africa, and also antiretroviral drugs (ARVs).

b. Potential exposure risks

There has been increasing concern regarding substances in the environment that could impact on the endocrine systems of humans and animals. The cost of monitoring the entire spectrum of potential EDCs in water and water related media would be prohibitive and it is not possible to estimate the potential health risks of endocrine disruptors based on the chemical composition alone. Biological methods are becoming progressively more popular as screening tools because the chemical nature of an environmental sample is not usually known. The human health effects of chemical mixtures cannot necessarily be based on their concentrations, therefore bioassays are used to assess the potential effects of complex mixtures of endocrine disrupting chemicals.

Ames Mutagenicity test

Toxicity was observed in raw wastewater, with reductions observed in the majority of wastewaters, the exception being the wastewater treatment plant treating two different wastewater streams. Where no mutagenic activity was observed it is likely that is was masked by the toxicity.

Daphnia 24 - 48 hour toxicity test

All wastewaters showed 100% toxicity, while drinking waters elicited high toxicity levels (WRP A and B). The presence of chlorine in treated drinking water and wastewater effluents will cause toxicity, illustrating the need to neutralise the chlorine used to disinfect the water, prior to testing.

YES Oestrogenicity Activity Test

Oestrogenic activity decreased in all wastewater treatment works with final effluents being below detection limits. These bio-assays have illustrated the improvements in wastewater quality following treatment through the various treatment works, and the results have shown how these bio-assays are able to be used to monitor the water quality.

c. Indicative CEC removal potential by treatment processes

Findings from this study indicated that the largest percentage of total PFC removal was found in the water reclamation plants (97%), while the removal in the wastewater treatment plants ranged from 52 – 65%. The highest concentration of PFOs in the raw wastewater to the wastewater treatment plants was 10.0 ng/ℓ), which was found in the WWTP that received inflow from both municipal and industrial wastewaters, as well as landfill leachates.

There was a major decrease in the concentration of BPA and acetaminophen through the different treatment processes, indicating that these compounds are effectively removed by the treatment processes. Removal efficiency for BPA in WRP A, WWTP C, WWTP B, and WWTP D were 98.5%, 99.7, 93.4%, and 86.5%, respectively. Removal efficiency of Acetaminophen was 100% (WRP A), 95.6% (WWTP C), 100% (WWTP C), and 95.8% (WWTP D).

d. Risk assessment

Findings from the case study health risk assessment studies revealed the need to manage two risks. The first risk corresponds to the constant presence of 17α-ethinylestradiol (EE2)

in the final effluent. Furthermore, the risk of children swimming in the brine channel and ingesting the contaminant EE2, was found to be an unacceptable risk.

Conclusions

Many lists of contaminants of emerging concern have been compiled internationally and locally. In this project, a priority list for CECs in direct potable reuse in South Africa was developed. It is recommended that each reclaimed potable water reuse project interrogate the relevance of these chemicals according to the specific area, to consider whether additional chemicals might need to be added to the priority list.

The bio-assays have illustrated the improvements in wastewater quality following treatment through the various treatment works, and the results have shown how these bio-assays are able to be used to monitor the water quality.

From the results of the analyses performed on the samples collected during the three sampling campaigns, it was clear the certain CECs and PFCs are much more prevalent in wastewaters than others. It was also found that in most cases, all the compounds were reduced by the various treatment units. In some cases, it was found that constituent concentrations increased, but it is suspected that this is the result of plug flow characteristics caused by the time delay between treatment units that were not considered during the sampling campaigns. In all cases, however, the final water complied with all standards available for the various compounds.

As the case study water reclamation processes were found not treat the water to a satisfying level with respect to EE2, countermeasures were recommended. Electrochemical removal could be a recommended option in a pilot project for the plant in the future, but more research needs to be completed for an appropriate design and implementation of this process. Ozonation and GAC are therefore recommended technologies because these technologies are already proven and mature.

Acknowledgement

Funding of this project by the Water Research Commission is gratefully acknowledged.

References

Grover, D.P., Balaam, J., Pacitto, S. Readman, J.W., White, S. and Zhou, J.L. (2011). Endocrine disrupting activities in sewage effluent and river water determined by chemical analysis and in vitro assay in the context of granular activated carbon upgrade. Chemosphere, 84: 1512-1520.

GWRC (2003). Endocrine Disrupting Compounds An overview of the sources and biological methods for measuring EDCs Prepared by: Kiwa Water Research (Netherlands). Global Water Research Coalition.

Lindhe, A. (2010). Risk Assessment and Decision Support for Managing Drinking Water Systems. GeoEngineering, Civil and Environmental Engineering. Gothenburg: Chalmers University of Technology.

OECD (2004) Guidelines for the Testing of Chemicals, Section 2 Effects on Biotic Systems. Test No. 202: Daphnia sp. Acute Immobilisation Test". OECD Guidelines for the Testing of Chemicals. Organisation for Economic Co-operation and Development. ISBN 9789264069947.

How will switching from water recycling to resource factories impact disinfection by product formation?

Bruce Jefferson, Cranfield Univeristy, Cranfield, UK; Chrysoula Sfynia, Cranfield University, Cranfield, UK; Emma Goslan, Cranfield University, Cranfield, UK; Peter Jarvis, Cranfield Univeristy, Cranfield, UK; Sergio Navalon, Polytechnic University of Valencia, Spain

Membrane bioreactors are the core technology utilized for water recycling from wastewater; both industrial and municipal. The membrane acts as a perfect barrier to suspended solids affording very stable control of the bioreactor and the generation of solid free, micro-organism free effluents. When the water is used for potable water production, the effluent is typically further processed through additional removal processes prior to reaction with chlorine. The disinfectant is delivered as either chlorine or chloramination, in order to add a stable residual to prevent regrowth. However, the chlorine reacts with residual organics forming disinfection by products which need to be minimized. In recent years, increased focus has been placed on resource recovery from wastewater, beyond just water reuse, advocating a switch from aerobic MBRs to anaerobic MBRs as this facilities energy and nutrient recovery (resource factories). The difference in the two relates to the biological reactors where completely different microbial communities will exist linked to the difference in the underlying redox chemistry with the former being a very oxidising environment and the other a very reducing environment. Accordingly, it is posited that the precursor make of organics generated from the two systems will likely be different and hence poses the question about the formed DBPS be different?

To answer the question, a pilot aerobic and a pilot anaerobic MBR were operated in parallel fed off the same source of sewage. Effluent samples were routinely taken and analyzed through a formation potential test based on either chlorination or chloramination at both pH 7 and 9 (the respective optimum pH for each). In addition, samples were spiked with ammonia and bromide to explore the impact of inorganic ion incorporation into the DBPs that formed. DBP formation was measured in terms of universally regulated (THM), regional regulated (HAAs) and emerging DBPs (HANs, CP). The overall results were then considered in terms of a hazard index by

dividing the concentration by the respective world health organization (WHO) standard for the individual DBPs.

Comparison of the two MBRs revealed a switch from a carbohydrate rich to a protein rich effluent when comparing the aerobic to the anaerobic MBRs. The anaerobic MBR effluent was also rich in ammonia and methane contained within a DOC which was roughly twice that of the aerobic MBR. The formation potential of THMs was observed to be lower in the case of anaerobic MBRs at 20-24 μg/L compared to 70-130 μg/L for the aerobic MBR when chlorinated. Switching to chloramination significantly reduced THMs to less than 6 μg/L in all cases. On a total mass basis, HAA were the most prominent with levels between 130-150 μg/L for the aerobic MBR and 110-125 μg/L for the anaerobic MBR. The addition of ammonia reduced the total HAA in all cases but addition of bromide had marginal impact on the total concertation. However, addition of bromide, altered the distribution of HAA species toward the brominated forms as expected. Switching the chloramination reduced the formation of brominated species although the formation of DCAA remained similar with either disinfectant. Formation of the emerging DBPs was minimal in all cases with a maximum concentration of 4 mg/L for the total HANs in the case of bromide adjusted aerobic effluent at pH7. However, in general the anaerobic effluent generated more nitrogen based DBPs, especially DCAN, congruent with the higher protein content of the residual DOC.

The overall picture is the switch to an anaerobic MBR from an aerobic MBR will decrease THMs, maintain HAAs and increase emerging DBP formation potentials. When considered in terms of potential hazard index, the HAAs are seen to dominate the overall index such that the adoption of anaerobic MBR based flowsheets should not negatively impact direct potable water production in terms of the likely DBPs formed.

Recycling of industrial process brines

Yuliya Schiesser, Christoph Blöcher, Rainer Weber,
Covestro Deutschland AG, Leverkusen, Germany
yuliya.schiesser@covestro.com

Abstract

Chemical production is associated with the use of a significant amount of water. The closure of water loops to recover materials and re-use of water is highly relevant for Covestro as world-leading manufacturer of high-tech polymer materials to achieve the company's sustainability goals and to contribute to the United Nations Sustainable Development Goal 6: "Clean Water and Sanitation". One example for such recycling-loops is the recovery of NaCl from process water streams to produce chlorine and caustic soda in the chlorine-alkali electrolysis. However, such re-use exhibit technical, economic and ecological challenges. Against this backdrop, Covestro is taking action to develop new, environmentally friendly and economically viable processes for the purification, desalination and use of the water, materials or purified concentrated salt solutions.

Keywords: chemical industry; salt recovery; water re-use; chlorine-alkali-electrolysis

1 Introduction

Around 200 Mio t/a NaCl are used in the chemical industry as a raw material, 120 Mio t/a thereof only for chlorine production (Eurochlor, 2019). Chlorine is a backbone of a chemical industry. Many chemical synthesis processes are realized via chlorination of intermediates, e. g. the production of polycarbonate, vinylchloride, epichlorhydrine or silicon tetrachloride. It is estimated that 60 to 70 percent of all chemically produced products come into contact with chlorine or caustic soda during their manufacturing process, even if most final products do contain neither chlorine nor sodium in their molecules. Those elements rather end up in the waste water.

The discharge of high salt loads into surface waters can be a significant burden on the ecosystem, especially when used for drinking water production. Therefore, efforts are needed to reduce salt loads. The environmental advantage of this is three-fold: (1) savings in raw material usage (NaCl), (2) savings in water consumption (demineralized water) and (3) relieving the water body from salt discharge.

An ongoing research project of Covestro deals with the recovery of salt (NaCl) that is contained in industrial process water streams from plastic manufacturing. The aim is to recycle it as a raw material to produce chlorine and caustic soda in the chlorine-alkali electrolysis as well as to recycle the resulting water. Chlorine is used as a key raw material for the manufacturing of polymers such as polycarbonate. This high-performance plastic is required in many areas such as automotive, electronics, and medical technology. In this way the salt and water cycles can be closed (Figure 1).

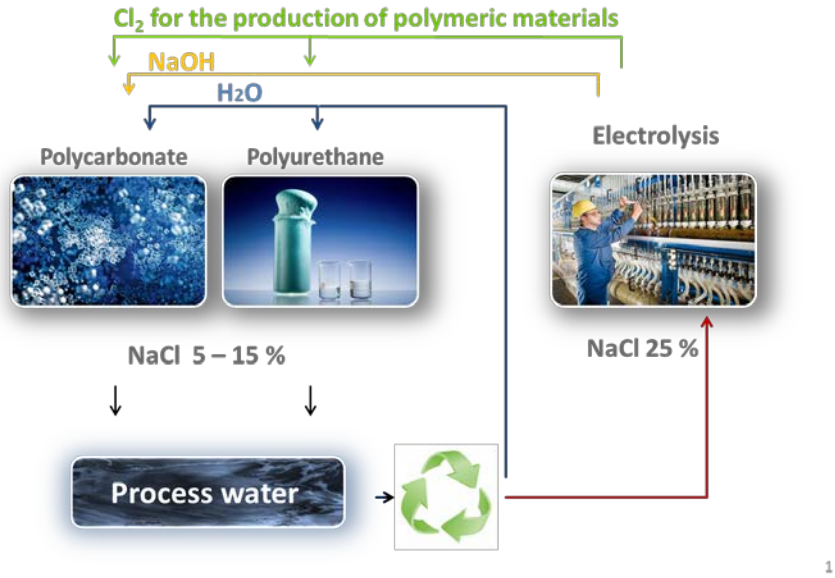


Figure 1: Recycling salt from industrial wastewater

Such salt water recycling schemes exhibit substantial technical challenges. Organic and inorganic impurities may influence the electrolysis process negatively, requiring sophisticated analytical methods and advanced purification processes. Due to the relatively low salt concentrations in the process streams and the limited amount of water that can be fed to the electrolysis, concentration processes are required.

In ecological terms, re-use schemes are mostly associated with additional resources or energy consumption. This has to be balanced against the benefit from the recovery of water or valuables. Moreover, closing loops means to increase the risk of cross-contamination within the processes to which recycling streams are fed. If cross-company or cross-sectoral re-use schemes are concerned, those technical issues gain even contractual significance which might multiply the effort.

Therefore, Covestro is taking action to research and develop new, environmentally friendly and economically viable processes for the purification, desalination and use of the water, salts or the purified concentrated salt solutions.

2 Results and Discussion

A key element for the economic and ecological operation of chlorine-alkali-electrolysis is the required cell voltage. To avoid higher energy demand and costs (especially relating to membrane life time) strong specification for supplied NaCl have to be fulfilled (Table 1).

Inorganic impurities can be removed by typical standard technologies during the brine preparation and purification processes of electrolysis plants (Fig. 2).

Table 1: Brine specification for membrane process operating at a current density up to 4 kA/m² (BVT 2001)

Impurities	Unit	Upper Limit
Ca + Mg	**ppb**	**20**
Sr	**ppm**	**0.04**
SiO2	**ppm**	**10**
Ba	**ppm**	**0.05**
Fe	**ppm**	**1**
Ni	**ppm**	**0.01**
Al	**ppm**	**0.1**
TOC	**ppm**	**1**

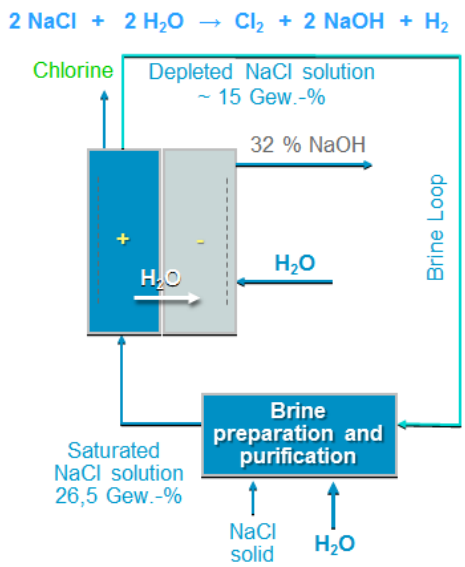


Figure 2: Brine cycle in chlorine-alkali electrolysis

The main challenge for the recycling process is the presence of organic impurities from the plastic manufacturing process in the saline waste water. Organic impurities may as well impair cell voltage already in concentrations in the ppb-range or even, in the long-term, to a damage of the membranes. Therefore, organic impurities have to be removed.

2.1 Analytics

To be able to remove organic impurities efficiently, information on the type and quantity of these compounds is required. However, the detection of these compounds is complicated by high salt concentrations, making it a challenge to find out which substances are present and even to quantify these. Figure 3 gives a visible difference between salt content in drinking water and in process brine.

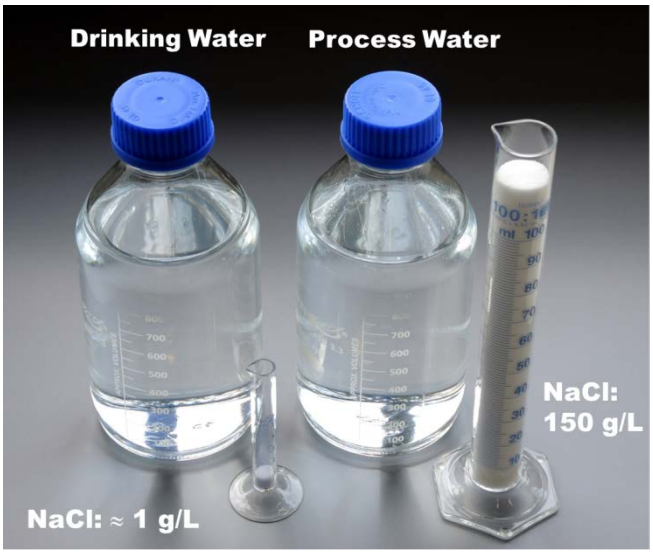


Figure 3: Difference between composition of drinking water and process brine (Source TZW)

The typical total organic carbon value of process brine is between 20 mg/l and 100 mg/l and consists of organic anions and cations, non-polar compounds, surface active substances and et al. More than 60 organic compounds could be identified. To improve the analytical capabilities in identifying such substances, specific analytical techniques had to be developed. Several sample preparation techniques were tested for their performance on separation or enrichment of organic compounds from saline waters (e.g. solid phase extraction, liquid-liquid extraction, distillation, derivatization, ion exchange). In addition to the methods concerning known target compounds, non-target screenings were also performed for the characterization or identification of yet unknown components. For this purpose, GC-, RP- and IC-separation techniques were coupled with several detectors (LF, UV, ESI-MS/MS, ESI-qTOF).

2.2 Purification

Adsorptive, oxidative, biological, thermal and electrochemical processes and combinations thereof are currently developed for the purification of brines. The cleaning itself is impaired by the fact that the organic impurities are only present in very low concentrations in the process water with very high salt content.

Brines from polycarbonate production can be purified by applying extraction of polycarbonate residues and VOC stripping, following by additional polishing steps that include pH-adjustment, adsorption using activated carbon, and stripping of CO_2. Based on positive results Covestro started several brine recycling projects (Figure 4).

NaCl-Recycling plant at Covestro site Krefeld-Uerdingen

Recycling project with Shanghai Chlorine-alkali Chemical Co., Ltd.

Figure 4: Recycling projects to re-use NaCl-containing process streams

One plant is located at the Covestro site in Krefeld-Uerdingen in the German federal state of North Rhine-Westphalia. There, Covestro is demonstrating now successfully the reuse of low-concentrated salt-containing wastewater streams. The process aims at a reduction of salt used in chlorine-alkali electrolysis by 20,000 tons per year. Additionally, 223,200 tons per year of deionized water are recycled. The plant has an explorative character, provides insight experience, and the know-how obtained can be partially transferred to other sites and application areas. This experience is especially valuable by establishing new cross-sectoral projects with external chlorine manufacturers, e. g. in China.

2.3 Concentration

Salt recovery can generally be increased by increasing the salt concentration in the waste water stream to be recycled. However, such concentration of saline solutions is one of the major challenges and may jeopardize any environmental gains achieved by not discharging salt to water bodies. For a specific process of Covestro it was assessed that the negative environmental impact in terms of energy consumption and carbon dioxide emission was higher than the gain from salt recovery when using MVR (mechanical vapor recompression) technology.

Therefore, research is done on energy-efficient membrane processes (e. g. high pressure reverse osmosis, HPRO) and thermal concentration technologies based on waste heat (e. g. membrane distillation, MD). A preliminary assessment revealed that in comparison to MVR (100 %) the use of membrane technologies may reduce the environmental impact. A major reduction, however, can only be achieved if waste heat is available as driving force (Figure 5).

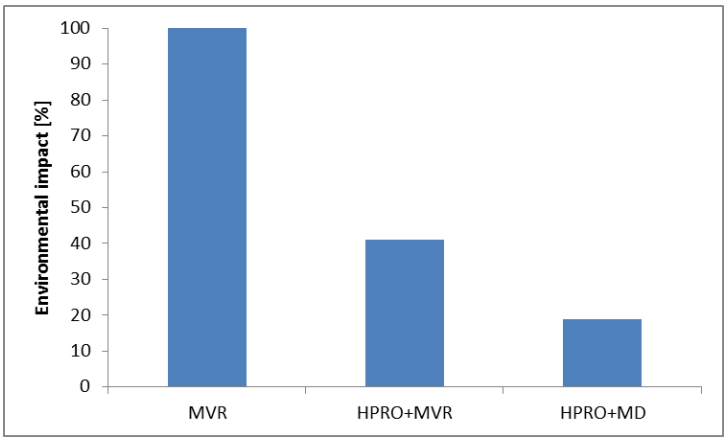


Figure 5: Comparison of environmental impact from different technologies

First investigations of a HPRO process indicated a strong influence of organic impurities from the process brine from polycarbonate production on the performance of the membranes. The long-time behaviour will be investigated in a demonstration plant at Krefeld-Uerdingen site. Long-term experimental data will be collected to be able to perform an economic and ecological assessment of the developed process steps. Also their transferability to other brine types can be completed.

Acknowledgement

For the ongoing research, the support of the German Ministry for Education and Research (BMBF) for the Re-Salt project (Recycling of industrial salty process water), funded within the measure WavE (Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination) – is gratefully acknowledged. The pilot plant in Uerdingen was funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMU) within the so-called Environmental Innovation Program.

References

Eurochlor (2019): Chlor-alkali Industry Review 2017/2018, https://chlorineindustryreview.com (Accessed on January 04, 2019)

BVT 2001: Referenzdokument über die Besten Verfügbaren Techniken in der Chloralkaliindustrie (December 2001): www.umweltbundesamt.de

Innovative technologies for reuse of petrochemical condensates.

I. Veleva, Ghent University, Ghent, Belgium; M. Vanoppen, Ghent University, Ghent, Belgium; C.K. Groot, Dow Benelux BV, Terneuzen, The Netherlands; A.R.D. Verliefde, Ghent University, Ghent, Belgium

1. Introduction

In the (petro)chemical industry, the importance of steam is highly emphasized as an essential heat transfer and reaction medium, as well as a diluent during crude feed cracking. Steam with very high quality is required to guarantee the stable and lasting performance of the plant and with this respect, the type of water source introduced into the boiler system for generation of steam needs to meet very stringent requirements and limitations.

The variety of process applications of steam leads to the generation of a broad range of condensate streams with different composition and specifics, which are further considered when these streams are contemplated for return and reuse in the steam/water cycle. The more heavily contaminated condensates are unsuitable for direct reuse or polishing and are treated at the Waste Water Treatment Plant (WWTP), leaving an opportunity for development of improved condensate treatment for higher steam/condensate recycle ratios and an increased water and energy efficiency.

As part of a project under the scope of the Institute for Sustainable Process Technology (ISPT) and together with several partners (Dow Benelux BV, Terneuzen, Ghent University, Evides Industriewater, Sitech, KWR Watercycle Research Institute, Kurita), this research aims to achieve more efficient production of steam in the (petro)chemical industry by enhancing the recycling of process condensates as high quality water and by reducing the freshwater intake intensity and dependence.

In order to study the main principals and requirements to reach this goal, a specific research case was initiated at the site of the chemical company Dow Benelux BV, Terneuzen, which is located in a water stressed Delta. This production site requires a fresh water supply of 22 million m^3 per year from which only 1-2 million m^3 are locally sourced and the rest is either delivered from recycling water or abstracted from the

natural park Biesbosch. Because of that, the company strives to decrease the intake and necessity of high quality fresh water and to rely only on more sustainable reused process water at the site. This goal has been realized up to 80%, but nevertheless, Dow aims to achieve 100% reuse.

1.2. Technologies of choice

The production process itself generates condensate streams at elevated temperatures, in which complex organics such as acetate, propionate, formate, phenol and emulsion breakers are still present. Due to the nature of these pollutants, such streams are sent to the WWTP.

By strategically by-passing the WWTP and applying an individual treatment on the condensate, a higher energy efficiency and improved water recovery can be achieved. Such approach would further decrease the load to the WWTP. Because of that, different treatment approaches were preselected amongst which Membrane Distillation (MD) and Membrane Aerated Biofilm Reactor (MABR).

2. Materials and methods

2.1 Membrane Distillation (MD)

Membrane distillation is a thermally driven (possible low grade waste heat) process which normally operates in the range between 30°C–80°C and applies a microporous hydrophobic membrane for the separation of a vapor from a liquid stream. In general, MD exists in different configurations, based on the principle that a vapor pressure difference is created across the membrane; Direct Contact MD (DCMD), Air Gap MD (AGMD), Sweep Gas MD (SGMD) and Vacuum MD (VMD).

2.1.1. Lab scale DCMD experiments with synthetic solutions

Due to the availability of waste heat in the condensate stream from Dow Benelux, MD was chosen as a technique for simultaneous water and energy recovery. The influence of key operational conditions on the process efficiency, such as the temperature difference between the feed and the distillate (ΔT), the average temperature of both streams ($T_{average}$) and the flow rate, were studied in a lab scale DCMD, treating a

synthetic solution containing the main pollutants measured in the condensate: acetate (200mg/L), propionate (40mg/L) and phenol (30mg/L) with a pH value between 8.5-9.

The experimental set-up consisted of an acrylic MD module with an active surface area of 163 cm^2 and counter current supply of feed and distillate. The temperature on both sides of the system were maintained by two heat exchangers and detected by Resistance Temperature Detector (RTD) sensors with an accuracy of 0.01°C. The collected data was continuously logged via the program LabView.

2.1.2. Set of parameters and operational conditions

The values selected for these parameters were chosen to represent a full scale MD configuration and secured to incorporate their influence on the amount and quality of the obtained distillate, making the lab scale results comparable to a real system. It was specifically taken into account that common driving force (ΔT) has been reported in the literature within the range of 2K to 10K, because on full scale the temperature drops along the membrane matrix due to temperature polarization.

The same process specific was also considered when talking about the average temperature in the module on a full scale system. In practice, 80°C is usually applied on the feed side and 20°C on the distillate side resulting in an average temperature of 50°C. Based on a Design of Experiments (DOE) approach, for each studied parameter a high (ΔT = 20°C; $T_{average}$= 60°C, flow rate = 90L/h) and low level (ΔT = 10°C; $T_{average}$= 40°C, flow rate = 60L/h) were given and 8 sets of conditions were tested.

At the beginning of the experiments, a bench mark test with Demi Water (DW) was conducted and repeated after a set of 2-3 experiments at the following conditions: T_F = 60°C, T_D = 45°C and flow rate F = 60L/h. The obtained flux was compared with the initially attained value and used to evaluate the integrity of the membrane.

2.1.3. Sampling procedure and analyzes

Samples were taken at the inlet of the feed and the outlet of the distillate of the MD module at every hour and they were immediately analyzed for pH and conductivity. The

composition of the samples was further examined for the presence of phenol via HACH spectrophotometry and for organic acids by Ion Chromatography (IC).

The rejection efficiency of the present compounds was determined via the following equation:

$$Rejection\ Efficiency\ (RE, \%) = \frac{C_{F_0} - C_D}{C_{F_0}} * 100\ \%$$

where C_{F_0} is the concentration of the component in the feed solution and C_D is the amount of the same pollutant in the distillate.

2.2. Biological treatment: MABR

In order to achieve higher effluent purity, a biological treatment step was also considered. An MABR was selected, where the membranes serve as the supplier of oxygen (~200mbar) for the treatment and as a support for the development of a biofilm. The wastewater surrounding the membranes provides the carbon source and nutrients needed for the growth of the biomass (Figure 1).

Because of the stated advantages, an MABR pilot unit with two identical 55L reactors was designed by OxyMem (Ireland) to study the treatment efficiency of the condensate stream generated at Dow, Figure 1. The system is operated in series in order to achieve the highest possible removal efficiency.

The pilot was inoculated with sludge from the WWTP of the company and was operated in a batch mode for 2-5 days, after which it was continuously supplied with synthetic feed. The composition of the mixture was adjusted gradually in order to reach the full load of all chemicals present in the condensate with the intention to replace it in time with real condensate. In order to assure all necessary elements for a healthy biofilm, macronutrients (N and P) as well as micronutrients were additionally added.

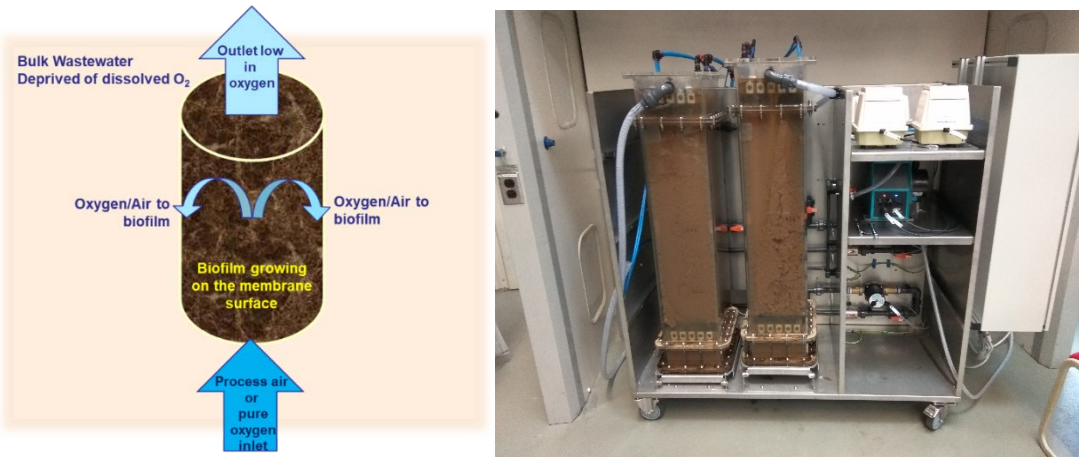


Figure 1 OxyMem MABR twin pilot at Dow, Terneuzen - main concept (left) and after inoculation (right)

The pilot system was operated at an HRT of 10 h per reactor, which resulted in a total flow rate to the system of 128 L/day. Since the main driving force for oxygen supply is through diffusion from the silicon membranes to the biofilm (Figure 1), mixing around the fibers is very important and this is conducted by recirculation pumps with a flow rate of up to 1200L/h. In addition, an ideal biofilm thickness is maintained via scouring, which removes the excess biomass.

The process performance is continuously evaluated by monitoring the main effluent quality parameters such as total organic carbon (TOC = TC-IC), total nitrogen (TN), ammonia (NH_3), nitrite (NO_2^-) and nitrate (NO_3^-) and by additional analyses on the amount of acids via IC and phenol HACH test kits.

3. Results

3.1. MD experiments

The low rejection of phenol observed during the experiments is probably due to its high pKa. For instance, since the pH of the treated synthetic mixture was highly basic (8.5-9) in order to resemble the real condensate, at this pH acetic and propionic acids were certainly above their dissociation constants of pKa = 4.76 at 25°C and pKa = 4.88 at 25°C, respectively. The acids in the feed were greatly rejected, which could be hypothetically explained by the presence of their unprotonated forms. On the other hand, phenol was less retained and has a pKa of 9.99, which could lower its removal since a fraction of phenol will still be in its protonated and more volatile form.

3.2. MABR experiments

The removal efficiency of each individual carbon constituent was monitored and regularly evaluated. Based on the collected data was concluded that the system is able to deplete the present organic acids with an average removal efficiency for acetate, propionate and formate of 95.5%, 83.7% and 57.9%, respectively. When looking into the extent to which phenol was also biodegraded, was noted a particularly high removal effectiveness of 93.3% on an average. Furthermore, in the effluent of the first MABR unit is continuously detected a hardly biodegradable carbon fraction, which persistently remains in the system and leads to an average removal of approximately 75% in R1.

In addition, the applied operational parameters such as air and mixing flow rate, the location of dosed nutrients, the carbon load and pH of the feed have proven their individual influence and importance to the system's performance. For instance, introducing the nutrients mixture directly into R1 rather than into its mixing loop has led to an improved mixing flow from 300L/h to 950L/h, but also to lower (0.5 mg/L) dissolved oxygen concentration in the bulk. Such depleted of oxygen environment secured the completion of denitrification, but on the other hand influenced the removal of the targeted carbon pollutants.

4. Future perspectives

It is of great importance for the real application of the MABR system that a load in the expected magnitude to the full scale reactors is tested on the pilot scale as well as to examine the limits and capacity of the process. Moreover, in order to achieve higher TOC removal a restart and re-inoculation of R2 has been considered as a polishing step for degradation of the persistent carbon fraction in the effluent of R1.

With respect to the MD configuration, future experiments with elevated pH (10.5-13) are planned as a methodology to achieve the highest phenol retention. In addition, given the nature of the pollutants of interest a comparison between the performance and rejection capability of a hydrophobic and an oleophobic membranes will be made.

Industrial reuse of advanced reclaimed water: A 6-year project in Camp de Tarragona

*Joan Sanz, Veolia Water Technologies, Sant Cugat del Vallès, Spain, presenting author(*); Rafael Mujeriego, Universidad Politécnica de Catalunya, Barcelona, Spain; Daniel Montserrat, AITASA, Bonavista, Spain; Yvan Poussade, Veolia, Aubervilliers, France; Verónica Gómez, DuPont, Tarragona, Spain; * email: joan.sanz@veolia.com*

Keywords: industrial reuse, advanced water reclamation, cooling water, demineralized water, boiler-feed water.

Introduction

Since November 2012, the Advanced Water Reclamation Plant (AWRP) of Camp de Tarragona has been continuously supplying highly-treated reclaimed water and demineralized water to the Tarragona Petrochemical Park (TPP), resulting in an annual supply of 4.9 hm^3 in 2018. The planning, design and implementation of the AWRP were previously presented by Sanz *et al.* (2015). Since 2012, reclaimed water quality monitoring is conducted following industry specific requirements, Spanish regulations (Royal Decree 1620/2007) and regional public health authorities' specifications. The process flow diagram of the AWRP is shown in Figure 1.

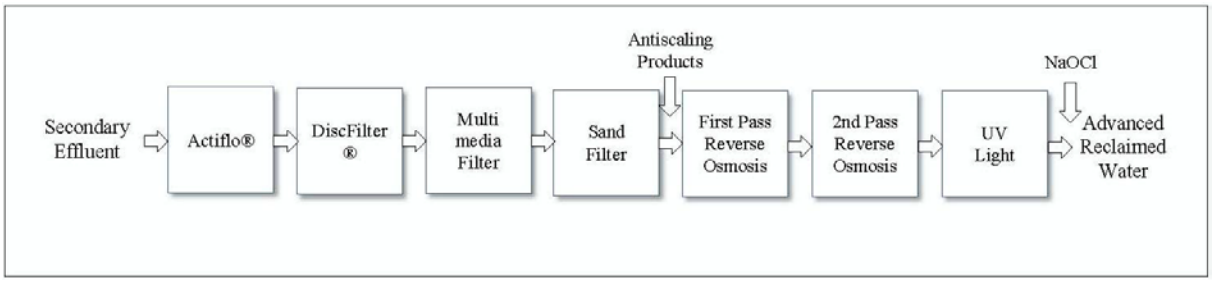


Figure 1: Process flow diagram of the Camp de Tarragona AWRP.

Objective

The paper presents the lessons learned from the 6-year continuous operation of the AWRP, the systematic follow-up of reclaimed water quality in the distribution network and the end-users' assessment of using reclaimed water for cooling water systems and high-pressure boilers. The lessons learned are presented with respect to the quality assurance program for reclaimed water, the reverse osmosis (RO)

pretreatment processes, the RO fouling and cleaning processes, the production of highly demineralized water and the operation and maintenance of the whole project. Finally, the paper offers conclusions and recommendations based on the results gathered during more than six years of production, distribution and use of advanced reclaimed water at a large petrochemical industrial complex.

Reclaimed water quality

Critical water quality parameters for water supply to cooling towers and evaporative condensers were selected in accordance to Spanish regulations (Royal Decree 1620/2007). Three critical control points were chosen for water quality assurance: 1) the water tank at the AWRP, 2) the point-of-entry at the south TPP water tank (chemical industries) and 3) the north TPP water tank (refineries). The initial public health operational permit required monitoring of halogenated and non-halogenated volatile organic compounds at the three critical control points. In addition to the water quality parameters specified by public health agencies, advanced reclaimed water has been monitored for the compounds of emerging concern (CEC) included in the DEMOWARE European project (2014-17) and the priority and hazardous substances proposed by the Institute of Environmental Assessment and Water Research. Several monitoring campaigns have also been conducted for dissolved and particulate organic carbon and microbiological quality, at the inlet and outlet of each reclamation unit process.

Reclaimed water quality control is conducted by: 1) the AWRP laboratory (process control), 2) an external certified laboratory (according ISO 17025) and 3) the technical and scientific services of the Rovira i Virgili University of Tarragona (microbiological redundancy control). The results obtained by the certified laboratory during the first two years of operation served to validate the conformity of reclaimed water quality with the RD 1620/2007 provisions in all critical control points. On that basis, a waiver was requested to regional public health authorities to decreasing monitoring frequencies; their subsequent approval allowed a cost reduction in the analytical program.

AWRP Performance

Increasing reclaimed water demands since November 2012 have required a continuous optimization of energy use, by adjusting the operation schedule to electricity variable hourly costs, with up to 58 % of the daily electricity consumption falling into the lowest hourly cost in 2018. The unit energy consumption has diminished gradually from 2.61 kWh/m^3 (2013) to 2.04 kWh/m^3 (2018).

Since 2013, all the 28 halogenated volatile organic compounds and the 10 non-halogenated volatile organic compounds analyzed on a 4-month frequency basis were below their limit of quantification (LOQ). The regional Public Health Agency also required reclaimed water to be analyzed in accordance to European drinking water regulations; the results from the last 6-year period satisfy all the quality parameters, with the exception of pH and Langelier index, as reclaimed water does not need to be chemically stabilized before its use for cooling water supply.

The removal of dissolved organic carbon (DOC) by coagulation-flocculation-ballasted sedimentation ranges from 16 % to 27 %, with the removal of the biopolymers fraction ranging from 60 % to 68 % and of humic substances by 51 %. The DOC fractions for building blocks (breakdown products of humic substances) and neutral lower molecular weight compounds remain constant throughout that unit process. The fraction of acidic low molecular weight compounds is below their LOQ both in the AWRP influent and in the unit operations included, with the exception of some occasional low water quality secondary influents. The gravity and pressure filtration processes contribute a very limited additional removal, for both total DOC and its different fractions.

The coagulation-flocculation-ballasted sedimentation process also contributes to the removal of particulate organic carbon (POC), with an efficiency ranging from 39 % to 84 %. This combined unit process also removes the POC fractions associated to total nitrogen (48 % to 98 %), proteins (73 % to 90 %) and carbohydrates (43 % to 94 %). Ammonia in cooling towers water has been mostly absent as it is stripped out from the tower packing.

Microbiological analyses of cooling towers water have been performed by an accredited external laboratory, according to ISO 17025. Total aerobic bacteria have

remained below required limits (10.000 CFU/100mL) and *Legionella pneumophila* has been permanently absent (below 40 CFU/mL) in cooling towers water.

From the 16 PAHs analyzed, eight were below their LOQ and the other eight slightly above, with a combined influent concentration of 78 ng/L and an effluent concentration of 2.5 ng/L. From the 24 pesticides analyzed, all but two were below their LOQ, and those two reached concentrations slightly above those limits. From the 10 common pharmaceutical products analyzed, all were below their LOQ.

Reclaimed water application in petrochemical industries

Reclaimed water is used in many industrial sites for water supply to cooling towers (main current use), use as process water and production of deionized water for medium and high-pressure boilers. It is a practice well documented at the Dow Chemical Ibérica Tarragona (DCI) North petrochemical production complex (Ethylene Cracker), located in La Pobla de Mafumet (Tarragona, Spain). Reclaimed water is blended with Ebro River water (up to 40 % reclaimed water) to provide make-up water for cooling towers. Reclaimed water from the AWRP has an average electrical conductivity (EC) of 20 µS/cm, a TOC lower than 0.1 mg/L, and a scaling tendency lower than surface water from the Ebro River, conventionally used to supply cooling towers. Those characteristics offer a possibility for increasing the number of concentration cycles beyond four, normally applied at the PCC. However, reclaimed water contains substances that promote microbial growth (ammonia, phosphate, and organic carbon) and, therefore, requires a detailed microbiological control program. The limited buffering capacity and the presence of chlorides can also promote corrosion. Treatment and operational simulations revealed that cooling towers could reach up to 8 concentration cycles, provided that a good corrosion control is adopted, using a dual cathode system. Cooling towers are currently operated at 7 concentration cycles, resulting in a total make-up water reduction of 110 m^3/h (22 %) as well as a reduction of water blowdown disposal of 76 m^3/h (49 %). The impact of microbial growth and corrosion was controlled and monitored using Nalco 3D TRASAR™ technology for cooling water. Based on ASTM corrosion guidelines and DOW requirements, the corrosion rate was rated as “negligible or excellent” at less than 1 mm/y for carbon steel and less than 0.1 mm/y for copper-based alloys. As a

result, the amount of chemicals needed for cooling water conditioning has been significantly reduced.

AWRP performance stability was the initial tool used for monitoring RO operation. RO fouling was assessed to determine the nature of the fouling agents and the optimum cleaning program. Investigation and identification of the fouling process was conducted using several analytical tools (microbiological analysis, LC-OCD, SEM-EDX, XFR, ATR-FTIR, CFM, LC/MS GC/MS and protein identification). Fouling analysis and characterization have been carefully monitored by Tarragona Dow Water & Process Solutions Global Water Technology Centre, external laboratories of three Universities and the Institute of Environmental Assessment and Water Research. The investigation revealed that proteins are the main cause of organic fouling. A preventive cleaning strategy using daily alkaline flushing combined with standard CIP has been implemented, after several cleaning strategies were tested at Dow Water Technology Centre using 8” elements from the AWRP. The replacement frequency of RO elements has ranged between three and four years.

Both the low levels of EC (20 µS/cm) and TOC (below 0.10 mg/L) of reclaimed water are very favorable for its use as feed water to a demineralization processes by mixed-bed ion-exchange resins. Since June 2014, a satellite plant for additional demineralization by ion-exchange resins has been in operation at the TPP site, producing 30 m^3/h of highly demineralized water (EC of 0.2 µS/cm) for its use as boiler-feed water. Aside from a sodium concentration of 0.028 µg/L, the concentration of nine other inorganic ions are below their LOQ and that of TOC is below 30 µg/L.

Since early 2019, reclaimed water users at the petrochemical and chemical complex of Camp de Tarragona are exploring the option of expanding the AWRP production capacity, as to secure a larger fraction of their water needs by advanced reclaimed water, instead of the surface water currently supplied from the Ebro River.

Conclusions

Since 2012, the AWRP of Camp de Tarragona has been supplying advanced reclaimed water to the TPP, satisfying the chemical and microbiological water quality requirements specified by Spanish regulations for water reuse, as well as the limits

for volatile organic compounds required by public health authorities. Reclaimed water also satisfies the European quality requirements for drinking water, with the exception of pH and Langelier index, as no chemical conditioning is applied to cooling waters.

The coagulation-flocculation-ballasted sedimentation is a critical treatment unit for reducing the humic substances fraction and biopolymers present in reclaimed water. Total organic carbon (TOC) removal ranges from 10 % to 20 %. That unit process is also critical for the removal of particulate organic carbon fractions and especially the proteins fraction related to the biofouling process observed, as well as carbohydrates (polysaccharides).

The two-pass RO advanced treatment process, followed by UV and chlorine disinfection is an advanced reclamation process capable of producing a very reliable high quality water supply at the Camp de Tarragona chemical and petrochemical industries, with a production unit energy use of 2.04 kWh/m^3 at a production capacity of 4.9 hm^3/y (2018). The low EC and TOC content of reclaimed water has favored its further demineralization, using onsite mixed-bed ion-exchange resins, to produce water suitable for high-pressure boilers and process water.

The AWRP of Camp de Tarragona offers an excellent showcase for documenting and following up its ability to produce a very reliable and high quality water, in terms of its content of PAHs, pesticides, and pharmaceutical products comparable to the best surface waters currently used for drinking water supply.

References

Innovation-demonstration for a competitive and innovative European water reuse sector (DEMOWARE) (2014-2017). The final publishable Summary Report can be downloaded from the project's webpage. http://demoware.eu/en/results/final-publishable-summary.pdf/view

Sanz, J., Suescun, J., Molist, J., Rubio, F., Mujeriego, R. and Salgado, B. (2015). Reclaimed water for the Tarragona Petrochemical Park. *Water Science & Technology: Water Supply* | 15.2 | 2015. DOI: 10.2166/ws.2014.114.

Condensate reuse in the chemical industry – pilot scale experience

M. Vanoppen, UGent, Ghent, BE; E. De Meyer, UGent, Ghent, BE; Ivaylo Hitsov, UGent, Ghent, BE, Farnoosh Fasaei, HZ, Vlissingen, NL; H. Cappon, HZ, Vlissingen, NL; E. van den Brande, Yara Sluiskil B.V., Sluiskil, NL; A.R.D. Verliefde, UGent, Gent, BE.

Abstract:

Water reuse in industry is a hot topic in times of droughts and water shortages. In boiler systems, quality requirements for feed water are high. That is why adequate treatment of the return condensate is needed before it can be reused. In the IMPROVED project, a mobile testing installation was developed that can test different treatment technologies on site on a relevant scale, to give an indication of the most suitable treatment, both technologically and economically. At Yara, RO proved to be the most economically interesting technology, but the water quality was not sufficient so an additional mixed bed treatment would be necessary. Membrane distillation on the other hand produced the right water quality, but turned out to be too expensive for application.

Keywords: Condensate reuse, boiler, pilot, RO, ED, MD

Introduction

Increasing fresh water shortages (caused for example by groundwater salinization) are pushing major industries to look for alternative water sources. However, alternative water sources bring uncertainties related to quality, quantity and their effect on the existing (pre-)treatments and processes themselves with them.

One of the processes most sensitive to water quality is the boiler in steam-water cycles. Impurities in the feed water can results in the formation of corrosive products, such as organic acids, under the influence of the high pressure and temperature (hydrothermolysis). In this research, the re-use of two process condensates, contaminated with NH_4^+, NO_3^- and organics, is investigated. Different technologies, traditional and cutting-edge, were investigated, both on lab-scale and in an innovative mobile pilot-scale testing facility, to compare their technical and economic potential for full-scale application. The resulting water was subjected to boiler conditions and the formation of corrosive products was investigated.

The IMPROVED project

This research is conducted as part of the Interreg IMPROVED project (Integral Mobile PROcesswaterproduction For an Economic Delta), which entails the design, build and exploitation of a mobile testing infrastructure containing several water treatment installations to be put on site of three large chemical companies. This allows flexible on-site testing of several technologies under realistic conditions.

The technologies available in the mobile installation are (in no particular order), the one used in this research are indicated in bold:

- Ion-exchange (WAC-SAC-degasser-WBA-SBA-MB)
- Granular activated carbon
- Ultrafiltration
- **Electrodialysis**
- **Reverse osmosis**
- **Membrane distillation**
- Advanced oxidation (UV, ozone and peroxide)

A virtual visit to this facility is available at www.virtualtourimproved.ugent.be.

Material and Methods

Water treatment

Electrodialysis (ED), reverse osmosis (RO) and membrane distillation (MD) were tested short-term on lab-scale and for 6 months in total in the mobile installation to treat the condensates and obtain a reusable water stream. A short description of all set-ups will be given here.

Lab-scale:

- ED: PCCell ED 64004, 5 cell-pairs (64 cm²), FujiFilm Type I membranes, batch operation
- RO: 110 cm² flat-sheet BW30HR-440i, batch operation
- MS: 110 cm² flat-sheet Aquastill, batch operation, feed pH 9, permeate pH 2

Pilot-scale:

- ED: PCCell ED 1000A, 25 cell-pairs (95 cm²), PCA membranes, feed-and-bleed mode.
- RO: LC HR4040 module, 20-25 lmh.
- MD/MS: 7.2 m² Aquastill module, temperature difference: 55-35°C (feed-condensate) in MD, pH difference: 10-4 (feed-condensate).

Boiler experiments

Boiler conditions (380°C and 40 bar in this case) were simulated in a mini-boiler set-up in the laboratory. The boiler has a volume of approximately 5 mL and was operated at a residence time of 1.24 seconds. 0.1 ppm carbohydrazide was added to the feed solution to keep the oxygen level in the feed vessel below 20 ppb. An overview of this set-up is given in Figure 1.

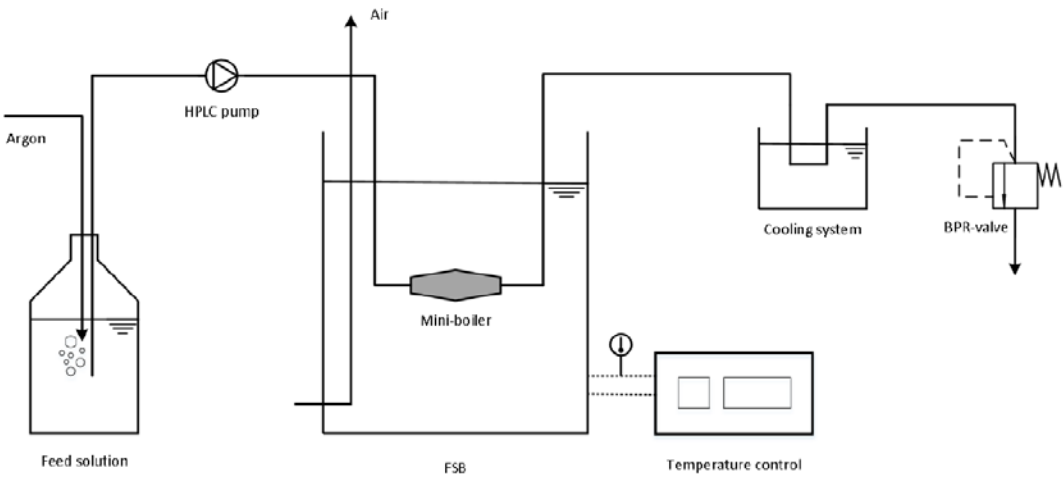


Figure 1 Schematic overview of the mini-boiler set-up.

Feed water

Two different condensates were investigated. The average composition of these condensate, from now on referred to as C1 and C2, is given in Table 1.

Table 1 Composition of the two condensates

	C1 (mg/L)	**C2 (mg/L)**
NH_4^+	10-15	130-400
NO_3^-	35-50	-
Fe(tot)	1.8	-
TOC	0.2-4	230-700
Formate	-	1-10
Acetate	-	10-15
Ethanol	-	20
Urea	-	0.2

Results and Discussion

Lab-scale tests

The efficiency of the techniques tested on lab-scale were compared based on produced water quality, to give an indication for their potential on larger scale. The variability of the composition on the different condensates caused a difference in starting concentrations between the different experiments. The ammonia removal and final concentration for the different techniques after treatment of C1 and C2 is shown in **Table *2***.

Table 2 Ammonia removal and final concentration after treatment of both condensates by ED, RO and MD.

	C1		**C2**	
	Removal (%)	Product (mg/L)	Removal (%)	Product (mg/L)
ED	97	0.32	94	24.88
RO	93	1.10	95	11.36
MS	55*	1.17	99	0.15

* Due to technical issues, removal was limited to 55%

Based on these preliminary lab experiments, ED is most capable of removing the ammonia from the feed stream for C1, but MS performs the best for C2. This can be attributed to the pH of the streams, influencing the volatility of the ammonia in the MD system. The same is expected for the C1 stream, but could not be reached due to technical issues.

All resulting water streams (after treatment) were also subjected to boiler conditions in the lab, after which the formation of organic acids was analyzed (propionic and acetic acid) and compared to that of the untreated condensate. The results are also compared to those after an additional mixed bed (MB) treatment, further polishing the treated water to reach the required quality. Results are shown in Figure 2.

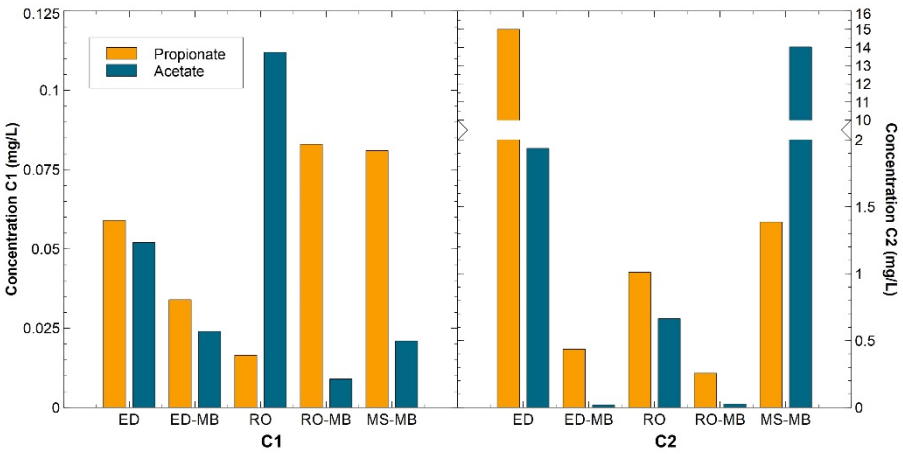


Figure 2 Propionate and acetate content of the treated condensate after the boiler and of the original condensate (without boiler treatment). Please not the different scales of the y-axes.

Organic acids are believed to be one of the main causes of corrosion in boiler feed systems, because of the local pH drop they induce when formed. Although initial concentrations in the condensates are low for C1, decomposition of the residual TOC after treatment results in higher concentrations of organic acids both in ED and RO treatment, with or without a mixed bed (MB) as a polishing step. For C2, with a high initial TOC and organic acid concentration, the treatment steps are able to the decrease the amount of organic acids formed in the boiler significantly. However, in ED and MS (the latter even after MB), the amount of organic acids formed is relatively high, causing concern regarding the application of these technologies for boiler feed water production.

Pilot scale tests

Based on the lab-scale testing, it was decided to run ED and RO for both streams on pilot-scale. For C1, MD was selected as a suitable technique, while for C2 (because of the higher initial ammonia concentration), MS was selected. The general results and estimated costs for all of these tests can be found in Table 3.

Table 3 Comparison of different treatment efficiency for the treatment of C1 and C2.

	C1			C2		
	ED	**RO**	**MD**	**ED**	**RO**	**MS**
Product conductivity (µS/cm)	39.3	140.9	BDL[1]	29.3[2]	469	28600[3]
Water recovery (%)	85-95	75-85	68-75	Max.80	70-85	50[4]
Energy requirement (kWh/m³)	0.10-0.26	0.58	0.29	2.7-4.1	0.87	2.85
CapEx (kEUR)	759	189	1 604	266	97.6	387
OpEx (EUR/m³)	0.26	0.06	0.74	2.74	0.22	1.46

[1]BDL = below detection limit.
[2]minimum conductivity reached in feed and bleed mode, in continuous mode, the minimum conductivity was 1839 µS/cm.
[3]A flux of 30 mg/m²/h of ammonia was reached. Methanol and ethanol also moved through the membrane until a concentration equilibrium was reached.
[4] in membrane stripping, water transport is minimal and flow rates are equal on the feed and condensate sides.

Although generally speaking, the quality attained is lowest when using RO, the costs is also lowest. Both ED and RO would need additional polishing before reuse of the water is possible, so an additional MB treatment is suggested. For C1, water quality is great after MD, but the costs render this technology unfeasible at this moment. For C2, ammonia can efficiently be captured in the product water, but methanol (up to 1499 ppm) and ethanol (up to 26 ppm) are also found in the product water. An additional IEX step before MS could solve this problem, as the resins would retain the alcohols.

Conclusions

By reusing condensates from the steam-water cycle, enormous amounts of water can be saved and the wastewater treatment plant can be downsized. At Yara Sluiskil B.V., two condensate streams were investigated on pilot scale. Although MD clearly resulted in the best product quality, RO and ED were more economically interesting. The latter technologies performed similar but would both need a polishing step for the water to be reused in the boiler system. MS offered interesting perspectives for the reuse of the ammonia in the water, but would also require an additional treatment step.

Acknowledgements

This work was funded by the EFRO Interreg V Flanders-Netherlands program under the IMPROVED project.

Advanced Zero Liquid Discharge concept for the chemical industry

M.Pastur, Clariant, Tarragona, Spain; S.Vila, Dow Chemical, Tarragona, Spain; C.Niewersch, Dow Chemical, Tarragona, Spain; C.Pătruț, Blue-Tec, Renkum, The Netherlands; J.Kochan, Clariant, Frankfurt, Germany; R.Wünsch, University of Applied Sciences and Arts Northwestern Switzerland, Basel, Switzerland; L.van Dijk, Blue-Tec, Renkum, The Netherlands; C.Kazner, Bochum University of Applied Sciences, Bochum, Germany; J.Koppe, MOL Katalysatortechnik GmbH, Schkopau, Germany; J.Palacín, Clariant, Tarragona, Spain; F.Zorn, Clariant, Frankfurt, Germany

The fresh water scarcity and the more stringent discharge limits are the main challenges for the industry in impacted regions. Meanwhile, the elimination of specific pollutants such as e.g. micro-pollutants from the effluent of wastewater treatment plants has gained more attention. In the presented demonstration study, we assess both the performance of the proposed ZLD concept to reuse industrial wastewater and the total treatment costs.

From a quality point of view, the water produced is compared with the requirements of the chemical industry and the Spanish Legislation about water reuse in the industry.

The core of the concept is ultrafiltration (DOW IntegraFlux™ SFP-2880XP) pretreated reverse osmosis (DOW FILMTEC™ FORTILIFE™ CR100) employing adsorption step to reduce organic load (granular activated carbon with 3 filters in series) and advanced oxidation process (UV/H_2O_2, 350W, low pressure UV lamp) as final polishing step to meet high quality permeate requirements.

The catalyst MOL®LIK was installed prior to ultrafiltration and reverse osmosis to enhance filtration performance by repressing fouling and scaling.

For the concentrate treatment the innovative concept of Blue-tec was tested. The RO brine was treated by forward osmosis coupled with high brine reverse osmosis and/or membrane distillation for the draw solution recovery.

To investigate the viability of the concept, a 5.0 m^3/h pilot unit were constructed and operated continuously for treatment of secondary effluent of the wastewater treatment plant of Clariant Ibérica Producción in Tarragona, Spain.

Acknowledgments

This work has been conducted with the financial support of the Horizon 2020 Programme of the European Commission within the framework of the INSPIREWater project (Grant Agreement Nº 723702)

Sustainable integration of water reuse in a multi-resources system

Avner Adin, Dept. Soil and Water Sciences, Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, Rehovot, Israel; Raanan Adin, Adin Holdings water consulting, Ganei Tikva, Israel; avner.adin@mail.huji.ac.il

Abstract:

Wastewater reuse is an emerging water generation tool for combating water stress. The work aims at paving a way for its sustainable integration in a multi-resources system. By holistic approach, the water cycle is divided into: (a) Potable production circle, and (b) Recycled water circle, including irrigation, industrial uses and stream rehabilitation. As a result, effective management of outcoming water quality challenges and innovative solutions are achieved, their wise use is discussed. e.g. long term threats of desalination to public health and agriculture are solved by restoring minerals from brine. In conclusion, holistic interpretation of the water cycle is necessary for effective and sustainable integration of water reuse in the multiple-resources systems of this century.

Keywords: Water reuse; recycling; holistic water management; integrated water systems

Introduction

Natural water resources alone cannot support the growing demand for both urban and rural areas around the world; some of them suffer from recent draught events and decades of groundwater over-pumping (Global Water Partnership, 2012). In parallel to taking socio-economic measures like combating climate change, birth control and water conservation, non-conventional water resources development is taking place for different urban, agricultural and industrial uses.

Wastewater reclamation and reuse (WRR) is an emerging water generation tool for combating water stress. Urban, agricultural and industrial uses of that water were introduced as components of the hydrological cycle (Asano, 1998) and engineering and management practices are becoming widely used. Yet, agriculture is commonly considered as the best and largest consumer of reused water, where impediments such as large capital investments, negative public perceptions and lack of regulatory frameworks prevent WRR from reaching its full potential (Sheikh et al., 2018).

The thirsty countries' strategy focuses today on water generation not only through WRR, but also via massive desalination of seawater and brackish water and by rain

harvesting (Negewo, 2011). Water conservation, rain enhancement, and storm water utilization have also been developed. For example, the Israeli Water Authority long-term program is the development of the alternative, non-conventional water resources, most of which are water reuse projects for agriculture and SWRO (sea water reverse osmosis) and some brackish water desalination plants for public supplies (Israel Water Authority, 2012). Australia, Spain, California and Singapore are going a similar way, where desalination in California is developing slower and Singapore is targeting the recycled, so called “New Water”, for industry and some for indirect drinking since there is almost no agriculture there (Tan et al, 2009). Since seawater and wastewater quantities are basically endless, and since the cost of desalinated water has considerably dropped to affordable levels, inadequate source water quality and water transport energy are becoming more significant factors. The growing complexity of the water resources and water supply systems nowadays dictates the development of holistic approach for WRR sustainable integration and effective water quality management.

Methodology

Looking at the big picture of the water market in the 21st Century, it can be concluded that quite a revolution is taking place - revolution of the water cycle. The classic natural cycle becomes more complex, an integration of natural and artificial water. This is illustrated in Fig. 1. Two circles may be observed here:

(1) The left circle describes the production of freshwater, consisting of natural sources accumulated in surface and sub-soil water reservoirs, desalinated water and harvested rainwater collection and treatment systems. This circle supplies quality drinking water primarily to the city and, at various qualities to agriculture and industry.

(2) The right circle is a circle of recycled water: the wastewaters are collected and treated. The treated effluents are supplied for agricultural irrigation, city parks,

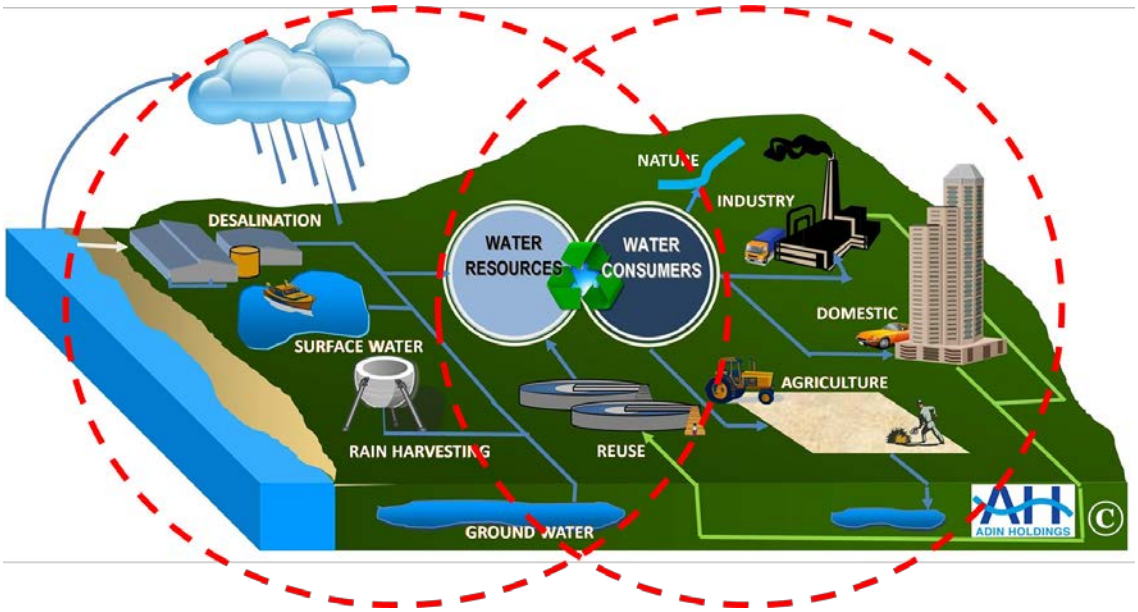


Fig. 1. Holistic water cycle.

industrial uses and streams rehabilitation. There could be smaller scale circuits, implemented in some industrial parks and plants which recycle their own pre-treated wastewater, thus saving on paying for incoming water on one hand and sewer discharge fees on the other. Greywater reuse is a potential additional water circuit, not widely developed yet. Direct potable use is a developing option.

Results and Discussion

Resulting Water Quality Encounters. Water quality challenges are numerous; some significant ones involving reuse of municipal wastewater particularly can be commonly assembled in few categories as follows:

(a) Tertiary effluents where potable water supply is provided from natural water resources: Salinity, boron, nutrients, contaminants of emerging concern (CEC) (Chefetz et al, 2018), nanoparticles (NPs)(Ma et al., 2016).

(b) Tertiary effluents where potable water supply is provided by desalinated water: Corrosion, boron, minerals deficiency in product water

(c) Direct potable reuse: Biofouling, corrosion, minerals deficiency, and

(d) Sludge and brine management.

The two circles described by figure 1 seem separate, yet intertwined and thus are affected by each other. The drinking water qualities, plus additional constituents resulting from its use, eventually dictate the quality of the wastewater generated by the water consumer. This quality impacts down the road on the processing of the wastewater at the treatment plant, the effluent quality it produces and hence the plant which is irrigated by it and the soil, groundwater below and surrounding environmental components. For example, desalination as water source (figure 2):

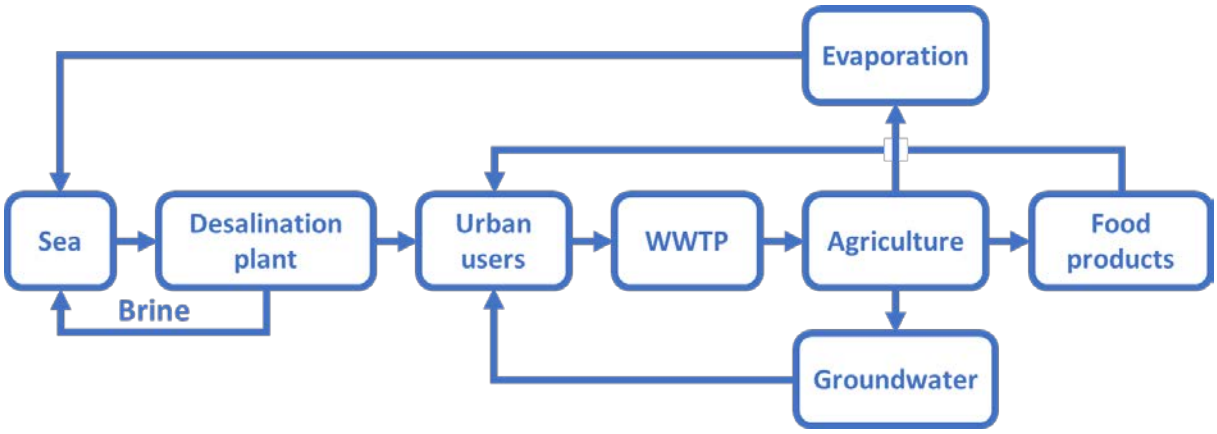


Fig.2. Holistic interpretation of desalination - agriculture pathway

On one hand, adding desalinated water to irrigation lines reduces water salinity which is quite favorable in many agricultural lands. On the other hand, it happens that excess minerals such as boron or lack of minerals such as magnesium, which passes through RO membranes or is completely removed by it respectively, in the SWRO plant product water supplied to the city, may cause the quality of the generated water not to fit for irrigation. Access Boron concentration is detrimental to crops and lack of magnesium is detrimental to both crops (growth and resulting food quality) and soil stability (SAR) (Penn et al., 2009, Lahav et al., 2010). Similarly, various contaminants in the effluents which are not affected by treatment or transport processes may reach natural water sources and penetrate the water classic cycle.

Industrial internal water cycle. Industrial water demand maybe lower than urban and agriculture water demands, e.g. Israel (Israel Water Authority, 2012), yet it's potential contribution of pollutants, particularly hazardous substances, is high. This causes stringent regulations and fierce enforcement on industrial wastewater discharge to city sewer or nature. Adding to this the sensitivity of industry to resource costs and discharge fees increases motivation to reuse water in industry. Example:

Industry can actually reach Zero Liquid Discharge (ZLD) by implementing reuse cycles in its holistic water cycle. A water cycle that can be found in food manufacturing factories (figure 3) is fed by a potable water source, which feeds boilers and cooling towers that altogether produce steam, hot water, room temperature water and cold water for the manufacturing lines, as well as for tools cleaning - which could be a major water user in food manufacturing. Alongside manufacturing, we can find water users such as laundry, shower and hand washing basins that can be designated as grey water generators, and toilets, which have to be addressed specifically, particularly in a food production facility. Water enters the factory's cycle as potable water and exits the factory's cycle (1) in the products; (2) through evaporation in cooling towers; and (3) in landscape irrigation. The result is that striving to reach ZLD is a must, and reaching it in some cases is reality.

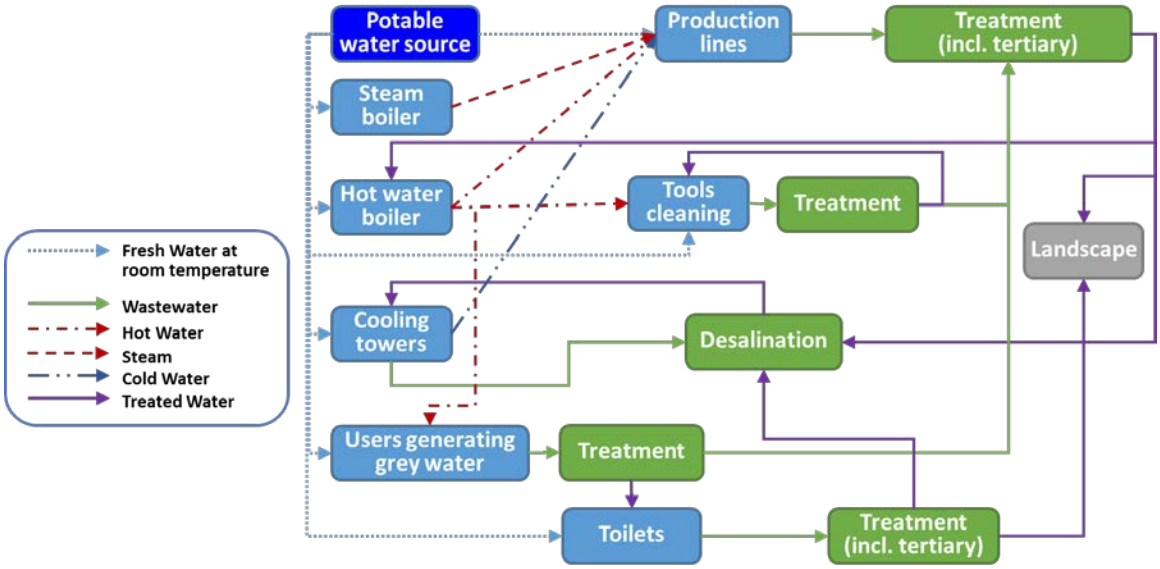


Fig. 3. Implementing reuse cycles in food industry holistic water cycle

Innovative solutions. Holistic managerial approach includes identifying gaps and directing research efforts to address them, resulting in development of innovative technologies such as remineralization of desalinated water by minerals recovery from seawater and brine (Penn et al, 2009), electrocoagulation-flocculation for particle separation and membrane pretreatment (Adin A, 2018), and biofilm formation prevention applying silver NPs (Dror-Ehre et al., 2012).

Conclusions

Holistic interpretation of the water cycle is necessary to define the water reuse integration, challenges and solutions in the multiple-resources systems of this

century. Planning should be assisted by managerial decisions supported by research and development of sustainable technologies. Implementing the holistic interpretation of the water cycle results in effective water use, minimizing environmental impacts.

References

Adin, A. The Water Energy Nexus: Electrocoagulation and Energy Conservation. Journal of Water Resources and Ocean Science, 7(2), 15-19 (2018).

Asano, T. (1998). Wastewater Reclamation, Recycling and Reuse: An Introduction. In: Wastewater Reclamation and Reuse. T. Asano (ed.). Technomic Publishing Co.

Dror-Ehre A., Adin, A. and Mamane H. (2012). Control of membrane biofouling by silver nanoparticles using Pseudomonas aeruginosa as a model bacterium. Desalination and Water Treatment, 48(1-3), 130-137.

Global Water Partnership (2012). Water Demand Management: The Mediterranean Experience, Technical Focus Paper.

Israel Water Authority (2012). Master Plan for the National Water Sector

Main Points of the Policy Paper.

Lahav O., Kochva M. and Tarchitzky, J. (2010). Potential drawbacks associated with agricultural irrigation with treated wastewaters from desalinated water origin and possible remedies. Water Science & Technology, 61(10) 2451-2460

Ma Z., Yin X., Ji X., Yue J., Zhang L., Qin J., Valiyaveettil S. and Adin, A. (2016). Evaluation and removal of emerging nanoparticle contaminants in water treatment: a review. Desalination and Water Treatment, 57(24), 11221-11232

Negewo, B.D. (2011). Middle-East and Northern Africa Water Outlook. World Bank Future Water Report: 98. Wageningen, The Netherlands.

Penn R., Birnhack L., Adin A. and Lahav O. (2009). New desalinated drinking water regulations are met by an innovative post-treatment process for improved public health. Water Science & Technology: Water Supply, 9(3) 225-231.

Sheikh, B., Nelson, K., Thebo, A., Haddad, B., Gardner, T., Kelly, J., Adin, A., Tsuchihashi, R., Spurlock, S. and Funamizu, N. (2018). Agricultural Use of Recycled Water: Impediments and Incentives. Water Reuse and Research Foundation Report.

Tan Y.S., Lee T.J. and Tan, K. (2009). Clean, Green and Blue. ISEAS, Singapore.

Evaluation of the sustainability of wastewater reuse in agriculture: development and application of a holistic approach

Paolo Roccaro, Università degli Studi di Catania, Catania, Italy; Giuseppe Bonanno, Università degli Studi di Catania, Catania, Italy; Federico G. A. Vagliasindi, Università degli Studi di Catania, Catania, Italy

Introduction

Water reclamation and reuse offer an effective means of conserving the limited high-quality freshwater supplies; however it is not well practiced due to social, economic and, sometimes, technical barriers. Therefore, a more integrated approach needs to be developed. In the present study, a Holistic Approach was developed in order to identify sustainable wastewater reuse solutions, whether they exist.

Methods

The developed holistic approach takes into account the evaluation of several Reuse Factors, which could play a major role in the evaluation of reuse projects. The major Reuse Factors (Political-Decisional Factors, Social-Economic Factors, Environmental Factors, Water Distribution Factors and Plant Factors) were identified and discussed.

A methodology, based on the proposed Holistic Approach, was developed for evaluating the feasibility of sustainable reuse projects and selecting the wastewater treatment scheme (Figure 1).

Alternative treatment trains and related costs (Capital, O&M and Total Unit Costs in €/m^3) were considered and the implications of the Reuse Factors on the selection of the treatment process were analyzed. The proposed methodology represents a rapid procedure for assessing the feasibility of reuse projects, through the evaluation of the Sustainable Wastewater Reuse Index (SWRI).

Results and discussion

The developed methodology was applied to the irrigation consortia and districts (about 100) present in Sicily (Italy) (Figure 2). For each irrigation district all the information concerning the Reuse Factors were collected. This information includes the demand of water, the available water and wastewater, the local water stress index, the quality of water, the type and operation of wastewater treatment plants, the type of cultures to be irrigated, the soil characteristic, the distance between the irrigation district and the wastewater treatment plant, etc. Such information resulted in

a number of Reuse Cost Factors and finally in the SWRI. The obtained values of SWRI for the different irrigation districts are useful to set a priority list of reuse projects.

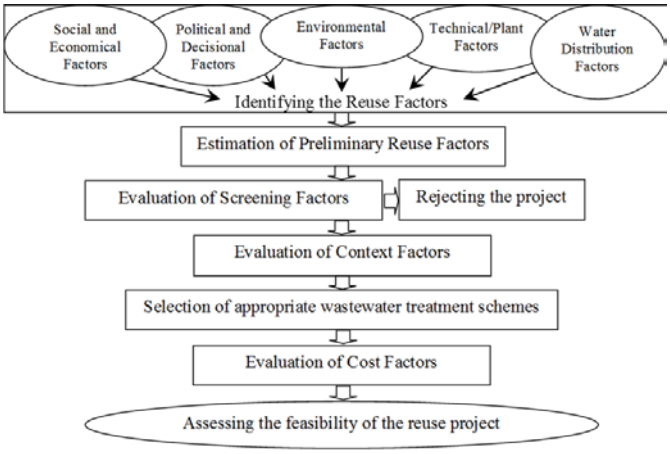


Figure 1. Layout of the methodology developed for applying the Holistic Approach

Figure 2. a) Irrigation Consortium and irrigation districts investigated (left), b) graphical representation of an irrigation district (right)

References

Roccaro P, Verlicchi P. (2018) Wastewater and reuse, Editorial, Current Opinion in Environmental Science & Health, 2, 61-63.

Sgroi M., Vagliasindi F.G.A., Roccaro P. (2018) Feasibility, sustainability and circular economy concepts in water reuse, Current Opinion in Environmental Science & Health, 2, 20-25.

Sgroi, M., Roccaro, P., Oelker, G.L., Snyder, S.A. (2015) N-nitrosodimethylamine (NDMA) formation at an indirect potable reuse facility. Water Research, 70, pp. 174-183.

WHO: Guidelines for the safe use of wastewater, excreta and greywater. Vol. II Wastewater use in agriculture. Geneva: World Health Organization; 2006. http://www.who.int/water_sanitation_health/publications/gsuweg2/en/. Accessed 15 June 2017.

Making it Happen: Overcoming Regulatory Barriers to Promote Water Reuse for Agriculture in Colombia

Natalia Jiménez, United Nations University UNU FLORES, Dresden, Germany;
Serena Caucci, United Nations University UNU FLORES, Dresden, Germany;
Hettiarachchi Hiroshan, United Nations University UNU FLORES, Dresden, Germany; caucci@unu.edu

Abstract:

Despite the attempts by the Colombian Government to stimulate water reuse for agriculture, the progress has been slow due to regulation issues. Stringent regulations introduced in 2014 are difficult to follow making the whole situation a wicked problem. Wickedness is caused by the lack of awareness of the benefits and risks of using wastewater as well as the lack of technical capacities, economic incentives and intersectoral coordination. This talk focuses on the wickedness of the issues as well as potential solutions. Some recommendations for promoting water reuse as an adaptation strategy of the agriculture sector to climate change, are also briefly presented at the end.

Keywords: Wastewater, regulatory, policy, reuse, Colombia, agriculture.

Introduction

Inhomogeneous water distribution in time and space and the ever increasing water abstraction of freshwater from the agricultural sector, makes of treated wastewater an attractive water surrogate for Colombia. The Colombian government through the Ministry of Environment and Sustainable Development (MADS) recognized the relevance of water reuse practices developing a regulatory framework (Water Resources Policy (2010), Water efficiency Law (1993)) and enforced the water reuse regulation (regulation 1207/2014) as controlling body in 2014. The regulation defines water quality criteria to be met, the technical studies, responsibilities and administrative and legal requirements that both the wastewater producers and the end-users have to comply priori water reuse practices (MADS, 2014).

Despite the strong attempts of the government to stimulate water reuse, only few cases were reported after five years from the regulation enforcement. In these few cases, water reuse have been reported only for agro industrial activities and for the

irrigation of palm oil, sugarcane or biofuel crops (Garay et al. 2017). It is an example the Meta region. Here 46 hectares of biofuel crops are being irrigated with treated wastewater originated from an oil industry located in the near (Garay et al. 2017). Only two are instead the documented cases of municipal wastewater for reuse practices: In Valle del Cauca, the wastewater collected and treated from two municipalities are used for irrigating sugarcane crops (Jaramillo, 2014).

This paper identifies and analyses mayor bottlenecks for Colombia cause of poor water reuse implementation in agriculture and propose recommendations for overcoming such barriers transforming it in drivers for success.

Material and Methods

The bottlenecks preventing water reuse in agriculture were first identified through a desk-analysis of Colombian water reuse policy, regulatory documents and official reports, as well as scientific documentation and workshops-related minutes obtained from stakeholders. A workshop conducted subsequently in November 2018 in Bogota Colombia, with all relevant stakeholders, was used to verify and fine tune the findings of the analysis

Results and Discussion

Lack of awareness of water reuse benefits

Water reuse in agriculture can address social, economic, and environmental challenges. It contributes, among others, issues of adaptation to climate change, nutrition, and food security, poverty reduction, prevention of water-related diseases, human and environmental health protection, and agriculture livelihood opportunities (WHO, 2006). The low level of water reuse implementation in Colombian agriculture is mainly due to the low awareness on its benefits in the low and long run. In Colombia, misperception of a high water offer (Garay et al. 2017) makes stakeholders less keen on alternative water sources. Climate change projections have instead shown how climatic variability will increase the probability of extreme events like water scarcity. The lack of awareness on water reuse in agriculture reflects also on government prioritization of reuse practices. It is a consequence that also economic resources allocated to this activities are limited (Garay et al. 2017). Lack of awareness of benefits generated by the water reuse in agriculture is also reflected in the water reuse regulation enforced by the MADS. This regulation does

not contemplate the possibility of reusing wastewater nutrients in agriculture (MADS 2014) Thus discouraging one of the most important benefits for using wastewater in agriculture.

Lack of awareness of water reuse risks

In Colombia poor is the awareness of health and environmental risks represented by the non-safe water reuse in agriculture In Colombia, 1.230.193 hectares of the country are irrigated with wastewater (Silva, 2008) (Lopera and Campos 2011). 73% of this area is irrigated with untreated wastewater, usually diluted with surface water (Silva 2008) (Lopera and Campos 2011). Bogotá Sabana it is an example. 3.500 hectares of vegetable, flower and pasture crops are irrigated with the water of the Bogotá River (Lopera and Campos 2011) an important receptor of municipal wastewater discharges as well as discharge of industrial transformation processes. Water reuse regulation has been designed for the prevention of environmental pollution and therefore appears weak in the protection of human health from water reuse. Guidelines and requirements for implementation are not present and thus health and agriculture impact of the water reuse cannot be tracked.

Lack of technical capacities

Colombia clearly lacks technical expertise for wastewater treatment personnel and thus the wastewater distributers cannot ensure a treated wastewater of quality to the end-users. Lack of skilled personal is not only confined to the wastewater producers. Technical competences are also missing on the end-users side like farmers or governmental local authorities. Study and monitoring of water reuse activities should be fostered and technical skills for harnessing wastewater fostered among end-users farmers. Infrastructure is also another pillar that Colombia should better implement for increasing the feasibility of water reuse projects. Infrastructure for treating, transporting, distributing and using wastewater are often lacking.

Lack of economic incentives

The regulatory framework in Colombia does not provide a scheme of incentives that promote economically water reuse in agriculture (Garay et al. 2017). Moreover, since the water reuse regulation is discouraging from the use of wastewater as provider of nutrients, it is making the reuse in agriculture not economically attractive for the wastewater producers and the end-users. In addition, no clear legislation is present

in Colombia that establishes how the treated wastewater should be marketed, priced (Garay et al. 2018). Additionally, due to the stringent regulation of reuse, wastewater discharge into freshwater bodies is more cost-effective than complying with the wastewater treatment to be complied for irrigation purposes. (Garay et al. 2018). At the other ends, end users rather prefer natural water sources than incurring in additional costs that the use of wastewater implies.

Sectorial thinking

The main approach of the water reuse regulation is focused on environmental issues and does not address needs for other sectors like agriculture or health. For this reason, when the water reuse regulation was formulated and implemented, the government had to face a very low degree of participation of health and agricultural entities. All in all the weak convergence at policy, regulatory and interinstitutional level reduce the positive efforts from water reuse regulation to promote the use of wastewater in agriculture. The regulation focuses only on environmental protection measures constraining the use of wastewater for agricultural purposes in a marginal role.

Recommendations for a Lasting Solution

Our main recommendation is to use the multi-barrier approach of the WHO Guidelines of 2006. This in order to make the regulation and the control procedures more practical, and at the same time decreasing health and environmental risks in each step of the process. Practicality of the water reuse in agriculture can also be potentially enhanced by allowing the controlled use of nutrients present in wastewater for soil conditioning. This will favor the decrease in the use of artificial fertilizers and therefore, serve as an economic incentive for farmers.

Moreover, we recommend to incorporate capacity building processes for raising awareness and training wastewater producers, end-users and authorities in their roles. This could be supported also with the development of a guideline of good practices that complements the regulation, with legal, administrative, and technical clarifications. It is important to include stakeholders from the agriculture, health, environment and water and sanitation sectors in the capacity building processes.

Finally we suggest that the country can benefit from developing wastewater reuse demonstrative projects with a co-participatory approach. This could be the first step

of interinstitutional work and coordination with the different sectors (health, water sanitation, agriculture, and environment). Pilots projects could be the possibility to test technical, socio-economical and administrative arrangements for improving the regulation.

Conclusions

The work presented in this paper focuses on the bottlenecks that are blocking water reuse in agriculture in Colombia. These bottlenecks raise five major concerns: lack of awareness of benefits, lack of awareness of risks, lack of technical capacities and sectorial thinking. To improve the regulatory frame of water reuse in agriculture it is very important the development of a cross-sectorial work. This implies the active participation of other ministries else than MADS. Thus, a concerted action among Ministries and associated entities of the Health, Environment, Housing and Agriculture sector is essential. At the same time the involvement of other stakeholders from the private sector, the academy and farmers associations would be fundamental to define co-participatory approach that would envisage new solution option for its implementation. This process would guarantee that the adopted measures will be consensual, accepted and implemented.

References

Álvarez, Gloria Lucía. 2017. “Interpretación legal de la norma de reuso R. 1207/14 MADS.” presented at the International Seminar on Reuse and Water Desalination, organized by the Association Latin American Water Desalination and Reuse, Medellín. https://docplayer.es/70564307-Interpretacion-legal-de-la-norma-de-reuso-r-1207-14-mads-gloria-lucia-alvarez-pinzon.html.

Garay, César, Andrea Carolina Guzmán, and Juan Camilo Múnera. 2017. “Informe de Avance - Misión Crecimiento Verde.” Medellín: Developed by: Centro de Ciencia y Tecnología de Antioquia – CTA Línea de Agua y Medio Ambiente, Presented to: Departamento Nacional de Planeación - DNP. https://www.dnp.gov.co/Crecimiento-Verde/Documents/ejes-tematicos/Agua/20180422_DIAGNOSTICO_Vfinal.pdf.

———. 2018. “Informe de priorización de los elementos críticos para mejorar la productividad del agua y la eficiencia en el tratamiento de aguas residuales y el reúso del agua - Misión Crecimiento Verde.” Medellín: Developed by: Centro de Ciencia y Tecnología de Antioquia – CTA Línea de Agua y Medio Ambiente, Presented to: Departamento Nacional de Planeación - DNP. https://www.dnp.gov.co/Crecimiento-Verde/Documents/ejes-tematicos/Agua/INFORME_PRIORIZACION_12_02_18.pdf.

Jaramillo, María Fernanda. 2014. “Potencial de reuso de agua residual doméstica como estrategia para el control de la contaminación en el valle geográfico del río cauca.” Santiago de Cali, Colombia: Universidad del Valle.

http://bibliotecadigital.univalle.edu.co/bitstream/10893/7632/1/7720-0446201.pdf.

Lopera, María Juliana, and Sara María Campos. 2011. “Proyecto: Desarrollo de capacidades en el uso seguro de aguas residuales para agricultura.” Bogotá: Ministerio de Agricultura y Desarrollo Rural. http://www.ais.unwater.org/ais/pluginfile.php/356/mod_page/content/119/Colombia_Informe%20Nacional.pdf.

MADS, Ministry of Environment and Sustainable Development. 2014. “Resolución 1207 de 2014. Por la cual se adoptan disposiciones relacionadas con el uso de aguas residuales tratadas.” https://www.icbf.gov.co/cargues/avance/docs/resolucion_minambienteds_1207_2014.htm.

Paredes, Cuervo, María del Pilar Pulgarín, and Álvaro Ignacio Ramirez. 2016. “Informe Final - Contrato interadministrativo N° 352 de 2016. Capítulo 1. Resolución 1207 de 2014 sobre reúso de aguas residuales tratadas.” Developed by: Universidad Tecnológica de Pereira-Grupo GIAS, Presented to: Ministerio de Ambiente y Desarrollo Sostenible.

Silva, Jorge Antonio. 2008. “Reuso del efluente de la planta de tratamiento de aguas residuales de Cañaveralejo PTAR-C en el riego de caña de azúcar.” Master Thesis, Santiago de Cali, Colombia: Universidad del Valle.

WHO, World Health Organization. 2006. *Guidelines for the Safe Use of Wastewater, Excreta and Greywater. Volume 1 Policy and Regulatory Aspects*. Vol. Volume 1.

Water reuse in hydroponic systems: results from four European feasibility studies

Marius Mohr, Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB, Stuttgart, Germany; Tobias Günkel-Lange, aquadrat Ingenieure, Griesheim, Germany; Michaela Fischer, ISOE-Institute for Social-ecological Research, Frankfurt a. M., Germany; Jörn Germer, University of Hohenheim, Stuttgart, Germany; Martina Winker, ISOE-Institute for Social-ecological Research, Frankfurt a. M., Germany, Grit Bürgow, aquatectura, Berlin, Germany; marius.mohr@igb.fraunhofer.de

Abstract: Four feasibility sites in Germany, Belgium and Portugal are evaluated in the research project HypoWave regarding the potential utilization of specifically treated municipal wastewater in hydroponic systems. An interdisciplinary team together with local stakeholders identified driving and limiting factors. Overall, a high interest in the concept and its implementation indicated the potential of this integrated solution.

Keywords: feasibility study, water reuse, recycling of nutrients, hydroponic system, plant production

Introduction

Already today, competition for water resources plays an important role in many regions. Climate change, urbanization and the pollution of water resources may aggravate conflicts over the next few decades. New concepts and processes for water reuse are therefore needed. In the research project "HypoWave - Use of hydroponic systems for resource-efficient agricultural water reuse", a water-resource-efficient concept for agriculture is being investigated in which treated wastewater is used for hydroponic plant production (Bliedung et al., 2019). Hydroponics is plant production without soil, the seedlings grow in closed plant containers filled with liquid, thus preventing irrigation water from seeping into the soil and minimizing evaporation losses (Lee and Lee, 2015). This makes hydroponic plant production a water-saving cultivation method that at the same time protects soil and groundwater.

How the concept can be implemented has been investigated in feasibility studies at four different sites in Germany, Belgium and Portugal (Figure 1). These studies were developed by interdisciplinary teams together with local actors. The aim is to identify beneficial and inhibitory factors for the use of treated wastewater in the hydroponic system and to create the basis for implementation at the investigated sites.

Results and Discussion

At each site, the interdisciplinary team encountered different conditions, thus the results show a high variety.

In Gifhorn county, there are still a number of sewage ponds in the rural areas, which shall be connected to larger sewage treatment plants in the coming years to protect the surface waters from nutrient loads. For one pond near the village of Weißenberge with 500 inhabitants, the utilization of the effluent of the pond in a hydroponic system for the production of lettuce has been analyzed. As the nitrogen in the pond water consists mainly of ammonium, a biofilter is proposed for nitrification. Filled with activated carbon, the biofilter can also reduce the concentration of micro-pollutants in the water. A UV-lamp acts as an additional barrier against microbial risks. The plants in the greenhouse will take up the nutrients nitrogen and phosphorous- a sensor system guarantees that the irrigation water is changed at the right time to reach effluent concentrations in the range of a larger wastewater treatment plant, thus a connection of the pond to the wastewater treatment plant is not necessary any more. A farmer willing to operate the hydroponic system could already be identified, the water utility also responsible for sewage treatment would operate the treatment processes. A contract between the farmer and the utility could define the respective responsibilities. Based on a cost estimate done during the study, the concept could be operated economically, as long as the produced lettuce can be marketed in the region.

In Eastern Belgium wastewater infrastructure is not fully established. In Raeren three neighbourhoods with 1650 inhabitants are connected to a sewer, while the connection to the wastewater treatment plant is missing. In the studied system, the wastewater is treated in a sequencing batch reactor (SBR) and flowers (chrysanthemum) are produced in the greenhouse. Due to a limitation in space, nutrient elimination is required. In the SBR wastewater can be treated in accordance to discharge standards (including denitrification and phosphate precipitation); if irrigation water for plant production is required, treatment stops after nitrification. UV treatment for disinfection and further nutrient management for plant production follows. Nutrient solution which, due to salinity, cannot be used in a hydroponic greenhouse any more can still be used in soil based systems, as an option for this a

short rotation plantation was suggested. A social farm close to Raeren, which operates a greenhouse, was involved in the feasibility study. The operator of the wastewater treatment plant would be the wastewater utility. A cooperation between both could be based on a public private partnership contract, including also the characteristics of the irrigation water. For the wastewater utility the support of the concept is mainly depending on cost-efficiency considering investment and operation as compared to other options for wastewater treatment in Raeren. For the economic assessment of the production of cut flowers, distribution was assumed mainly via flower auctions, 10% via direct marketing. Amortization of the investments for plant production (1.4 Mio. €) is possible in 10 years.

The situation in the Hessian Ried is characterized by the great importance of the groundwater for the drinking water supply of the Rhine-Main metropolitan region. Due to the high population density, the small rivers in the region consist mainly of treated wastewater. In addition, agricultural land is increasingly in competition with the growing urban areas of the agglomeration. The wastewater infrastructure in Hessian Ried is fully developed and subject to very high legal requirements for nutrient elimination (in part total phosphorus < 0.2 mg/l). In the context with the currently discussed expansion of existing wastewater treatment plants for the elimination of trace substances, there may be potential for water reuse in the Hessian Ried. The existing high purification level of the treatment plants would be further improved, for example by the combination of ozone and activated carbon. High quality water for agricultural reuse can be produced in a disinfection stage and possibly with an additional membrane-filtration for post-treatment. This would support a sustainable and resource-efficient groundwater management in Hessian Ried.

The feasibility study in Évora is representative for most drought prone Mediterranean areas, where water availability is very low especially during the summer months and soil salinization is an inherent threat. Temporal water deficiency drives stakeholders to tap into any available water resources including wastewater after different treatment steps. In the Mediterranean, wastewater is usually treated by the activated sludge process. The biological treatment removes nitrogen in an energy intensive process. Nitrogen needs to be supplied again as a fertilizer when the water is subsequently used in a plant production system. Therefore, the Évora study

compares two scenarios: a) aerobic wastewater treatment and utilization of the treated water in agriculture and b) anaerobic wastewater treatment with subsequent nitrification coupled with a hydroponic system. During summer when demand for water and nutrients is high, treated water will be employed directly for the same crops as under a). Concurrently, the hydroponic system will be fed with ground water. The hydroponic system will deplete nitrate from the water, which can then be used for livestock or groundwater recharge. In winter, the treated water will be depleted from nutrients by the hydroponic system and consequently used for groundwater recharge or disposed in natural bodies of water.

Conclusion

Currently, hydroponic systems run with treated wastewater offer the greatest advantage in areas of severe water scarcity. The two regions selected in Germany already use a relevant part of their water resources for agricultural irrigation. While Évora (Portugal) is threatened by desertification, Raeren (Belgium) usually does not experience seasonal water shortage. Where wastewater treatment infrastructure is lacking, water reuse within a hydroponic system can be beneficial as well. In Raeren and around Évora, a number of villages and settlements are not connected to any wastewater treatment plant yet. Here, combined wastewater treatment and crop production systems might offer an economical solution for the greenhouse operator and an interesting solution for the wastewater utility as long as the new system works cost-efficient. In the area of Gifhorn, many treatment ponds have to be connected to a centralized treatment system as the nutrient concentrations in the discharge are considered as too high. The utilization of the nutrients in a hydroponic system is an alternative solution. In contrast, the wastewater infrastructure in the Hessian Ried is highly developed, but upgrade of wastewater treatment plants with a fourth treatment stage might offer an additional window of opportunity for the connection with a hydroponic system, as the quality of the effluent will be higher. Very important driving factors are the local actors, someone has to take up the innovation and implement it as a first mover. Here, especially the operator of the hydroponic system is in the focus. In some cases, first movers could be identified and an implementation is feasible.

A risk seen by the involved stakeholders is the potential lack of acceptance for products irrigated with treated wastewater. One measure to deal with this limitation is a proper quality and risk management (Schramm et al., 2019), combined with good marketing, based on trust in regional products. Therefore, careful wording might be helpful, e.g. by referring to “treated water” or “water and nutrient resources” instead of “wastewater”. Another measure is the production of plants not meant for direct consumption, like flowers and vegetables to be further processed. The feasibility study in Raeren took up the second measure and focused on horticultural flowers, while the others evaluated the chances to grow food products for direct consumption as salad and tomatoes, where tomatoes could be further processed as well. Lacking off-the-shelf solutions render cost estimates a challenge. This typical difficulty of innovative solutions can only be overcome by courageous first movers or by publicly funded pilot measures.

Overall it can be stated that this innovation can be a promising alternative in the available set of solutions and a high interest in implementing it in the studied sites indicated a potential for this integrated solution.

Acknowledgement

The authors would like to thank the German Federal Ministry of Education and Research for funding the research project “HypoWave – New Pathways Towards Wastewater Re-Use in Agriculture” (grant number: 02WAV1402).

References

Bliedung A., Dockhorn T., Ebert B., Jörn G., Mohr M., Schramm E., Winker, M. (2019). HypoWave - Ressourceneffiziente Nutzung von gereinigtem Abwasser in hydroponischen Systemen (HypoWave - Resource efficient water reuse in hydroponic systems). Zentralblatt für Geologie und Paläontologie Teil I, 95-104.

Lee S., Lee J. (2015). Beneficial bacteria and fungi in hydroponic systems: Types and characteristics of hydroponic food production methods. Scientia Horticulturae 195, 206-215.

Schramm E., Beythien U., Dockhorn T., Ebert B., Fischer M., Mohr M., Wieland A., Winker M., Zimmermann M. (2019). Wasserwiederverwendung zur landwirtschaft - lichen Nutzung in hydroponischen Systemen: Anforderungen an die Qualitätssicherung (Water reuse for agricultural hydroponic systems: Quality assurance requirements). Zentralblatt für Geologie und Paläontologie Teil I, 73–82.

Design of a water reuse network in an industrial site in Kenya

Elham Ramin[1]; Carina Schneider[2]; Vasiliki Takou[2]; Anders Damgaard[2]: Alessandro Setti[3]; Claus Hélix-Nielsen[2]; Xavier Flores Alsina[1]; Pedram Ramin[1]; Krist V. Gernaey[1]; Maj M. Andersen[3]

[1]Technical University of Denmark, Department of Chemical and Biochemical Engineering

[2]Technical University of Denmark, Department of Environmental Engineering

[3]Technical University of Denmark, Department of Management Engineering

Sustainable growth of industries in fast developing but water-scarce countries like Kenya can only be achieved by optimizing water usage and reducing wastewater discharge. Besides internal recycling, industries can greatly reduce their freshwater intake by exchanging wastewater streams with neighboring industries and creating symbiosis relations. Previous studies have attempted to design an optimal network of water exchange streams in industrial parks by applying a global multi-objective optimization approach (e.g., [1]). However, only a few have considered the complexity of used water streams in terms of flow rate variation [2] and number of significant pollutants [3].

In this study, we present the outcome of the optimization analysis, covering the above-mentioned knowledge gaps, for water exchange between 10 companies in an industrial park in Ruaraka, Nairobi. A combination of clarification, physico-chemical, membrane-based (Inside® by Aquaporin A/S, Denmark) and disinfection treatments was considered in the optimization exercise as decentralized fit-for-purpose treatment units. Information on volumes and quality of water usage and wastewater discharge was gathered through on-site visits and interviews. The analysis forms part of a research project, Gecko (Green and Circular Innovation for Kenyan Companies), investigating circular solutions within water, materials and energy by specifically focusing on wastewater reuse and targeting industrial symbiosis potentials.

The formulation of the water reuse network is shown in the superstructure (an example for three processes) in Figure 1 using a series of multiple treatment units prior to reuse. The multi-objective evolutionary algorithm NSGA II [4] was applied, considering (i) an economic objective (i.e. capital and operational cost of treatment, piping cost and freshwater consumption volume); (ii) an environmental objective (i.e. CO_2 emission, wastewater discharge pollution load); (iii) social constraints, considered as a matrix of collaboration interests among industries (as gathered

during on-site surveys). Life Cycle Assessment (LCA) was performed on the applied water treatment processes, as well as post-optimization evaluation of multiple optimum solutions.

Preliminary optimization results show the potential of 10% economic and 20% environmental improvements in the industrial park through a water exchange network among the considered companies. More detailed analysis on the optimization objectives including fresh water saving and wastewater discharge, as well as LCA of optimum solutions will be presented later. The water network will be expanded to up to 32 companies in the same industrial park. The presented methodology can also be used to perform uncertainty and flexibility assessments of water reuse networks.

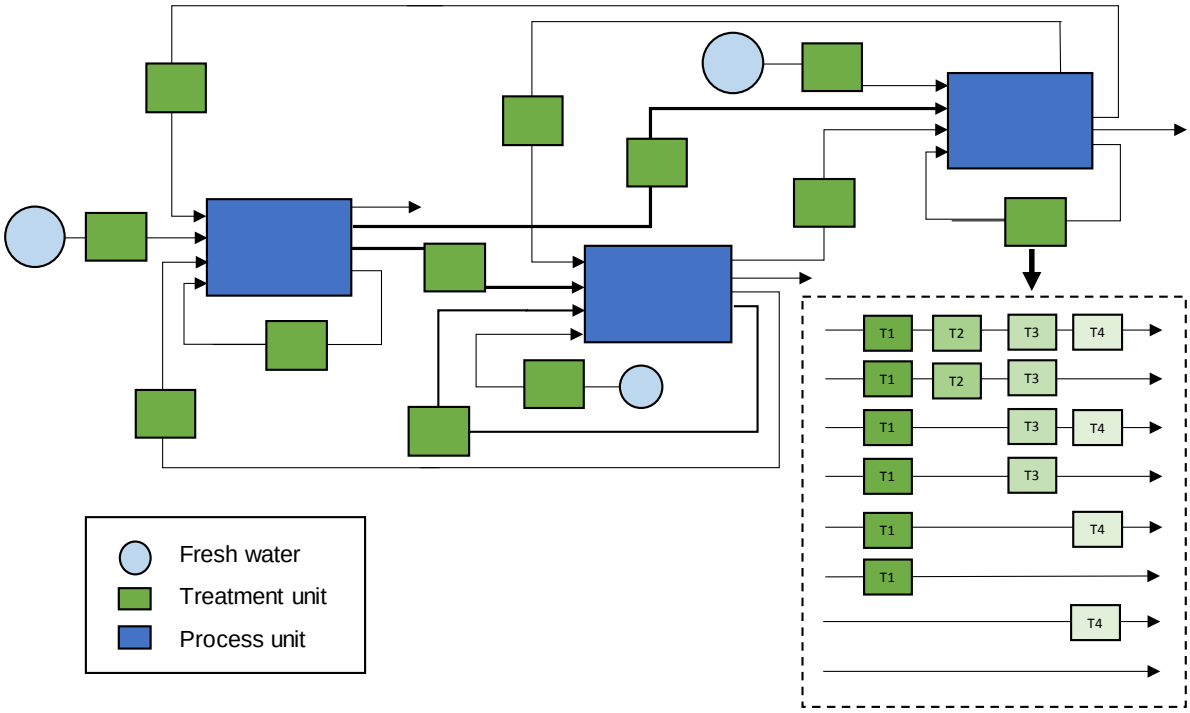


Figure 1. *Superstructure of water reuse network among multiple processes (in this case, three) including multiple treatment options. T1-4 denote different wastewater treatment steps in different configurations.*

Acknowledgments

This study is carried out within the Gecko (Green and Circular Innovation for Kenyan Companies) pilot research project funded by the Danish International Development Agency (DANIDA) for the period 2018-2020.

References

[1] Boix, M., et al. (2012), J. Clean. Prod. 22:85-97.

[2] Montastruc, L., et al. (2013). J. Clean. Prod. 43:1-11.

[3] Rubio-Castro, E., et al. (2011). Comput. Chem. Eng. 35:1558-1574.

[4] Deb, K., et al. (2002). IEEE Trans. Evolut. Comput. 6:182-197.

Evaluating Woven Textile Filtration and Ultraviolet Light Emitting Diodes (UV-LEDs) for Water Reuse in Developing Economies

Sara Beck, Eawag, Swiss Federal Institute of Aquatic Science and Technology, Dubendorf, Switzerland; Hong Nguyen, Asian Institute of Technology, Pathumthani, Thailand; Efemena Ovie, University of Stuttgart, Stuttgart, Germany; Poonyanooch Suwan, Asian Institute of Technology, Pathumthani, Thailand; Thusitha Rathnayeke, Asian Institute of Technology, Pathumthani, Thailand; Thammarat Koottatepk Asian Institute of Technology, Pathumthani, Thailand.

Keywords

Wastewater Reuse for Agriculture, Woven Fiber Textile, Microfiltration, UV-C Light Emitting Diodes, Gravity Driven Membranes

Abstract

The global population is expected to rise to approximately 8.3 billion people by 2030, reflecting an unprecedented 25% growth in just over two decades. With this rise in population and the trend toward urbanization comes an increased demand on already stressed water resources. In many regions of the world, the water demand already exceeds sustainable supplies. By 2025, an estimated 1.7 billion people will not have access to enough water to satisfy their basic human needs. Since a majority of population growth occurs in areas that lack centralized water supply and sanitation systems, this research focuses on a decentralized water treatment process. The research is needs-based and problem-driven, targeted at developing and evaluating water reuse technology for addressing water scarcity and contamination in low- to middle-income countries.

A progression of three research projects, involving students from Vietnam, Thailand, Nigeria, and Sri Lanka, the research investigated the application of a polyester, woven-fiber microfilter (WFMF) as pretreatment for ultraviolet (UV) disinfection with UV light emitting diodes (LEDs) with the ultimate goal of wastewater reuse for agriculture in low- to middle-income countries.

The first stage of the research, which was conducted at the Asian Institute of Technology (AIT) near Bangkok, Thailand evaluated options for pretreating domestic wastewater to an appropriate quality for disinfection by UV-C LED irradiation. This

initial study evaluated UV disinfection of wastewater following pretreatment by woven-fiber microfiltration. Domestic wastewater from a primary sedimentation tank was pumped through a submerged woven-fiber microfilter to decrease the suspended solids content and lower turbidity to appropriate levels for UV disinfection. The two permeates were pumped through flow-through UV reactors manufactured in-house, encased in stainless steel, including a UV-C LED reactor emitting at 280 nm as well as an LP UV reactor for comparison. For permeate with a minimum UV transmittance of 40%, the UV-C LED flow-through reactor operating at 10 mL/min inactivated MS2 coliphage, a surrogate for enteric viruses, by 3.5-log, compared to over 7-log reduction by the LP UV reactor at 1.5 L/min.

A follow-up study evaluated less expensive pre-treatment options as well as the operation and maintenance of a commercially-available UV-C LED reactor. Domestic wastewater continuously flowed through a tube settler and sand filter before flowing through a UV-C LED reactor emitting at 280 nm. For pre-treated wastewater at a UV transmittance of 70%, a flow rate of 30 mL/min was sufficient for 3.7-log reduction of MS2. Fouling of the reactor by organic material and UV-induced calcium, magnesium, phosphorus, and iron complexes decreased the disinfection efficacy by approximately 1-log reduction of MS2 after 8 days. The fouling layers were reversible and removed with four hours of citric acid exposure.

Whereas the previous two studies used a peristaltic pump to pump the water through the filter, a subsequent study at the Swiss Federal Institute of Aquatic Science and Technology (Eawag) evaluated the woven-fiber microfilter as a gravity-driven membrane. Researchers evaluated the woven fiber material for its efficacy at removing suspended solids, lowering turbidity, and increasing UV-transmittance. Biofilm formation on the membrane surface was characterized using Optical Coherence Tomagraphy, Scanning Electron Microscopy and Confocal Laser Scanning Microscopy. As before, the permeate was pumped through a UV-LED reactor emitting at 280 nm to inactivate the remaining bacterial and viral pathogens in order to meet WHO standards of water quality for irrigation and to protect consumer and farmer health.

The combination of an inexpensive woven-fiber material in series with UV-C LED technology has potential to improve quality of wastewater effluent for agricultural reuse in developing economies.

Comparison of Characteristics of Treated Effluents from Full-Scale Wetland Systems in Thailand, Japan, and USA

Pongsak (Lek) Noophan[1], Supaporn Phanwilai[1], Kevin D. Daniels[2], Tamao Kasahara[3] and Shane A. Snyder[2,4]*

[1]Department of Environmental Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand, [2]Department of Chemical & Environmental Engineering, University of Arizona, Tucson, AZ, USA, [3]Laboratory of Ecohydrology, Division of Forest Sciences, Department of Agro-environmental Sciences, Kyushu University, Fukuoka, Japan and [4]Nanyang Environment and Water Research Institute, Nanyang Technological University, Singapore

[*]Corresponding author (E-mail: pongsak.n@ku.ac.th)

Abstract

In this study, three full-scale of wetlands sites - the Laem Phak Bia Environmental Study and Development Project's wetlands, Phetchaburi Province, Thailand; Fukuoka, Japan; and Tucson, Arizona, United States of America - were selected for comparison of the characteristics of their treated effluents. Quantitative polymerase chain reaction (qPCR) was used to quantify anammox bacteria in the sediments and plant roots at each wetland site. High amounts of anammox bacteria (more than10^5 copy/g-sludge) were found in the sediment and plant roots of the wetland at Phetchaburi Province, Thailand and Tucson, Arizona USA. However, a large quantity of anammox bacteria ($4.17x10^3$±$1.24x10^3$ copy/g-wet root) was found only in the plant roots but not in the sediment at Fukuoka, Japan. Polymerase chain reaction denaturing gradient gel electrophoresis (PCR-DGGE) was used to identify microbial communities of ammonia-oxidizing bacteria (AOB), nitrite-oxidizing bacteria (NOB), denitrifying bacteria (DEB), and other bacteria from sediment and biofilm on plant roots of the wetland systems from Phetchaburi Province, Thailand and Tucson Arizona USA, but not for the wetland system at Fukuoka, Japan. Only the wetland site at Tucson, Arizona was investigated for concentrations of the following contaminants of emerging concern (CECs): perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), perfluorohexanoic acid (PFHxA) degradation product of perfluorohexane sulfonic acid (PFHxS), and perfluorobutanesulfonic acid (PFBS). The treated effluent from this wetland is used as indirect potable reuse. These chemicals were found in the effluent from the Tucson wetland. However, all concentrations of these CECs were still lower than the USA standard. These results suggest that wetlands at Phetchaburi Province, Thailand and Tucson, Arizona USA could effectively treat wastewaters with low BOD but high nitrogen. The nitrogen removal efficiencies from these two plants were very high.

Keywords: Treated effluent; wetland; Thailand; Japan; USA

Introduction

In developed areas with rapid growth there is often a water shortage. Water reclamation and reuse of treated effluents from wastewater treatment plants (WWTP) may be reasonable and possible. However, such use of treated WWTP effluent is not easy because of treatment, health issues, and safety concerns. For these reasons, indirect potable reuse in areas of water shortage must address regulatory compliance and public perceptions.

A major factor in public acceptance of reclamation and reuse of WWTP treated effluent is the remaining nitrogen concentration. The conventional nitrification and denitrification process is used worldwide for nitrogen removal from wastewater. However, in some cases wastewater consists of high nitrogen but low carbon. The conventional process might not be the best option for nitrogen removal because low efficiencies could occur and high costs might be required. For this reason, an alternative process (anaerobic ammonium oxidation, anammox) of biological removal is recommended. However, the anammox process is not easily applied to full-scale WWTPs because anammox cultures need a long startup time and the cultures are significantly slow growing. A major factor with the anammox process is maintaining the nitrification intermediate, NO_2^-, at a consistent level. Temperature can significantly affect anammox activity (Tao et al. 2012). Moreover, the anammox process might require highly skilled operators. For these reasons, application of the anammox process in practice faces many significant obstacles. Currently, the anammox treatment system is not popular and is quite difficult to apply in full-scale WWTPs.

Kadlec and Knight, 1996 and Tao et al., 2012 reported that the anammox process might be found in the wetlands because these are barrier areas between land and waters that could be used to remove nitrogen from effluents with insufficient carbon source. For this reason, many researchers have strongly recommended that wetland treatment systems might be suitable for the partial nitritation and anammox process. However, optimal

conditions are essential for the anammox process. For example, anammox bacteria require NH_4^+ as an electron donor and NO_2^- as an electron acceptor in ratio of 1 NH_4^+: 1.32 NO_2, pH between 7.6 and 8.4, high alkalinity, temperature above 20°C, very low dissolved oxygen and COD. Anammox bacteria are strictly autotrophic, using carbon dioxide as a carbon source. In practice for full-scale WWTPs, wetland treatment systems could be considered for application of the anammox process because constructed wetlands require a low cost and would be appropriate for both developing and developed countries (Thailand, Japan, and United States of America).

Health issues and safety concerns are other major considerations in using the treated effluent from WWTP for water reclamation and reuse. The technologies need to be reliable and must be proven to remove contaminants of emerging concern (CECs) such as perfluorinated compounds (PFCs), perfluorinated alkyl substances (PFASs), pharmaceuticals, cyanotoxins, personal care products, nanoparticles, et. Such CECs are suspected of being human carcinogens.

The goals of this research were to compare the characteristics of influents and effluents from three wetland systems: Phetchaburi Province, Thailand; Fukuoka, Japan; and Sweetwater wetland at Tucson, Arizona, USA (Tucson wetland). Only influent and effluent from Tucson's wetland was analyzed for CECs. Quantitative polymerase chain reaction (qPCR) technique was used to determine the amount of anammox bacteria in sediments and plant roots from each wetland site. Later, the PCR technique was used to identify microbial communities of ammonia-oxidizing bacteria (AOB), nitrite-oxidizing bacteria (NOB), denitrifying bacteria (DEB), and other bacteria from Phetchaburi Province, Thailand and Tucson, AZ, USA. The results from this work were used to improve effluent quantities of water through reclamation and reuse.

Materials and Methods

Full-scale constructed wetlands

Three full-scale constructed wetlands were studied. The first site is located in Phetchaburi Province west of Bangkok. This constructed wetland is called the Laem Phak Bia (Thai wetland) and is used to treat domestic wastewater from the city of Phetchaburi. The second site, located in Fukuoka in southern Japan (Fukuoka wetland) is used to treat runoff water. The third site, Sweetwater wetland at Tucson, Arizona, USA (Tucson wetland) is used to treat the effluent from a WWTP. These three sites are shown in Fig 1.

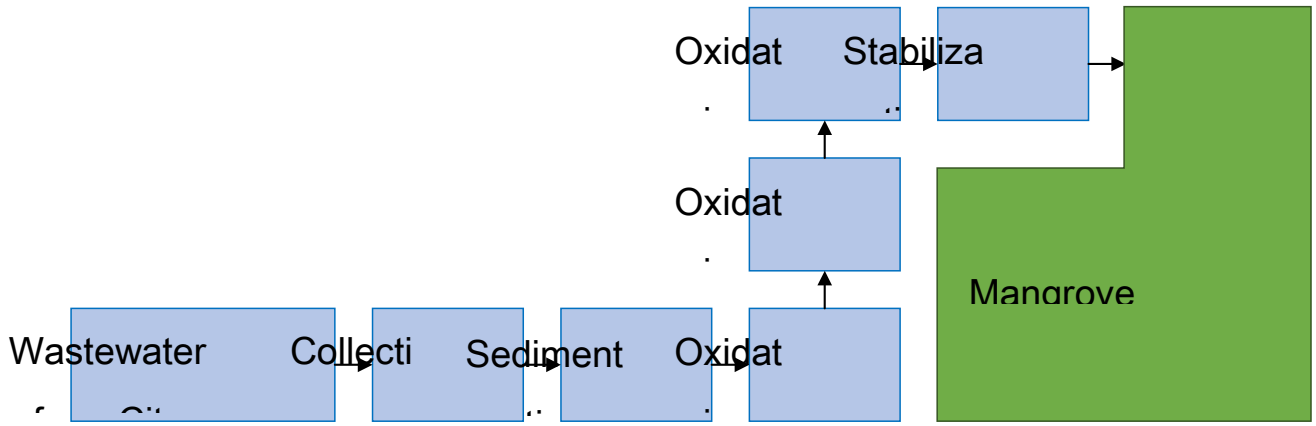
Analytical methods

Water quality parameters were measured according to *Standard Methods for the Examination of Water and Wastewater* (APHA et al. 2005). Contaminants of emerging concern (CECs) in this work were focused on perfluorooctanoic acid (PFOA), perfluorooctane sulfonate (PFOS), perfluorohexanoic acid (PFHxA) degradation product of perfluorohexane sulfonic acid (PFHxS), and perfluorobutanesulfonic acid (PFBS). These CECs were analyzed by using Dionex HPLC system (Dionex UltiMate 3000 system) with a quaternary pump, a vacuum degasser, an autosampler, and a column oven kept at 35°C. Sample aliquots of 10 µL were injected to the C18 column which were gradient-eluted with different solvents. For analysis in the positive ion mode, eluent A was acetonitrile and eluent B was 0.1% formic acid (water solution) at a flow rate of 0.2 mL/min. The concentration of the mobile phase was initially 5% ACN and maintained for 5 min; then changed linearly between 5 and 20 min to be 50% ACN; then changed in 0.1 min to be 5% ACN; and was then maintained for 6 min. Analysis in the negative mode was done with 20% acetonitrile as eluent A and 80% MilliQ water as eluent B at a flow rate of 0.2 mL/min.

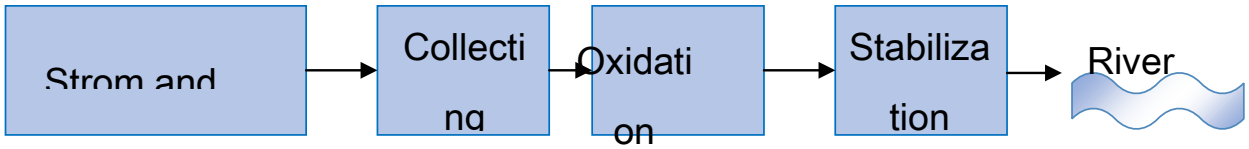
Quantitative polymerase chain reaction (qPCR) for anammox bacteria

Samples of sediments and plant roots were collected from the three full-scale constructed wetlands sites for DNA analysis. The sediment samples were collected at 2-3 cm. from the surface and biofilm was taken from surrounding plant roots. DNA extraction of sediments and root biofilm samples was conducted according to a modified manufacturer's protocol by using sediments DNA isolation mini kit (FavorPrep, Vianna). Specificity gene copy number of anammox (hzo gene) was quantified by quantitative polymerase chain reaction (qPCR) analysis with primer sets (hzocl1F: 5'-TGYAAGACYTGYCAYTGG-3' and hzocl1R2: 5'-ACTCCAGATRTGCTGACC-3') (Schmid et al., 2008). Total volume of PCR mixture was 20 µL containing 10 µL of Luna® Universal qPCR Master Mix (2X) (New England Biolabs, UK), 0.4 µL of each primer (20 µM) and 1 µL DNA template. Thermocycling step of qPCR amplification was 95°C (2 min), followed by 40 cycles at 94°C (5 s), 56°C (20 s) and 72°C (1 min). The standard curve was constructed from a series of 10-flod dilution (102 to 108) with amplification efficiency and correlation coefficients above 99.8% and 0.96, respectively.

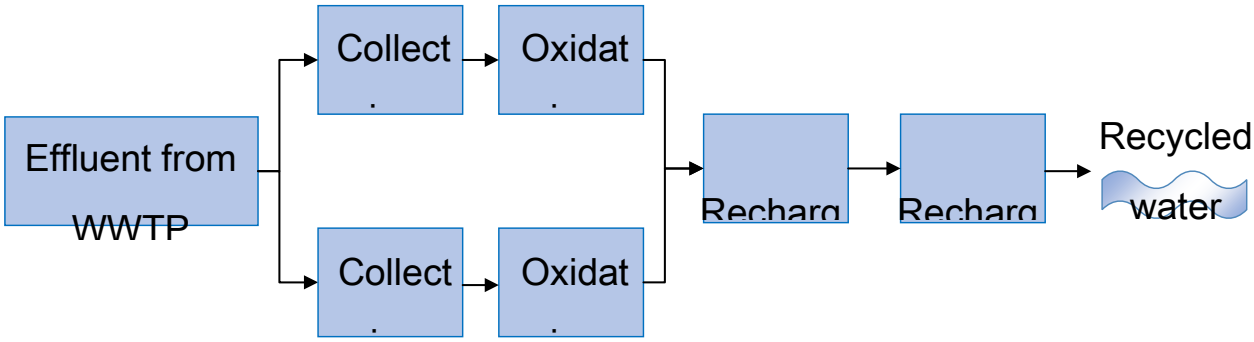
Lam puk bia, Phetchaburi Province, Thailand



Fukuoka, Japan



Sweetwater wetland, Tucson, Arizona, USA



Identification of nitrogen-transforming bacteria

The samples from sediments and roots from two of the full-scale constructed wetlands: (Thai and Tucson wetland sites) were used to identify microbial communities of ammonia-oxidizing bacteria (AOB), nitrite-oxidizing bacteria (NOB), denitrifying bacteria (DEB), and other bacteria. Total DNA was extracted from wetland samples with QIAamp DNA Stool Mini Kit (Qiagen, Germany) according to the manufacturer's protocol. DNA concentrations were determined with a NanoDrop 2000C spectrophotometer (Thermo Scientific). PCR amplification of bacterial 16S rRNA gene fragments of bacterial group was performed using primers Bac338F-GC/Bac805R (Table 1). Cycle conditions for the touchdown PCR amplification were denaturation at 94°C for 10 min; 20 cycles consisting of denaturation at 94°C for 30 s, annealing at 65 to 55°C (reducing the temperature by 0.5°C per cycle) and extension at 72°C for 1 min; additional 15 cycles of 94°C for 30 s, 55°C for 30 s, and 72°C for 1 min; and final extension at 72°C for 7 min. The identity of the dominant ammonia oxidizers (AOB), nitrite oxidizers (NOB),

denitrifying bacteria (DEB) and other bacteria were determined by denaturing gradient gel electrophoresis (DGGE). DGGE was performed using a DCode universal mutation detection system (Bio-Rad, USA). The gels were prepared in 0.5X TAE buffer (20 mM Tris, 10mM acetic acid, 0.5 mM ethylenediamine tetraacetic acid (EDTA), pH 8.0), which was also used as the electrophoresis buffer. Electrophoresis was run at 58°C, 150 mV at 16 h at a constant voltage. After electrophoresis, the gels were stained with SYBR Gold nucleic acid gel stain (1:10,000 dilutions) for 40 min, followed by holding in distilled water for 20 min. DGGE images were captured using CUV10 Alphalmager MiNi (Cell Biosciences, Santa Clara, CA). PCR products were purified by a Wizard® SVGel and PCR Clean-up System (Promega, WI, USA). Database searches were conducted using BLAST (Alschul et al., 1990) from DNA Data Bank of National Center for Biotechnology Information (NCBI).

Table 1. Oligonucleotide primer

Specificity group	Primer name	Sequence (5'–3')	Annealing T (°C)	References
All bacteria	Bac338F*	ACTCCTACGGGAGGCAG	52	Yu et al. 2005
	Bac805R	GACTACCAGGGTATCTTATCC	48	
Planctomycetes	PLA46F*	GACTTGCATGCCTAATCC	59	Schmid et al. (2000)

*attached GC-clamp (5'–CGCCCGCCGCGCGCGGCGGGCGGGGCGGGGGCACGGGGGG–3') (Muyzer et al. 1993)

Results and Discussion

Full-scale constructed wetland sites

Average water qualities from three full-scale constructed wetland sites are provided in Table 2. The influent BOD at the wetland treating domestic wastewater from Thailand was quite low, as seen in Table 2, as compared to the other wetlands from Fukuoka and Tucson. Most of the influent from Fukuoka comes from runoff and storm water (non-point sources). The influent from Tucson comes from the treated effluent from the WWTP. For these reasons both influents from Japan and USA have even lower BODs than the influent from Thailand.

Table 2 Physical and Chemical Characteristics of Water qualities from three wetlands sites

Parameters	Fukuoka Wetland		Thai Wetland		Tucson Wetland	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	7.0±0.1	7.0±0.1	6.8±0.5	7.1±0.3	7.1±0.2	7.2±0.3
Temp (°C) in summer	20±3	20±3	25±2	25±3	28±5	28±3
Temp (°C) in winter	17±3	18±3	23±2	22±1	15±2	15±3
BOD (mg/L)	2.5±1.5	1±0.5	30±10	2±1	4±2	1±0.5
NH_4^+ (mg N/L)	0.5±0.2	0.1±0.1	25±10	0.8±0.5	2±1	1±0.5
NO_3^-(mg N/L)	0.2±0.1	0.2±0.1	15±5	2±1	8±5	2±1

The Thai site is used to treat raw domestic wastewaters from Phetchaburi Province (western province of Thailand). In the Thai wetland site, influents typically have low BOD but high nitrogen and high temperature for the whole year, see Table 2. The nitrogen removal efficiency for nitrification-denitrification is very low because of insufficient carbon for denitrification. The results from the Thai wetland are similar to the work of Noophan et al. (2017) who summarized that Thai BOD influents of domestic wastewaters are quite low for these reasons: combination of sewage and storm water, significant infiltration and inflow, and rapid BOD degradation in the sewage pipe because of the warm climate. In addition, sewage piping from point sources to WWTP is very long, leading to long residence times. Also significant is that virtually every house in Thailand has a primary treatment system (such as grease trap, septic tank), which removes a significant portion of BOD. Theoretically, the nitrogen removal efficiency in nitrification-denitrification was quite low because of insufficient carbon content for denitrification. However, the result from this work contradicts the work of Noophan et al. Because high nitrogen removal efficiency was found in the Thai wetland systems, it could be postulated that the anammox process is involved in the Thai wetland systems. Although influents typically have low BOD, high nitrogen and high temperature for the whole year from this wetland site, high nitrogen removal efficiency was still found. For this reason, the molecular technique was used to

identify microorganism groups which are related to the partial nitritation and anammox process. See the results on the qPCR for anammox bacteria and identification of microbial communities.

Contaminants of emerging concern (CECs)

Only the full-scale wetland system from Tucson, Arizona, USA was investigated for CECs because large quantities of the treated effluent was routed to indirect potable water reuse. CECs such as PFOA, PFOS, PFHxA degradation product of PFHxS, and PFBS concentrations were determined for both influent and effluent of this wetland site, but these chemical concentrations were still lower than the USA standard, see Figure 1. The main source for PFOA is from nonstick surfaces and PFOS comes from firefighting foam. These chemical reagents are cancer concerns if taken up by human every day. USEPA developed Provisional Health Advisory levels protective for short-term exposures to PFOA of 70 ng/L and PFOS of 70 ng/L. UCMR 3 Minimum Reporting Levels (MRL), PFHxA and PFBs are 30 ng/L and 90 ng/L (μg/L).

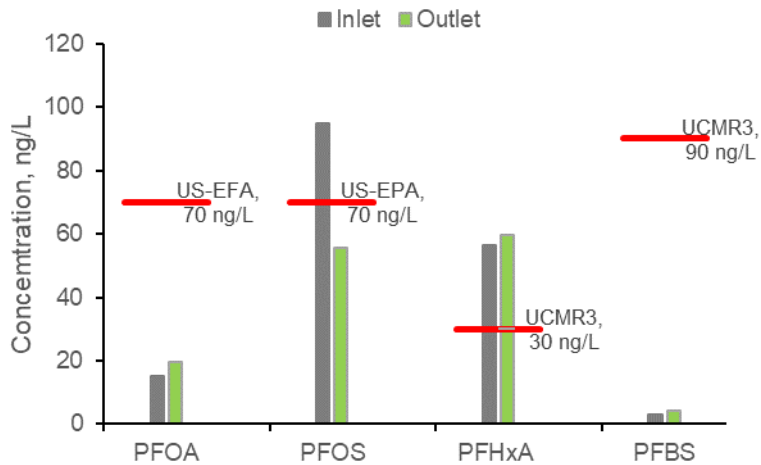


Figure 1 PFOA, PFOS, PFHxA, and PFBS concentrations from influent and effluent of wetland site from Tucson, Arizona, USA

qPCR for anammox bacteria

The quantity of anammox bacteria from plant roots and sediments of constructed wetland at Phetchaburi Province, Thailand and Tucson, Arizona USA was found $3.09x10^5 \pm 3.19x10^4$ copy/g-wet root and $7.06\ x10^5 \pm 3.94x10^4$ copy/g-sediment and $1.9x10^4 \pm 1.65x10^3$ copy/g-wet root and $1.25\ x10^6 \pm 1.4x10^5$ copy/g-sediment, respectively. However, a lower amount of anammox bacteria ($4.17x10^3 \pm 1.24x10^3$ copy/g-wet root) was found in the roots but not in the sediment at wetland of Fukuoka, Japan. Based on water qualities, the nitrogen removal efficiencies at these two wetland systems were quite high. From the results it could be postulated that the constructed wetlands at Phetchaburi Province, Thailand and Tucson, Arizona USA could be used to effectively treat wastewater with low BOD but high nitrogen. Polymerase chain reaction denaturing gradient gel electrophoresis (PCR-DGGE) was used in order to identify other microbial communities such as ammonia-oxidizing bacteria (AOB), nitrite-oxidizing bacteria (NOB), denitrifying bacteria (DEB), and other bacteria from sediment and biofilm of plant roots of these wetland systems from Phetchaburi Province, Thailand and Tucson Arizona USA but not Fukuoka's wetland system.

Identification of microbial communities

The DGGE results on known AOB, NOB, DEB and other bacteria communities from two full-scale constructed wetlands: Phetchaburi Province, Thailand and Tucson, Arizona, USA) are summarized in Table 3. AOB *Nitrosospira multiformi*, *Nitrosococcus oceani* and NOB *Nitrospira* sp. were found. Nitrification was likely a significant process for conversion of NH_4^+ to NO_2^- and into NO_3^- in Phetchaburi Province's wetland based on the presence of these microorganisms (Mota et al. 2005). Typically, *Nitrospira* sp. is widespread and the key nitrifier in wastewater treatment by wetlands (Pester et al. 2014). Daims et al. (2001) demonstrated that *Nitrospira* sp. can grow

in an aerated bioreactor with lower nitrite and oxygen concentrations. DEB *Chondromyces robustus*, *Comamonas jiangduensis*, *Desulfococcus multivorans*, *Dechloromonas hortensis*, and Uncultured *Methylibium* were found; denitrification could be related to NO_3^- removal. *Candidatus Accumulibacteria phosphatis* clade was also found in the sediment constructed wetlands treating domestic wastewater. It may be suggested that these organisms are related to anammox and biological phosphorus removal activities, respectively. High nitrogen removal efficiency was found in this wetland although there was insufficient organic carbon for denitrifying bacteria. For these reasons, it is assumed that biological nitrogen removal in this wetland treatment systems is not only through the nitrification-denitrification process but also by partial nitritation and anammox processes. This postulation is made for biological nitrogen removal in the Tucson's wetland, Arizona also. In this wetland AOB *Nitrosospira* sp. and DEB *Burkholderia denitrificans*, *Dechloromonas denitrificans*, and *Thiobacillus denitrificans* but on NOB at all were found in sediment and plant roots. Although there was insufficient organic carbon for denitrifying bacteria, high nitrogen removal efficiency was found in this wetland site.

Table 3 Appearances of microbial communities in wetlands

Microbial		**USA**			**Thailand**		
		Inlet	**Pond**	**Outlet**	**Inlet**	**Pond**	**Outlet**
AOB	*Nitrosospira multiformis*		✓	✓	✓		✓
	Nitrosococcus oceani					✓	✓
NOB	*Nitrospira tenuis*				✓	✓	
	Nitrospira sp.				✓	✓	
	Uncultured *Nitrospira*				✓	✓	✓
DEB	*Burkholderia denitrificans*	✓	✓	✓			
	Chondromyces robustus				✓		
	Comamonas jiangduensis				✓	✓	
	Dechloromonas denitrificans	✓	✓	✓			
	Dechloromonas hortensis					✓	
	Desulfococcus multivorans				✓		
	Thiobacillus denitrificans	✓	✓	✓			
	Uncultured *Methylibium*				✓		
Other	*Acidovorax radicis*				✓		
	Candidatus accumulibacter phosphatis clade IIA				✓		
	Fusibacter fontis	✓	✓	✓			
	Iamia majanohamensis				✓	✓	✓
	Terrimonas lutea		✓	✓			
	Terrimonas sp.	✓					
	Streptococcus dentisani				✓		✓
	Streptococcus cristatus				✓		✓
	Sulfurovum lithotrophicum		✓	✓			
	Zoogloea resiniphila	✓	✓	✓			
	Uncultured *Clostridium*				✓		
	Uncultured *Haliscomenobacter*	✓					
	Uncultured *Saprospiraceae*	✓	✓				
	Uncultured *Sphingobacteriaceae*	✓					
	Uncultured *Sufflavibacter*	✓					

Remark: ✓ = found

The molecular results suggest that these two constructed wetlands would be able to remove nitrogen under anaerobic conditions without a significant organic carbon source. Moreover, Kadlec and Knight, 1996 and Tao et al., 2012 postulated that the anammox process could be a main mechanism of nitrogen removal without oxygen and insufficient organic carbon in wetland systems. For these reasons, wetland systems have gained increasing interest in wastewater treatment and as such have been intensively studied around the world. In developed regions such as Europe, Australia, Japan, and USA, constructed wetlands are often used in urban and rural areas to treat storm water runoff before discharge to the environment. Constructed wetlands represent low-cost and appropriate technology for domestic wastewater treatment in developing countries. The aerobic conditions around the biofilm of plant roots,

anaerobic conditions in the subsurface, and high temperature are factors in the treatment performance of constructed wetlands systems. Humbert et al. (2012) found anammox bacteria in sediment in seven natural wetlands. Wetland systems with anammox should be able to remove nitrogen from influents with low BOD but high nitrogen, despite the lack of a carbon source for denitrification. However, additional study is still needed in order to better understand how to promote the partial nitritation and further investigation of the anammox process in constructed wetlands is strongly indicated.

Conclusion

The results from this study suggest that the biological nitrogen removal processes in these wetland treatment systems includes not only nitrification-denitrification but also partial nitritation and anammox activity. The biological mechanism on the biofilm of plant roots might be a key parameter of the partial nitritation and anammox process. Contaminants of emerging concern (PFOA, PFOS, PFHxA) degradation product of PFHxS, and PFBS concentrations were found in the influent and effluent in Tucson wetland site, but the levels were lower than USA standard. Based on the results of these three wetlands sites study, the effluent from these wetlands could be considered for water reclamation and reuse.

Acknowledgements

The authors are extremely appreciative for a grant from the Kasetsart University Research and Development Institute (KURDI). The authors also would like to thank the Faculty of Engineering, Kasetsart University for encouraging support throughout this entire project.

References

Alschul S. F, Gish W., Miller W., Myers E. W. & Lipman J. 1990 Basic local alignment search tool. *Journal of Molecular Biology*, **215**, 403-410.

APHA, AWA & WPCF. 2005 *Standard methods for the examination of water and wastewater*, 22th ed. American Public Health Association, Washington, DC, USA.

Daims H., Nielsen J. L., Nielsen P. H., Schleifer K. H. & Wagner M. 2001 In situ characterization of *Nitrospira*-Like nitrite oxidizing bacteria active in wastewater treatment plants. *Applied and Environmental Microbiology*, **67**(11), 5273-5284.

Humbert S., Zopfi J. & Tarnawski S. E. 2012 Abundance of anammox bacteria in different wetland sediment. *Environmental Microbiology Reports*, **4**(5), 484-490.

Kadlec R. & Knight R. 1996 *Treatment Wetlands*. Lewis Publishers, Chelsea, MI, USA.

Mota C., Head M. A., Ridenoure J. A., Cheng J.J. & de los Reyes F. L. 2005 Effects of aeration cycles on nitrifying bacterial populations and nitrogen removal in intermittently aerated reactors. *Applied and Environmental Microbiology*, **71**(12), 8565-8572.

Muyzer G., Waal E.C. & Uitterlinden A.G. 1993 Profiling of complex microbial populations by denaturing gradient gel electrophoresis analysis of polymerase chain reaction-amplified genes coding for 16S rRNA. *Applied and Environmental Microbiology*, **59**, 695-700.

Noophan L. P., Phanwilai S., Kasahara T., Munakata-Marr J. & Figueroa L.A. 2017 Comparison of nitrogen removal and full-scale wastewater treatment plant characteristics in Thailand and Japan. *EnvironmentAsia*, **10**(1), 92-98.

Pester M., Maixner F., Berry D., Rattei T., Koch H., Lucker S., Nowka B., Richter A., Speick E., Lebedeva E., Loy A., Wagner M. & Daims H. 2014 *NxrB* encoding the beta subunit of nitrite oxidoreductase as functional and phylogenetic marker for nitrite-oxidizing *Nitrospira*. *Environmental Microbiology*, 1**6**(10), 3055-3071.

Schmid M., Twachtmann U., Klein M., Strous M., Juretschko S., Jetten M. S. M., Metzger J. W., Schleifer K. H. & Wagner M. 2002 Molecular evidence for genus level diversity of bacteria capable of catalyzing anaerobic ammonium oxidation. *Systematic and Applied Microbiology*, **23**(1), 93-106.

Tao W., He Y., Wang Z., Smith R., Shayya W. & Pei Y. 2012 Effects of pH and temperature on coupling nitritation and anammox in biofilters treating dairy wastewater. *Ecological Engineering*, **47**, 76-82.

Yu Y., Lee C., Kim J., Hwang, S. 2005 Group-specific primer and probe sets to detect methanogenic communities using quantitative real-time polymerase chain reaction. *Biotechnology Bioengineering*. **89**, 670-679.

Wastewater Reclamation and Reuse in India: Review and Strategic Issues

Kirti Goyal, Indian Institute of Technology, Roorkee, India; Arun kumar, Indian Institute of Technology, Roorkee, India; Email: goyalkirti2012@gmail.com

Abstract:

Water availability, a key component of sustainable development has become a global concern due to rising population and economic development. The mounting water crisis has encouraged the use of treated wastewater as an alternate resource. The aim of the study is to analyze and discuss the factors causing the necessity of water reuse in India along with the associated challenges and opportunities. An overview of the existing reuse practices in India is also presented. The study shows that water reuse is a lost opportunity due to lack of planning and placing effective regulatory framework and technical challenges. Developing a holistic water management approach incorporating various factors affecting reuse, is essential for successful implementation of water reuse projects.

Keywords: Reuse, Treated wastewater, Water resources, Demand, Availability, Potential.

Introduction:

Throughout the world, the demand for water is increasing at an alarming rate due to many factors such as rapid population growth, industrial development, changing water use patterns etc. due to which a condition of water scarcity is being experienced worldwide. Water scarcity is already affecting almost every continent of the world which has built a pressure on the existing water supplies.

Despite having 4% of the world water resources and a widespread river network, the availability of water resources has unique intricacies in India. Even though the average annual water resources potential is 1869 BCM, the actual amount of water that can be used beneficially is approximately 1123 BCM due to limitations of physiography, topography, inter-state political issues[4]. Climate change, industrialization and associated anthropogenic activities are taking a toll on the existing water resources causing extreme events and shifting of precipitation and pollution of water bodies. The country is currently whirling under a cumulative rainfall deficiency of nine percent[5].

Indian rivers carrying 4% of the world's water contain 35% of global sediments. As per an assessment by the Indian Central Pollution Control Board (CPCB) 2015, there are 351 polluted river stretches in the country with 45 of them being critically polluted[1].

It has been estimated that by the year 2030, the anticipated water demand would reach 1498 BCM against an expected water availability of 744 BCM, creating a wide gap between demand and availability. Based on utilizable resources, with respect to increasing population, the country is already facing water stress (<1700 m^3/year) and is fast approaching towards water scarcity (<1000 m^3/year) (Figure 1).

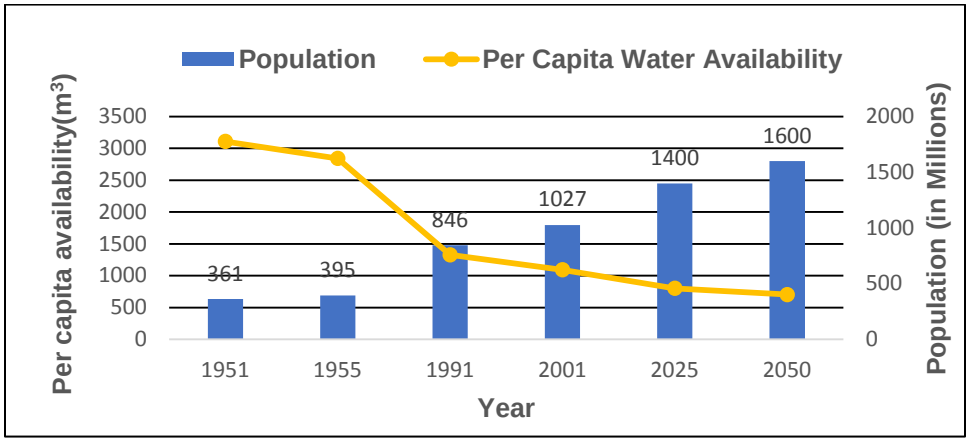


Figure 1. Projected Per capita water availability v/s Population growth[4]

To meet the existing and projected demand for water, more than half of the countries around the world including India, are forced to explore alternate sources and management practices to augment the water availability. One of the most promising, economical and environment friendly management practices is the reuse of treated wastewater. Reuse of wastewater, both planned and unplanned, has been identified as an alternate source of water supply for various applications including indirect and direct potable reuse in many countries.

The concept of reuse of water has existed in India since long especially in water stressed areas. Treated wastewater is being used sparsely for many industrial and non-contact domestic applications such as toilet flushing, cooling towers, horticulture, crop irrigation etc. Yet this approach does not garner mainstream appeal due to numerous reasons such as non-existence of supportive regulation to encourage and incentivize the implementation of reuse projects, limited volume of water available for reuse due to

gap in wastewater collection and treatment and non-availability of required infrastructure.

The main focus of this study is to delineate the factors driving the need of reusing wastewater along with analyzing the challenges and opportunities associated with reuse of wastewater in India. An overview of the existing wastewater reuse practices is also presented.

Factors driving the need to reuse treated wastewater:

There are many factors contributing to necessitate the implementation of wastewater reuse systems in India such as declining level of water resources, increase in per capita consumption, industrial development etc. as summarized in table 1.

Table 1. Factors affecting the need to reuse wastewater[4,7,9]

Food demand v/s Population growth	Surface & Groundwater scenario	Climate change	Industrialization & Urbanization
• Being an agrarian economy, main priority is food security. • Population increase is directly related to food demand. • By the year 2050, the anticipated food demand will reach about 450 M tonnes for a population of 1600 M.	• Surface & groundwater resources are unevenly distributed, depleting and polluted. • 275 out of 445 rivers and 76 among 85 urban lakes are severely contaminated. • GW level has declined by 61% in last 10 years. • Net annual withdrawal is more than net annual recharge.	• Temperature & rainfall changes have serious impact on water resources. • 67% of the glaciers in the Himalayan mountain ranges have retreated. • Rainfall has exhibited a declining pattern. • In the year 2017, 202 districts in various states of country were faced with deficient rainfall.	• By 2050, urban residents will have an anticipated population increase of 404 million. • Rapid urban growth is linked with higher industrial output and greater energy and water demands. • Water shortage has led to rise in the cost of fresh water production in industrial metros.

Challenges and Opportunities associated with reuse:

There are several challenges in reusing treated wastewater, making it difficult to effectively implement such projects and achieve sustainability, discussed as follows.

- Wastewater generation is around 60-70% more than the treatment capacity, limiting the wastewater availability for reuse[1]. This infrastructural lag of wastewater networks and treatment facilities is further followed by obsolete and faulty sewer networks, insufficient treatment capacity, sub-optimal capacity utilization etc.
- Scarcity of data for several critical sectors, mainly, water use patterns limits the planning and feasibility studies.

- Non-consideration of socio-psychological factor of poor public awareness and acceptance and lack of relevant policy and guiding framework makes employing wastewater reuse systems difficult.

Despite the waning water situation and major challenges, over the past few years, focus has been shifting to find solutions for effective management of water resources. Various opportunities promoting the reuse of wastewater in India as shown in Figure 2.

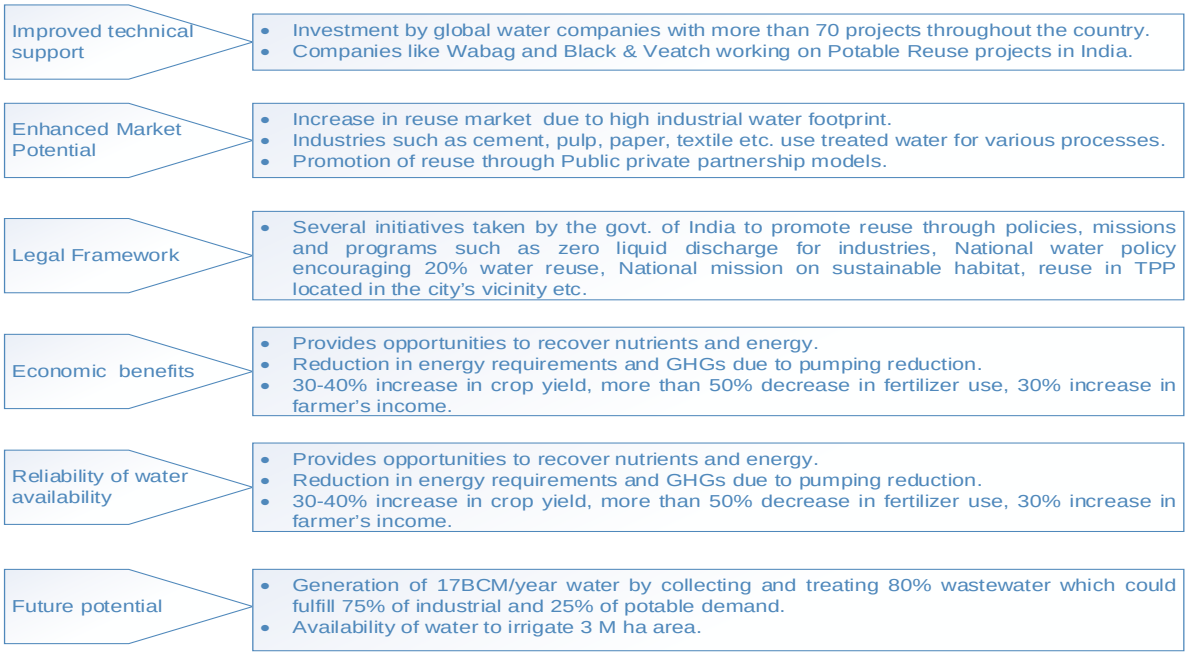


Figure 2. Opportunities promoting reuse of wastewater in India[3,10]

In order to achieve effective and planned reuse of treated water, there is a need to develop a systematic and integrated approach considering the full range of factors i.e. technical (water quality, distribution system design), social and legal (public awareness and education, water tariff, existing and upcoming regulations), economic (costs and benefits), environmental (energy requirements, impact on air, soil etc.) to successfully implement a reuse project.

A high potential exists for reuse in India especially in agriculture along with commercial, industrial, agricultural, environmental and recreational use, groundwater recharge and augmentation of potable water supplies. Some cases related to reuse of treated wastewater with respect to various applications are presented in figure 3.

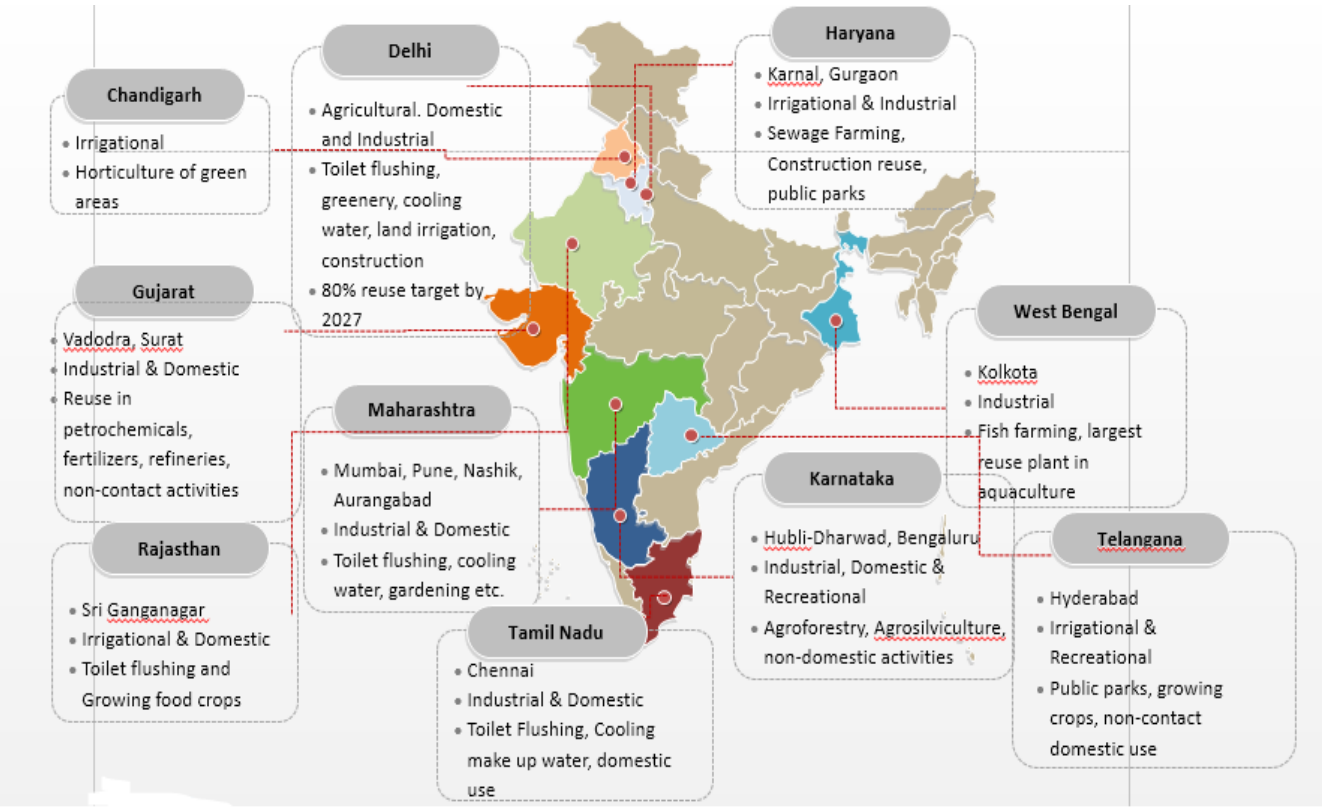


Figure 3. Wastewater reuse cases in India[2,6,8]

Conclusions:

In India, to fulfill the increasing water demand, the reuse of treated wastewater is the most viable option as it has many environmental and economic benefits. There are many opportunities for reuse of wastewater but there is a strong need to overcome the existing challenges such as lack of wastewater collection infrastructure, public awareness, market viability, policy framework and incentives and coordination among stakeholders. Many governing policies and regulatory framework exist at the central government level, but the adjustment and implementation at state and local levels still needs a lot of push and planning.

Thus, to achieve sustainable reuse of wastewater, there is a need to enforce and mandate stringent government policies, funding and engineering research. It is necessary to form national wastewater reuse policy with targets, regulatory and financial measures. Additionally, development of an integrated approach by combining health and environmental risk assessment along with a cost-benefit analysis is essential to

help the administrators to decide amongst the available wastewater management options.

References:

1. Annual Report by Central pollution Control Board. (2015). Ministry of Environment, Forest and Climate Change, Government of India.
2. Barringer.J. (2014). Urban Domestic and Commercial Water Reuse in Pune and Its Influence on the Present Water Crisis. Water Qual Expo Heal. Vol. 6. pp 35–38.
3. Recycling and Reuse of Treated Wastewater in Urban India: A proposed advisory and guidance document. (2016). Report by CGIAR Research Program on Water, Land and Ecosystems, International Water Management Institute (IWMI).
4. Srivastava S.K., Chaskar D.S. and Mitra.S. (2017). Water – Its Conservation, Management and Governance. Report by Central Water Commission, National Water Academy, Government of India.
5. Sub: 2018 southwest monsoon rainfall. (2018). Available at: http://www.imd.gov.in/pages/press_release_view.php?ff=20181001_pr_333. (Accessed on: 3rd January, 2019).
6. Sub: National workshop on wastewater recycle and reuse. (2014). Available at: http://mohua.gov.in/upload/uploadfiles/files/NATIONAL WORKSHOP ON WASTEWATER RECYCLE AND REUSE_Background Note02 .pdf. (Accessed on: 5th January, 2019).
7. Sub: Rainfall statistics of India. (2017). Available at: http://hydro.imd.gov.in/hydrometweb/(S(3gvjaxze4oabkb552viabmn5))/PRODUCTS/Publications/Rainfall Statistics of India - 2017/Rainfall Statistics of India - 2017.pdf. (Accessed on: 2nd january, 2019).
8. Sub: Recycling and reuse in India. Available at: http://cpheeo.gov.in/upload/uploadfiles/files/engineering_chapter7.pdf. (Accessed on: 4th January, 2019).
9. Sub: Surface and groundwater pollution in India. (2018). Available at: https://swachhindia.ndtv.com/world-water-day-2018-surface-and-groundwater-pollution-are-pushing-india-towards-an-irreversible-water-crisis-17882/. (Accessed on: 30th January, 2019).

10. Water and wastewater in India. (2011). Report by European Business and Technology Centre, New Delhi, India.

Evaluation of water reuse models and development potentials in urban areas of China

Zhuo Chen[1], Chun Wang[1], Tong Yu[2], Guo-Qiang Li[3], Xue-Hao Zhao[1], Yong Cui[4], Yin-Hu Wu[1], Hong-Ying Hu[1]

1 School of Environment, Tsinghua University, Beijing 100084, PR China;

2 School of Environmental and Municipal Engineering, Qingdao University of Technology, Qingdao 266033, PR China

3 College of Water Conservancy and Environment, Zhengzhou University, Zhengzhou 450001, PR China

4 Beijing Boda Water Co., Ltd, Beijing 100176, PR China

Background

China is facing water environmental problems across the country, including water shortage, water pollution, water ecological destruction and water space shrink. Water reuse is considered as an essential strategy to alleviate water environmental issues and extend water supply capacity of cities. By 2016, wastewater treatment capacity and reclaimed water use in urban areas of China were 150×10^6 m^3/day and 4.53×10^9 m^3/year respectively. Scenic environment and industrial applications are the two largest applications of reclaimed water, representing over 80% of the total reclaimed water consumption. The current water reuse rate nationwide is only 10.1% compared to that of 68% in Beijing city and even higher levels in other places. Hence, this is still a large potential to further boost water reuse quantity and exploit new end uses.

Methods

To promote safe, reliable, efficient and economic water reuse at different scales, strategies for centralized and decentralized water reuse systems are proposed, including the multiple utilization model for centralized water reuse

and the integration of different decentralized/onsite water reuse systems into a broader centralized management. Water reuse potentials are evaluated based on three different scenarios.

Results and discussion

Centralized systems can play the leading role in urban areas of China while decentralized ones can exist in different scales with flexibility and convenience (Fig. 1). A centralized multiple utilization model is found to be effective for large scale schemes and a case study is conducted at E-town of Beijing, China to further illustrate the effectiveness. The overall water reuse quantity is projected to be over 20 billion m^3/year by 2020 and specific values with respect to different applications are calculated based on three different scenarios (Table 1).

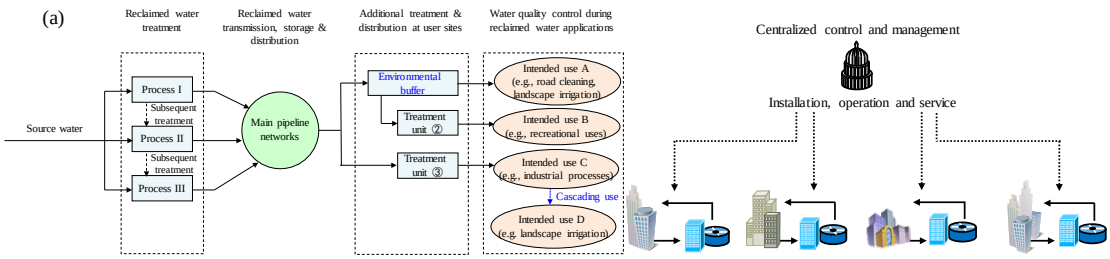


Fig.1 Framework of the proposed centralized model (a) and decentralized systems with centralized management (b)

Table 1 Estimated water reuse potentials in China (10^8 m^3/year)

Application	Current	S1 Potential	S2 Potential	S3 Potential
All types	45.3	313	259	
Environmental use	20.1		56	
Industrial use	16.4			45.5

Note: S1, S2 and S3 are the scenarios of reaching Israel level (80%), Beijing level (68%) and Singapore level (39% of water reuse in industry) respectively.

Conclusion

The study identifies feasible water reuse models and possible utilization potentials in urban areas of China. The findings can facilitate in identifying optimal ways to initiate and manage water reuse projects.

Opportunities and Obstacles for Wastewater Reclamation and Reuse in the Selected Industries of Turkey

Bilgehan Nas, Department of Environmental Engineering, Konya Technical University, Konya, Turkey;
Sinan Uyanik, Department of Environmental Engineering, Harran University, Sanliurfa, Turkey;
Selim Dogan, Department of Environmental Engineering, Konya Technical University, Konya, Turkey;
Ahmet Aygun, Department of Environmental Engineering, Bursa Technical University, Bursa, Turkey;
Taylan Dolu, Department of Environmental Engineering, Konya Technical University, Konya, Turkey.

Abstract:

The reuse of reclaimed industrial wastewater on-site increases in Turkey as it increases in the world. The reuse of reclaimed domestic wastewater in the industry increases as well. The amount of water reclaimed and reused from WWTPs was determined as 29.6 million m^3 in Turkey. Accordingly, the reuse rate of domestic wastewater in Turkey is defined as 0.78%. The reuse rate of reclaimed domestic wastewater in the industry in the world is 19%. In Turkey, industrial reuse ratio is 56.8%. The Ministry of Environment and Urbanization (MoEU) has set the 2023 water reuse rate target as 5% in Turkey. There are some obstacles to achieve this 5% target. In order to achieve this goal, a comprehensive project was supported by MoEU. In this paper; opportunities and obstacles of reuse of reclaimed wastewater in the selected industries (sugar industry, the paper and cardboard industry, thermal power plants) are evaluated.

Keywords: Water reuse; industrial reuse; sugar industry; paper industry; thermal power plants

Introduction

Turkey is not a water rich country in terms of existing water potential. Approximately 1400 m^3 fresh water per capita is available annually for water consumption. Turkish Statistical Institute (TurkStat) has estimated that the population will reach 100 million by 2030 and the water availability in Turkey will decrease to 1120 m^3 per capita. Turkey is situated in a semi-arid region and water demand increases with population growth, industrialization, and urbanization. Regarding to actual water consumption in Turkey; 73% of usage is dedicated to agricultural irrigation, 16% of usage to domestic purposes and 11% of usage for industrial sectors (www.dsi.gov.tr). Turkey aims to reduce agricultural irrigation ratio to 64% in 2023 while currently using 32 billion m^3/year water in irrigation. In addition, Turkey used 5 billion m^3/year for

industry in 2012, and it is expected to use 22 billion m^3/year of water in the industry in 2023. With the present water potential and sectoral water use rates, Turkey should perform key administrative and technical regulations about the reuse of reclaimed wastewater in the coming years.

In 2011; 7 billion m^3/year reclaimed wastewater is reused and the ratio of this value to the total water use is 0.59%. 32% of the reclaimed wastewater in the world is reused for irrigation purposes. Landscape irrigation (20%) and industrial water use (%19) follow irrigation (EPA, 2012).

The reuse of reclaimed industrial wastewater on-site increases in Turkey as it increases in the world. The reuse of reclaimed domestic wastewater in the industry increases as well. The reasons such as water shortages experienced in some basins in Turkey, the rise in water prices and increased product costs, and the idea of reducing water footprint of products promote the reuse of reclaimed wastewater in the industry. The amount of reclaimed and reused water from domestic/urban WWTPs was 29.6 million m^3 in Turkey. Accordingly, the reuse rate of domestic wastewater in Turkey was defined as 0.78%. The reclaimed wastewater capacity in domestic wastewater treatment plants is 1.2%. The MoEU has set the target of 2023 as 5% for reuse in agricultural irrigation, industrial reuse, groundwater supply, irrigation for urban purposes, irrigation for wetlands and rivers, environmental/ecological use in Turkey. There are some obstacles to achieve this 5% target. In order to achieve this goal, a comprehensive project about the opportunities and obstacles of reuse of reclaimed wastewater in the selected industries was supported by MoEU. In Turkey, industrial reuse of treated domestic wastewater has the first place with 56.8% ratio, followed by 16.3% environmental/ecological reuse, in-plant reuse with 6.4% (green area irrigation, processes, washing etc.) and urban reuse (green area irrigation) with 2.6% (Figure 1).

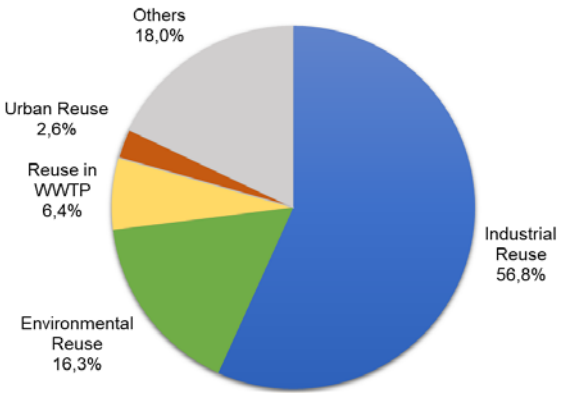


Figure 1. Nationwide reuse summaries of reclaimed water in Turkey (TURAAT, 2016)

In the industries, wastewater generated as a result of the process can be used as a loopback in another process without any further processing. On the other hand, in a recovery facility (usually depending on the desired water quality, but also including multimedia filters, membrane processes and ion exchange systems), wastewater is treated in order to reuse them as boiler completion waters, cooling tower completion water, process waters, fire water, water treatment unit backwash water, in-plant dust control / site irrigation, sanitation and general cleaning, in-house green area irrigation, in-plant urinal and siphon use.

Material and Methods

Project of “Reuse of Reclaimed Wastewater” was completed in 2018 examining mining industry, food industry, beverage industry, paper and cardboard industry, thermal power plant, and organized industrial zones. A total of 9 industries under 6 main sectors were surveyed in the project (Table 1).

In this paper; for the selected only 3 sectors (sugar industry, paper cardboard industry and thermal power plants) from the industrial sectors examined in this project; opportunities and barriers to water reuse were investigated beside investigating the wastewater generation and characteristics, the reuse potential of reclaimed domestic wastewater for the selected sectors.

Table 1. Industrial sectors investigated under the project (TURAAT, 2016)

Industry	Sub Sectors
Mining Industry	• Mineral Preparing and Processing Plants • Ready-Mixed Concrete Plants
Food Industry	• Vegetable, Fruit Washing and Processing Plants • Sugar Factories

Beverage Industry	• Soft and Similar Drinks Production
Cellulose, Paper, Cardboard and Similar Industries	• Waste Paper, Straw and Paper Bleached Cellulose Production • Starch Additive Paper • Surface Coated, Filled Paper
Coal Preparation, Processing and Energy Production Plants	• Thermal Power Plants • Natural Gas Cycle Power Plants
Mixed Industries	• Organized Industrial Zones

30 industrial plants located in different regions of Turkey were examined in the project. While selecting the facilities; the prevalence of the sector in Turkey, the sector's water use quantities, recycling wastewater in the sector and re-use potential, different geographical areas location (for comparison opportunity in terms of water unit price water constraints,) factors were taken into consideration. The facilities were visited by the project team and the required information for the facilities were taken at the site. At the facility; water supply sources, water treatment processes, water usage and wastewater treatment processes were evaluated, and water samples were taken from 3 different points in June-September 2017. In addition to the water quality parameters included in the Turkish Water Quality and Control Regulation sector table, additional water quality parameters were also analyzed by taking into consideration the possible reuse alternatives (process water, irrigation water, cooling tower / boiler completion water etc.) in the sector. In project scope; number of samples taken from industrial facilities were 88, number of sampling points were 181, number of analyzed water quality parameters were 37 and the total number of wastewater analyzes were 1795.

“Reuse of Reclaimed Wastewater Project” aimed to propose technical and administrative criteria for national and international practices and standards for investigating all kinds of re-use of specific purified wastewater to urban and industrial treated wastewater reuse. In the project; the initial investment and operating costs, operational problems, process efficiency and re-use categories of urban wastewater treatment plants of Turkey are evaluated. At the end, alternative treatment technologies, water quality criteria and monitoring frequencies that can be applied for each of the different re-use categories (urban, agricultural, environmental, industrial, aquifer feeding, etc.) have been proposed.

Results and Discussion

Sugar Factories in Turkey

Turkey, among the sugar beet sugar producing countries, ranks 5th with 6.8% share in 2016/2017. There are 33 sugar factories, according to the 2018 in Turkey. The water use range for the sugar factories examined in the project is 0.6-1.1 m^3 water/ton.sugar beet. If the average of 0.75 m3 of water used for kg sugar production, the amount of water used in the sugar industry in Turkey will be about 14 million m^3 water/ year. It was seen in the Project that it is quite possible to recover the water used in the process and reuse it in the plant. Under the lights of the sugar sector and sugar factories examined within the scope of the project; some recommendations are summarized below (TURAAT, 2016);

- All sugar factories have water cycles to minimize water use.
- Reuse of transport and washing water in settling tanks can reduce the flow rate of wastewater to biological wastewater treatment plant.
- It is recommended to use sugar factory wastewater and treated wastewater primarily in in-plant water cycles, to evaluate the re-use alternatives instead of discharge to the receiving environment and ultimately discharge to the receiving environment.
- Anaerobic denitrification / nitrification are used efficiently in the purification of the sugar factory wastewater in Turkey.
- Since sugar factories are in operation in the campaign period between October and February of the year, the use of wastewater reuse is restricted to irrigation water. Storage areas should be established for alternative treatment of treated wastewater as irrigation water.

Paper Industry in Turkey

While it is known that approximately 100 m^3 of water is used per tonne of paper produced, the amount of wastewater generated from paper cardboard production processes is only 10 m^3 wastewater due to in-process returns. There is a good water management and operation facilities and waste paper / paper carton production

Reducing the wastewater to be produced in paper and cardboard production and managing it within the system is a complicated issue and it depends on the performance of the water recycling systems to be used in a large proportion. The level of acceptable wastewater recycling systems depends on the raw material used and the quality of paper required. The main processes that should be done in wastewater management in paper and cardboard production are as follows (TURAAT, 2016).

- The wastewater released in different areas should be collected separately and the ones with good quality should be re-used in the process without any purification or simple in-process treatments. For example, as in all paper and cardboard producing plants, the sieve water that is produced during dewatering of the wet paper must be reused in the system. There are two reasons for this. Firstly, in these waters, the fibers required for paper production are highly available and must be recycled. Secondly, due to the fact that one of the highest and best quality wastewater sources that can be recovered during the production process is this wastewater (so called white wastewater).
- The wastewater treatment plant at the end of the plant should be modular and capable of producing different quality outlet waters. The required treated wastewater produced in enough quantity and quality should be recycled to the areas where is needed.
- A separate piping system must be used for cooling water and must be used repeatedly without mixing with any other wastewater.

Thermal Power Plants in Turkey

A large part of energy needs are met by thermal power plants in Turkey. By the end of November 2017, the total installed power plants capacity is 83 139 MW. 46.183 MW of this is a thermal power plant. 41% of the water used in thermal power plants is used in ash transmission and 30% in cooling towers. According to the results of TurkStat, Thermal Power Plant Water, Wastewater and Waste Statistics Survey, in 2016, 98.4% of water used in the thermal power plants was drawn from the sea which is about 8,6 billion m^3 and 98.3% of the total water was used as cooling water. Of the 8.5 billion m^3 wastewater discharged by thermal power plants in 2016, 98.9% of the total wastewater generated was cooling wastewater and 99.7% of the total

wastewater was discharged into the sea. In the thermal power plants, there are 84 wastewater treatment plants, the total capacity of 43.6 million m^3 in and they treated 18.5 million m^3 of wastewater in Turkey.

Conclusions

A production model that includes elements such as the use of less water in production and the reduction of the amount of wastewater generated reduces the production costs and reduces the effects of the production processes on water resources. Reuse of wastewater or reclaimed wastewater in industry provides efficiency in resource utilization, reduction in production and waste management costs, compliance with environmental laws, regulations and relevant national strategies, meeting the relevant expectations of international brands, increasing brand values, and enabling national and international financial institutions to benefit from the relevant financial opportunities. Field studies, water analysis and data interpretation results showed that the most important obstacle to water reuse was particularly the absence of any legislation on access to groundwater and uncontrolled groundwater use.

Moreover, one of the most important results achieved is that Turkey has a very high reuse potential possibility in case of incentives and regulations associated with water reuse are implemented.

ACKNOWLEDGMENT

This study was prepared with the data obtained from the Projects of "Determination of the Current Status of Domestic/Urban Wastewater Treatment Plants and Determining the Need for Revision (TURAAT)” and "Reuse of Treated Wastewater in Turkey", carried out by the Ministry of Environment and Urbanization and Selcuk University. We would like to thank the Ministry of Environment and Urbanization as a project team.

REFERENCES

http://www.dsi.gov.tr/toprak-ve-su-kaynaklari, Access date: 28.10.2017)

"Reuse of Treated Wastewater in Turkey" (2018), Ministry of Environment and Urbanization & Selcuk University, Final Report, 2018, Turkey

TURAAT, (2016), “Determination of the Current Status of Domestic/Urban Wastewater Treatment Plants and Determining the Need for Revision (TURAAT)”, Ministry of Environment and Urbanization & Selcuk University, Final Report, 2016, Turkey

Turkish Statistical Institute (TurkStat), (2017), Thermal Power Plant Water, Wastewater and Waste Statistics. Ankara, Turkey. December 18, 2017, Number: 24873

U.S. Environmental Protection Agency (EPA). 2012. Guidelines for Water Reuse. EPA/600/R-12/618. Environmental Protection Agency. Washington, D.C.

Managed aquifer recharge: history, practice and applied research in Berlin, Germany

A. Sperlich[1], S. Schimmelpfennig[1], G. Massmann[2], J.E. Drewes[3], Hübner, U.[3], R. Gnirss[1,4]

[1]Berliner Wasserbetriebe, Neue Jüdenstr. 1, 10179 Berlin, Germany

[2]Carl von Ossietzky Universität Oldenburg, Germany

[3]Technical University of Munich, Am Coulombwall 3, 85748 Garching, Germany

[4]Kompetenzzentrum Wasser Berlin gGmbh

Abstract

For decades, managed aquifer recharge (MAR) has been used to augment drinking water resources in Berlin, Germany. Several investigations have shown that MAR is an efficient barrier for several trace organic chemicals (TOrCs), but some TOrCs are persistent. Complementing the implementation of additional barriers into the urban water cycle, upgrading the existing barrier of MAR is investigated. Recent investigations have proposed to control redox conditions and carbon input during infiltration by re-aeration of bank filtrate and subsequent infiltration, also termed as sequential MAR (SMART). Demonstration-scale SMART tests at the infiltration site Baumwerder indicate that removal can only be enhanced for some redox-sensitive TOrCs such as acesulfame, benzotriazole, and gabapentin, if stable oxic and carbon-limited conditions can be reliably controlled during infiltration.

Keywords: MAR, groundwater recharge, sequential MAR, infiltration

Introduction

In Berlin, drinking water is produced mainly from bank filtration and aquifer recharge via infiltration ponds (approximately 75%) as well as naturally recharged groundwater. At waterworks Spandau, approx. 15 Mio. m³ per year of surface water are treated by coagulation/filtration and subsequently recharged via infiltration basins. At waterworks Tegel, approx. 10 Mio. m^3 of surface water are pumped to the infiltration basins in Saatwinkel and at the island Baumwerder.

Long-term investigations have shown that bank filtration and groundwater recharge are important links and efficient barriers in Berlin's partially closed urban water cycle [1,2]. Continuous monitoring shows, however, that some polar and persistent TOrCs are not completely removed by the existing barriers and have been detected in

ground and also drinking water. Research at the Lake Tegel MAR sites has shown that TOrC removal strongly depends on the prevalent redox conditions in the subsurface [3].

Material and Methods

Fate of TOrCs was monitored by sampling of 7 groundwater monitoring wells located beneath and directly adjacent to the infiltration basin as illustrated in Figure 1. Additionally, two monitoring sites were established to monitor dissolved oxygen (DO) concentrations in the basin and in depths of 50, 100 and 200 cm below the surface. In order to achieve more favorable conditions for biodegradation of some relevant TOrCs, the concept of sequential managed aquifer recharge technology (SMART) [4] was recently tested. SMART involves two infiltration phases in series with intermediate re-aeration where the first step removes biodegradable DOC and the subsequent step maintains oxic and carbon-limited conditions where a more specialized biocenosis is established. An infiltration basin was fed with bank filtrate from three production wells located on Baumwerder island to establish quasi-steady state hydraulic conditions by means of six inlets. By percolating the inflowing water via rocks, the bank filtered water was re-aerated prior to infiltration, also resulting in the formation of iron and manganese hydroxides. The subsurface below the basin is characterized by medium grained sand, poor in clay and organic matter content.

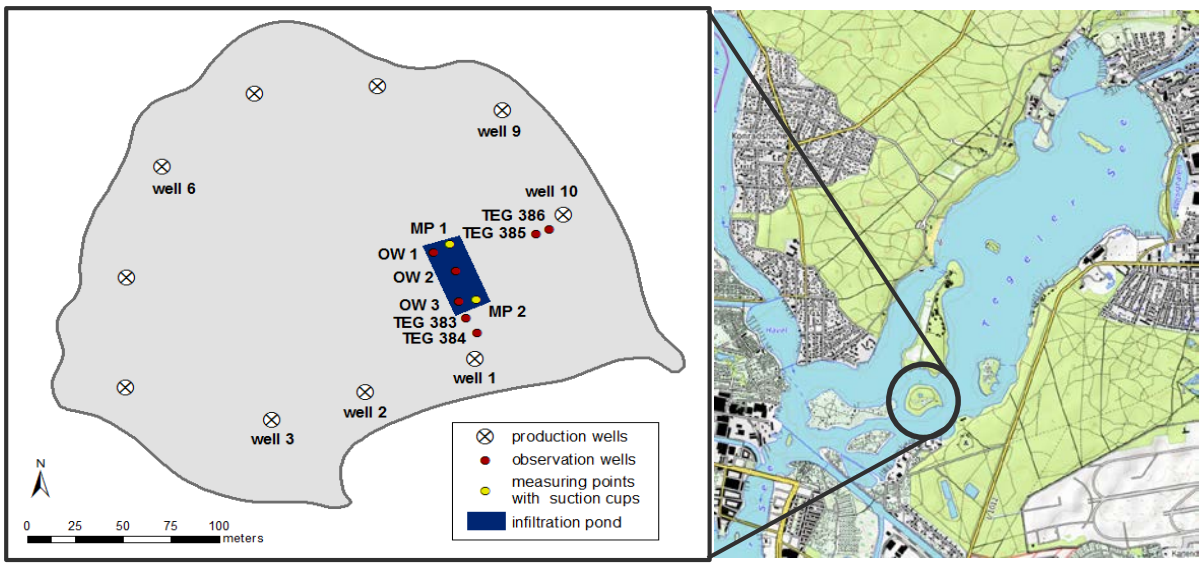


Fig. 1. Left: scheme of the infiltration pond and production wells, observation wells (OW) and suction cups (MP); right: location of the study area [5]

Demonstration-scale SMART operation of the infiltration basin was tested in two phases from March 2016 to January 2017 (Test A) and from July 2018 to February 2019 (Test B). After 11 months of operation and an intensive sampling campaign (OW and MP) in Test A, an intermediate 17-months period of drying and conventional infiltration of untreated surface water (cMAR) followed. Subsequently, Test B included a second sampling campaign (OW) in order to verify results of the first campaign and gain insight into long-term performance of SMART. In order to reduce the input of biodegradable organic carbon into the basin, the vegetation was removed prior to the infiltration phase, but the upper sand layer was removed, which might have led to pools of particulate organic carbon (POC) present in the soil.

Results and Discussion

Infiltration rates during Test A and B are shown in Figure 2. Operation in 2016/17 were relatively stable, but were increased in in May 2016 in order to achieve a higher water level in the basin. In the last 4 months of infiltration, however, infiltration rates steadily decreased probably due to clogging. The infiltration regime was less constant in 2018/19, showing an increase in infiltration rates approximately 2 months after start-up as well as interrupted infiltration in November 2018, where water from the infiltration basin was drained. After re-filling the basin, infiltration remained constant until the end of Test B in February 2019.

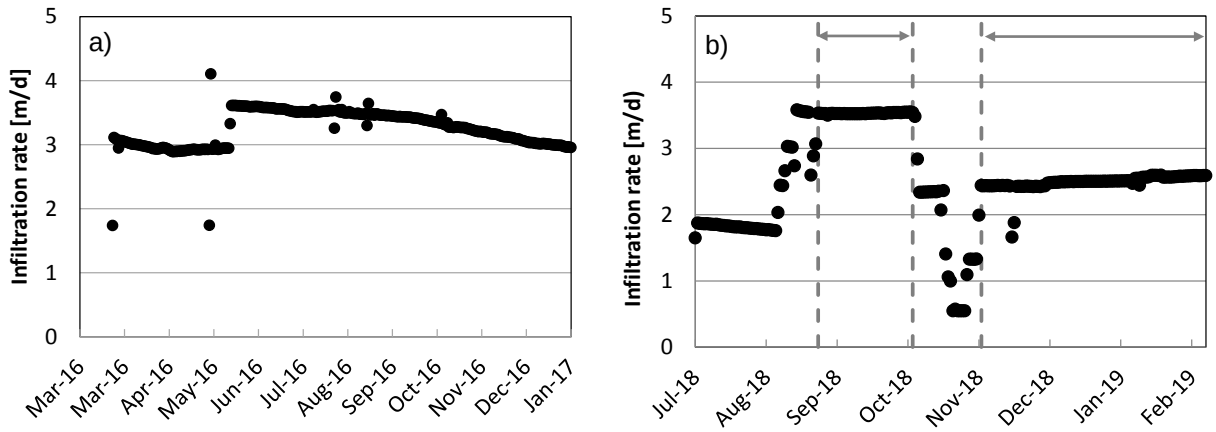


Fig. 2. Infiltration rates during SMART operation from (a) March 2016 – January 2017 [5] and from (b) July 2018 – February 2019. During Test B, Monitoring data were only evaluated for steady-state operation phases marked by dotted lines.

During Test A, mean redox conditions 50 cm below the basin remained oxic, as shown in Figure 3 a). Also, DOC was only very slightly removed from 4.7 mg/L in the

infiltration basin to 4.5 mg/L after 200 cm of infiltration (MP), confirming the refractory character of the DOC in the bank filtrate. Similarly, Figure 3 b) shows DOC and DO concentrations together with UVA_{254} monitored during Test B. Here, mean DO concentrations after 400 cm of infiltration (OW) show high variation, as indicated by the large standard deviation. Also, DOC concentration in the bank filtrate is higher (5.8 mg/L) and is reduced down to a mean value of 5.4 mg/L. Comparison of UVA_{254} values for both demonstration-scale tests seems to indicate that the removal of bulk organics in the first meters of infiltration is higher during Test B.

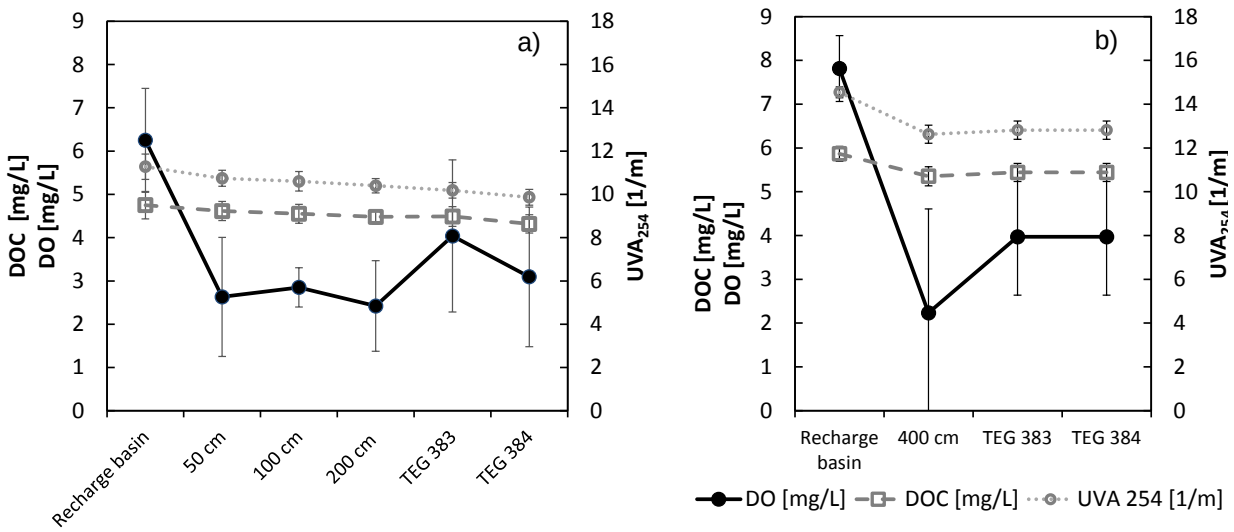


Fig. 3. DOC and DO concentration (left axis) and UVA_{254} (right axis) measured during SMART operation from (a) March 2016 – January 2017 [5] and from (b) July 2018 – February 2019.

Monitoring of TOrCs in the bank filtrate and in the monitoring wells during Test A (2016-17) revealed that gabapentin, acesulfame and benzotriazole present in surface water due to relevant shares of treated wastewater showed better removal using SMART when bank filtrate was used for infiltration in Baumwerder as compared to conventional MAR at the neighboring site Saatwinkel [4]. In this period, an average removal of 58 %, 93 % and 83 % was measured for gabapentin, acesulfame and benzotriazole after 200 cm of infiltration, respectively. This also confirmed earlier lab-scale and field studies showing improved TOrC removal using SMART [3,6].

TOrC concentrations monitored during Test B (2018-19) show only very slight average reduction of 6 %, 13 % and 7 % for gabapentin, acesulfame and benzotriazole after 400 cm of infiltration, respectively (Figure 4). Confirming the

earlier results, carbamazepine and oxypurinol showed persistent behavior, whereas valsartan acid showed 79 % removal after 400 cm of infiltration, as compared to very efficient removal of 97 % after 200 cm of infiltration in Test A.

These results clearly show that TOrC removal performance was significantly lower during the second period of SMART operation at the same field site Baumwerder. Several differences between the two operational phases of SMART might be the reason for these findings. Firstly, enhanced TOrC transformation is linked to stable favorable oxic and carbon-limited conditions at the infiltration site. Compared to the first infiltration period, DO concentrations below the basin are less stable and a higher DOC removal is observed during Test B, indicating a higher share of biodegradable DOC in the feed water. Secondly, total DOC feed water concentrations and UVA_{254} were higher 2018-19. Finally, infiltration rates showed more variations during the second phase, which might have prevented the establishment of a specialized biocenosis for enhanced TOrC removal.

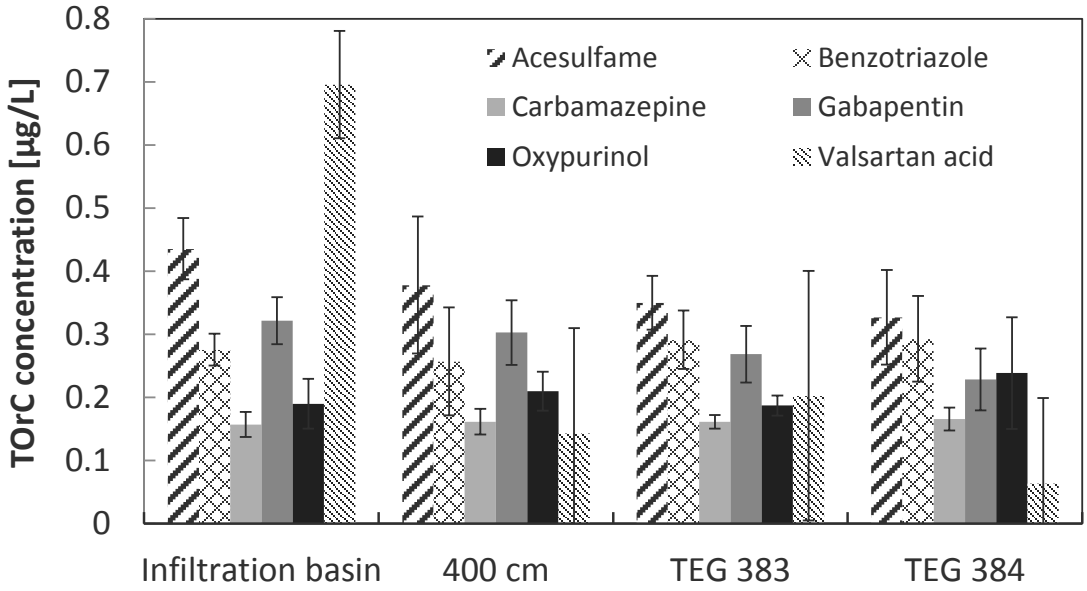


Fig. 4. Average TOrC concentrations measured at Baumwerder demonstration-scale SMART infiltration site during Test B (September 2018 – February 2019); error bars represent standard deviation, n=7.

Conclusions

In conclusion, enhanced TOrC removal by re-aeration and subsequent infiltration of bank filtrate can only be achieved if oxic and carbon-limited conditions can be sustained over the period of infiltration. Changing the influent feed water from surface

water to aerated bank filtrate alone is not necessarily sufficient to improve biodegradation of redox-sensitive TOrCs such as gabapentin, acesulfame and benzotriazole. In addition, stable oxic conditions and low input of dissolved and particulate organic carbon into the infiltration basin need to be carefully controlled. Further research is needed to (1) verify long-term removal rates for specific TOrCs and (2) reliably control redox and carbon-limited conditions, e.g. by suitable pre-treatment as well as in-situ addition of electron acceptors.

References

[1] Gruenheid, S.; Amy, G.; Jekel; M. (2005) Removal of bulk dissolved organic carbon (DOC) and trace organic compounds by bank filtration and artificial recharge. Water Research 39(14), 3219

[2] Heberer, T.; Mechlinski, A.; Fanck, B.; Knappe, A.; Massmann, G.; Pekdeger, A.; Fritz, B. (2004). Field Studies on the Fate and Transport of Pharmaceutical Residues in Bank Filtration. Groundwater Monitoring & Remediation 24, 70

[3] Massmann, G.; Greskowiak, J.; Duennbier, U.; Zuehlke, S.; Knappe, A.; Pekdeger, A. (2006) The impact of variable temperatures on the redox conditions and the behaviour of pharmaceutical residues during artificial recharge. Journal of Hydrology 328, 141– 156.

[4] Regnery, J.; Wing, A.D.; Kautz, J.; Drewes, J.E. (2016). Introducing sequential managed aquifer recharge technology (SMART) - From laboratory to full-scale application. Chemosphere 154, 8-16.

[5] Hellauer, K.; Karakurt, S.; Sperlich, A.; Burke, V.; Massmann, G.; Huebner, U.; Drewes, J.E. (2018). Establishing sequential managed aquifer recharge technology (SMART) for enhanced removal of trace organic chemicals: Experiences from field studies in Berlin, Germany. Journal of Hydrology 563, 1161-1168

[6] Hellauer, K., Mergel, D., Ruhl, A., Filter, J., Huebner, U., Jekel, M., Drewes, J.E. (2018). Advancing sequential managed aquifer recharge technology (SMART) using different intermediate oxidation processes. Water 9 (3), 221.

Groundwater recharge as a key technology for water reuse

Dr.-Ing. Heiko Gerdes, BGS Umweltplanung GmbH, Darmstadt, Deutschland
Martin Ergh, BGS Umweltplanung GmbH, Darmstadt, Deutschland

Groundwater recharge in Germany

For many decades groundwater recharge has been a tried and tested tool of active groundwater management to increase the natural supply of drinking water in Germany. With the construction and operation of plants for the discharge of surface water into the aquifer, the focus was placed very early on the substances that can enter the groundwater with the infiltrated water and - if necessary - require treatment prior to infiltration.

Groundwater recharge in the context of TrinkWave

In the context of the BMBF collaborative project: *„Planungsoptionen und Technologien der Wasserwiederverwendung zur Stützung der Trinkwasserversorgung in urbanen Wasserkreisläufen (TrinkWave)“,* various technology elements are being developed and tested which could become part of new treatment concepts for wastewater and its reuse. The underground passage with different highly reactive zones plays an important part here. An essential technological element is the infiltration organ as an interface between the treatment of the wastewater and the subsequent sequential underground passage for the removal of further substances.

Seepage slits as a technology element

In addition to the groundwater-hydraulic performance, the aspired removal of substances during the underground passage within TrinkWave requires the establishment and control of sequential redox conditions. This can only succeed if the flow through the aquifer is characterized by a clearly defined flow regime in the sense of specified flow paths and residence times. Prerequisite for this are unambiguous hydraulic groundwater boundary conditions. In TrinkWave, infiltration is accomplished by means of slit trench technology, which has been in use for decades with high infiltration volumes in the ‘Ried’, Hesse, Germany, among other places, to increase the usable supply of drinking water. The implementation comprises a pilot plant on a semi-technical scale operated at the Technical University of Munich and

also a demonstration project on a technical scale planned for the ‘Berliner Wasserbetriebe’.

Design features and operating experience

Already in the semi-technical scale of an approximately 6m long channel filled with filter-sand, a test-accompanying analysis of the flow and dispersion processes is carried out by numerical simulations in order to allow the transfer of the hydraulic groundwater parameters for a reproduction of the flow processes to other scale stages. Based on initial operational experience, the detailed planning of a demonstration project for the ‘Berliner Wasserbetriebe’ was carried out. By means of a net groundwater extraction, this demonstration project establishes a groundwater flow which is hydraulically separated from the surrounding aquifer between the seepage slit and the downstream withdrawal well. Numerous groundwater monitoring wells allow the extraction of groundwater for different flow times and distances to the seepage slit.

An essential criterion for the design of the seepage slit is the greatest possible avoidance of ageing in the infiltration organ. In addition to the nature of the infiltrate, the increase in local flow velocities associated with enrichment plays a decisive role.

An assessment of the risk of ageing thus depends both on the quality of the water (infiltration water and existing groundwater) and on the hydraulic characteristics of the installations. Criteria and parameters are being developed for this purpose.

Multidimensional reactive transport model of trace organic compounds in an infiltration pond (Baumwerder Island, Berlin)

Sanz-Prat, Alicia, Carl von Ossietzky University of Oldenburg, Working Group Hydrogeology and Landscape Hydrology, Oldenburg, Germany
Burke, Victoria, Carl von Ossietzky University of Oldenburg, Working Group Hydrogeology and Landscape Hydrology, Oldenburg, Germany
Greskowiak, Janek, Carl von Ossietzky University of Oldenburg, Working Group Hydrogeology and Landscape Hydrology, Oldenburg, Germany
Schröter, Ina, Carl von Ossietzky University of Oldenburg, Working Group Hydrogeology and Landscape Hydrology, Oldenburg, Germany
Rohde, Clara, Carl von Ossietzky University of Oldenburg, Working Group Hydrogeology and Landscape Hydrology, Oldenburg, Germany
Diether, Josephin, Berliner Wasserbetriebe, Berlin, Germany
Frankenstein, Jörn, Berliner Wasserbetriebe, Berlin, Germany
Sperlich, Alexander, Berliner Wasserbetriebe, Berlin, Germany
Massmann, Gudrun, Carl von Ossietzky University of Oldenburg, Working Group Hydrogeology and Landscape Hydrology, Oldenburg, Germany

Managed aquifer recharge is an efficient and low-energetic water pretreatment system to increase drinking water resources and aquifer reservoirs, which helps to overcome the water stress in many regions. This technology relies on the attenuation of undesired compounds through biogeochemical reactions taking place in the subsurface media. There, the behaviour of many trace organic compounds (e.g. pharmaceuticals and personal care products) is subject to high uncertainty, as it strongly depends on scale factors and environmental conditions [1,2]. This study aims to describe the fate and occurrence of the trace organic compounds during the soil passage by re-infiltration of water that had already been undergone a subsurface passage induced by river bank filtration. To achieve that, a multidimensional reactive transport model was established to simulate the performance of an infiltration pond on Baumwerder island in Lake Tegel (Berlin). The basin was temporally fed with bank filtrate to enhance the trace organic compound removal within the framework of a research project [3]. The model allows the evaluation of biodegradation and

sorption as control processes, as well as the estimation of reaction rate constants under natural conditions. In order to gain information on the hydraulic conditions at the site, a tracer test experiment was performed in September 2018 by spreading sodium bromide on the ground of the infiltration pond followed by tracking the bromide considering several observation wells nearby. The lake Tegel is the second largest lake in Berlin and receives water from the Havel river, the Tegeler stream and the Nordgraben stream; the latter transports the outflow from an upstream located wastewater treatment plant (Schönerlinde), which is pre-treated to reduce phosphate concentration before discharge in nature [2]. This contribution (< 30%) is adjusted according to the environmental and drinking water quality standards, since the lake Tegel is a recreational area and it is surrounded by more than 100 production wells. Along the bank shore of Baumwerder island, ten bank filtrate wells also force the circulation of the water from the infiltration ponds. Below the basin ponds, the subsurface is formed by medium grain sand, poor in clay and organic matter. During the tracer experiment (and continuing to the beginning of 2019) three wells are used to feed filtration pond with groundwater. The filling method implies the re-aeration of the anoxic water before infiltration. Seven groundwater monitoring wells below and surrounding the pond were intensively sampled during the tracer test, as well as bi-weekly thereafter for physicochemical parameters, major ions, and trace organic compounds.

References

[1] Greskowiak, J.; Hamann, E.; Burke, V.; Massmann, G. (2017) The uncertainty of biodegradation rate constants of emerging organic compounds in soil and groundwater: A compilation of literature values for 82 substances. Water Research, 126, 122-133.

[2] Massmann, G.; Greskowiak, J.; Dünnbier, U.; Zuehlke, S.; Knappe, A.; Pekdeger, A. (2006) The impact of variable temperatures on the redox conditions and the behaviour of pharmaceutical residues during artificial recharge. Journal of Hydrology, 328, 141-156.

[3] Hellauer, K.; Karakurt, S.; Sperlich, A.; Burke, V.; Massmann, G., Hubner, U.; Drewes, J. (2018) Establishing sequential managed aquifer recharge technology

(SMART) for enhanced removal of trace organic chemicals: Experiences from field studies in Berlin, Germany. Journal of Hydrology, 563, 1161-1168.

Elimination of antibiotic resistant bacteria, viruses and indicator bacteria in sequential bio filtration for purification of WWTP effluent

Johannes Ho, TZW: DVGW-Technologiezentrum Wasser, Karlsruhe, Germany; Uwe Hübner, Technical University of Munich, Garching, Germany; Jessica Bühler, TZW: DVGW-Technologiezentrum Wasser, Karlsruhe, Germany; Jörg E. Drewes, Technical University of Munich, Garching, Germany; Andreas Tiehm, TZW: DVGW-Technologiezentrum Wasser, Karlsruhe, Germany

In regions with limited water resources, groundwater recharge through potable water reuse is a conceivable alternative to maintain or improve water supply and safety of the local population. However, a wide range of pathogenic bacteria and viruses as well as trace organic chemicals can be present in the final effluent of wastewater treatment plants. Biologically active filtration and managed aquifer recharge can provide simple and low-cost methods for advanced water treatment. Many compounds are preferably removed by immobilized bacteria in the filter under oxic conditions. However, as fast oxygen depletion leads to anoxic conditions in deeper parts of the filters, a sequential approach combining two infiltration systems with an intermediate aeration (sequential managed aquifer recharge technology, SMART) has previously been developed to enhance removal of trace organic chemicals. In this study, intermediate aeration with hydrogen peroxide and oxidation with ozone was tested in two parallel column systems. A wide range of parameters was measured to show the effect of prolonged oxic passage focusing on the removal of antibiotic resistant bacteria and genes, viruses and indicator bacteria.

Material and methods

Four columns with 880 mm length and 100 mm diameter were filled with silica sand and operated as two parallel systems with two columns in series. Both systems were fed with effluent of a municipal waste water treatment plant at a flow rate of 16 L/d. After 8 weeks of maturation, oxygen/ozone and hydrogen peroxide were introduced into the influent of the second columns. Influents and effluents of all columns were collected weekly. In addition to the general sampling program, phages were spiked in high numbers in the inflow to simulate a challenge event with a high virus load and samples were collected every hour over a day. Somatic and f-specific coliphages were analyzed by plaque assay, for viruses (HAdV, EV, NV and PMMoV) qPCR was applied, *E. coli*, Coliforms and enterococci were measured by IDEEX culture assay

and antibiotic resistant bacteria were quantified by agar plates with identification via MALDI-TOF-MS. Antibiotic resistance genes (sul1, intl1, TEM) were measured by qPCR as well as total and intact cell count by flowcytometry. Trace organic chemicals were quantified by HPLC-MS/MS.

Results

In the initial phase without adding oxygen, major elimination occurred in the first column (oxic) of each column set. The average reduction of *E. coli*, enterococci, somatic and f-specific coliphages and antibiotic resistant bacteria (ESBL) was between 1.2 and 1.8 log. Antibiotic resistance genes were not removed. Human pathogen virus removal was about 0.5 log, but could not be determined exactly due to a very low virus concentration in the inflow. Establishment of intermediate aeration in the next phase enhanced the reduction of all parameters in the second column. In addition, direct removal by ozone and hydrogen peroxide could be detected. The effluent of the 2nd column contained a very low number of *E. coli*, enterococci and bacteriophages resulting in an average 3.5 log reduction. Antibiotic resistant bacteria could not be detected in the effluent. The reduction of antibiotic resistance genes was increased from nearly no reduction in the first phase to an average of 1.4 log.

Conclusion

While the efficiency of intermediate aeration to increase removal of trace organic chemicals in a second infiltration system has been demonstrated before, presented results show that the reconstitution of extended oxic conditions can also improve removal efficiency of bacteria, viruses, antibiotic resistance genes and antibiotic resistant bacteria. Though, not all drinking water quality parameter could be met directly, the effluent after this sequential treatment provides a raw water quality that demands less complex treatment for subsequent drinking water generation. Additionally, the columns showed capacity to buffer peaks of high virus or bacterial loads by environmental events like storms or heavy rainfall. It can be assumed, that the removal of pathogens could be increased further with column age or by dosing increased concentrations of hydrogen peroxide or oxygen/ozone, possibly resulting in a complete elimination of bacteria and viruses – opening a wide range of reuse possibilities.

Acknowledgement

Financial support by the German Ministry of Education and Research gratefully acknowledged (TrinkWave project, WavE res. priority, BMBF grant 02WAV1404).

Enhancing the removal of trace organic contaminants in an ozone-biofiltration process for advanced water treatment and managed aquifer recharge

Ramola Vaidya (presenting author), Virginia Tech, Blacksburg, VA, USA; Germano Salazar-Benites, HRSD, Virginia Beach, VA, USA; Chris Wilson, HRSD, Virginia Beach, VA, USA; Charles Bott, HRSD, Virginia Beach, VA, USA
ramolav@vt.edu Presenting author

Abstract

An ozone-biofiltration pilot was used for advanced water treatment as part of HRSD's SWIFT initiative. The secondary effluent from a wastewater treatment plant was treated with advanced water treatment techniques such as coagulation/flocculation and sedimentation, ozone, biofiltration and activated carbon adsorption and final UV disinfection before injecting in the aquifer. The removal of trace contaminants was monitored as part of the project. NDMA removal as high as 74% was achieved in the biofilters alone and the effluent concentrations were below the California health advisory limit of 10 ng/L. Iohexal, acesulfame-K and sucralose were consistently detected in the final effluent and the concentrations increased with increasing bed volumes in the granular activated carbon adsorption column. Ozone removed 30% of 1,4-dioxane to an effluent concentration below the health advisory levels. Future research will look into removal of 1,4-dioxane in the biofilters by co-substrate metabolism.

Keywords: Biofiltration; Ozone; Trace Organic Contaminants

Introduction

The increasing use of pharmaceuticals and personal care products has led to the concern of these compounds entering wastewater and ending up in the water bodies, thus potentially affecting the public health and the environment. These compounds are not always removed in conventional activated sludge and might need advanced treatment techniques such as ozone-biofiltration and activated carbon adsorption (Knopp *et al*., 2016). Most of these compounds are present at very low concentrations,

on the order of micro or nanograms per liter, but have been shown to have estrogenic activity and can be endocrine distruptors (Bolong *et al*., 2009).

The goal of the study was to optimize the removal of trace organic contaminants in the ozone biofiltration process and to improve their removal in the BAC by addition of co-substrates to promote cometabolic degradation. 1,4 dioxane was used as a model compound for this purpose. 1,4 dioxane is commonly used as a solvent stabilizer for 1,1,1 trichloroethane and has a low partition coefficient and hence is poorly removed by conventional air stripping techniques. Certain bacteria such as *Rhodococcus*, *Pseudonocardia* and *Mycobacterium* have shown to biodegrade 1,4 dioxane using co-substrates such as propane, isobutane and tetrahydrofuran (Vainberg *et al*. 2006; Mahendra *et al*. 2007) . The removal pharmaceuticals and disinfection byproducts such as NDMA was also explored.

Material and Methods

An ozone biofiltration pilot was set up at HSRD as a part of the Sustainable Water Initiative For Tomorrow (SWIFT). The secondary effluent from a biological nutrient removal plant was treated with coagulation/flocculation/sedimentation, followed by ozone and biological activated carbon (BAC) filtration and granular activated carbon (GAC) adsorption. BAC and GAC columns were operated at two different empty bed contact times (EBCT). Two BAC columns were operated in parallel with EBCT of 5 and 10 minutes, while two GAC columns were operated in parallel at an EBCT of 10 and 20 minutes. Monochloramine was used upstream of ozone to inhibit bromate formation, and was quenched ahead of BAC using sodium bisulfite. Samples were collected for a period of two years for total organic carbon (TOC), NDMA and 1,4 dioxane. In addition, 24 sampling events were conducted to analyze for a suite of 96 trace contaminants including pharmaceuticals and industrial solvents.

Results and Discussion

The results showed that NDMA was formed by ozone and depended on the ozone dose. The BAC with 10 min EBCT was better at NDMA removal with an average removal of 74% as compared to 58% removal for the BAC with 5 min EBCT. Further,

the removal of NDMA in the BAC was highly dependent on the monochloramine residual post ozone and quenching by sodium bisulfite. A residual monochloramine of 3 mg/L to the BAC resulted in NDMA concentrations above the California, US health advisory limit of 10 ng/L in the BAC effluent. This NDMA removal was also affected by colder temperatures below 15°C during winter. However, the GAC was able to remove NDMA below the 10 ng/L limit, with the 20 min EBCT GAC removing an average of 58% as compared to 22% removal in the 10 min EBCT.

Out of the 96 trace contaminants only three compounds were consistently detected in both in the GAC columns, namely iohexal, acesulfame-K and sucralose. It was interesting to see that the concentration of these compounds was well correlated to the bulk TOC concentration. Thus these compounds can be used as indicators for other trace organics and for determining the carbon regeneration in GAC which is a cost intensive process. The removal of these compounds was also a function of the ozone dose, temperature and EBCT in the BAC and the number of bed volumes in GAC. All the trace contaminants except for NDMA were still below the health advisory limits in the GAC effluent.

Ozone was able to remove an average of 30% of 1,4 dioxane, while still meeting the bromate limit of 0.01 mg/L. To enhance this removal by biodegradation, future work will focus on addition of tetrahydrofuran in the biofilters to promote cometabolic degradation. Apart from tetrahydrofuran other co-substrates such as propane, isobutane will be explored.

Conclusions

The conclusions from this study are as follows:

- NDMA was primarily formed by ozone and was removed by biofiltration. The removal of NDMA was a function of EBCT, temperature and presence of monochloramine residual post ozonation and quenching by sodium bisulfite.
- Iohexal, acesulfame-K and sucralose were the prominent trace contaminants that were detected in GAC consistently. These can be used as indicators for treatment performance.

- 1,4-dioxane was mostly removed by ozone to concentrations below the health advisory limit. Future research will be focused on further optimization of 1,4-dioxane removal by co-substrate metabolism in the biofilters.

This study will improve the understanding of removal of trace contaminants in an ozone-biofiltration process used for advanced water treatment. It will also implement the use of a novel technique for enhancing the removal of 1,4 dioxane by cometabolic degradation.

References

Bolong, N., Ismail, A. F., Salim, M. R., Matsuura, T. (2009) A review of the effects of emerging contaminants in wastewater and options for their removal. Desalination, 239, 229-246.

Knopp, G., Prasse, C., Ternes, T. A., Cornel, P. (2016) Elimination of micropollutants and transformation products from a wastewater treatment plant effluent through pilot scale ozonation followed by various activated carbon and biological filters. Water Research, 100, 580-592.

Mahendra, S., Petzold, C. J., Baidoo, E. E., Keasling, J. D., Alvarez-Cohen, L. (2007) Identification of the intermediates of in vivo oxidation of 1,4-Dioxane by monooxygenase-containing bacteria. Environmental Science and Technology 41, 7330-7336.

Vainberg, S., McClay, K., Masuda, H., Root, D., Condee, C., Zylstra, G. J., Steffan, R. J. (2006) Biodegradation of Ether Pollutants by Pseudonocardia sp. Strain ENV478. Applied and Environmental Microbiology 72 (8) 5218-5224.

UV/H_2O_2 as Pre-Treatment before Managed Aquifer Recharge in Drinking Water Production – Impact on Bulk Water Parameters and Micropollutant Abatement

Robin Wünsch[1,2], Julia Plattner[3], Fabienne Eugster[3], David Cayon[1], Nadja Rastetter[1], Rita Hochstrat[1], Jens Gebhardt[4], Pascal Temmler[3], Richard Wülser[3], Urs von Gunten[2,5], Thomas Wintgens[1]

[1] FHNW University of Applied Sciences and Arts Northwestern Switzerland, School of Life Sciences, Gründenstrasse 40, 4132 Muttenz, Switzerland
[2] School of Architecture, Civil and Environmental Engineering (ENAC), Ecole Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland
[3] IWB (Industrielle Werke Basel), Margarethenstrasse 40, 4002 Basel, Switzerland
[4] Xylem Services GmbH, Boschstraße 4, 32051 Herford, Germany
[5] Eawag, Swiss Federal Institute of Aquatic Science and Technology, Überlandstrasse 133, 8600 Dübendorf, Switzerland

Abstract

Organic micropollutants such as pharmaceuticals, pesticides, etc. are present in drinking water resources, e.g., river waters or groundwaters. These compounds are generally unwanted in the finished product; hence have to be abated during the production process. One option for their abatement is the *in situ* production of $^{\bullet}OH$ radicals via H_2O_2 dosage and subsequent UV-C irradiation (UV/H_2O_2). However, $^{\bullet}OH$ radicals are relatively non-selective and also react with the organic background matrix, thereby producing biodegradable organic matter. Therefore, the water needs to be re-stabilized before its distribution to avoid microbial regrowth in the distribution system. One cost-efficient option for this treatment might be the use of a natural treatment step, e.g., managed aquifer recharge (MAR).

Within this study, MAR was simulated by column tests on a pilot plant, which was continuously operated for 18 months. Two MAR columns were operated in parallel with empty bed contact times of 24h, one receiving pre-filtered water from the river Rhine, the other pre-filtered water after UV/H_2O_2 treatment (4 mg H_2O_2/L, 6000 J/m^2). Treatment effects on bulk organic parameters (e.g., dissolved organic matter -

DOC, specific UV absorption at 254 nm - SUVA), micropollutant abatement, as well as biological parameters (e.g., bacterial ATP in aqueous phase) were investigated.
It was demonstrated that the DOC removal was comparable at both MAR column effluents, while the SUVA removal was higher in the UV/H_2O_2 – MAR system. The addition treatment effects from UV/H_2O_2 and MAR could explain the latter observation. Most observed micropollutants were well abated by the UV/H_2O_2 process, e.g., benzotriazole or iopromide. Others showed good removal by MAR, like metformin. For most substances, no synergistic abatement, but an addition of treatment effects of UV/H_2O_2 and MAR was measured, which resulted in higher total abatement in the UV/H_2O_2 – MAR system. As the applied UV dose was 15-20 times higher than commonly used for drinking water disinfection, an added benefit of the UV/H_2O_2 process is an excellent disinfection, showing no bacterial activity by means of bacterial ATP. The bacterial activity in the aqueous phase remained lower along the whole MAR column compared to the column receiving the filtered water without UV/H_2O_2 treatment. Overall, a higher abatement of undesired micropollutants can be expected for the combined UV/H_2O_2 - MAR process than for both processes alone and no principal stumbling block was found in this study for this process combination.

Acknowledgement

This study was conducted within the AquaNES project, which received funding from the European Union's Horizon 2020 research and innovation program (grant agreement no. 689450).

The removal of emerging organic contaminants in managed aquifer recharge schemes to ensure a safe, sustainable and high quality water resource.

Peter J. Reeve presenting author; Ilka Wallis, John Hutson, Howard J. Fallowfield,
College of Science and Engineering, Flinders University, Adelaide, Australia

Abstract:

Water reuse via managed aquifer recharge (MAR) has significant potential to lessen the worst effects of increasing global water scarcity. MAR often involves the injection of nutrient-rich waters into nutrient-starved groundwater environments, increasing the system's microbial activity and causing biofilm to form on the aquifer's surfaces. Too much biofilm growth can clog the aquifer – a known and well researched operational issue. Emerging organic contaminants (EOCs) are becoming globally ubiquitous. This paper contends biofilm in MAR has significant potential to affect appropriate conditions for the natural bioattenuation of EOCs within managed groundwater environments – assisting mitigation of the real and perceived public and environmental risks of EOCs and warranting further research.

Introduction

As urban development increases, so too does stormwater runoff and wastewater discharge. With water scarcity becoming a significant concern in numerous locations globally, strategies to capture and reuse these under-utilised waters are of great interest. In space-limited urban environments, additional above-ground storage is often not possible. Managed Aquifer Recharge (MAR) has the potential to overcome this issue by artificially redirecting surplus water into underground aquifers for later use.

As wastewater and stormwater discharges are increasing globally, so too are the discharges of emerging organic contaminants (EOCs), such as pesticides, pharmaceuticals, surfactants and endocrine disruptors, into the environment (aus der Beek *et al.* 2016). Indeed, wastewater, coupled with industry, agriculture and healthcare are recognised as the major emission pathways for EOCs into the

environment (aus der Beek *et al.* 2016). Concerns regarding the presence of these chemicals tend to relate to potential ecotoxicological effects, as well as real or perceived risks to human health from the use of recovered water (Pal *et al.* 2010).

It is generally recognised that the aquifer can provide a degree of treatment (Bekele *et al.* 2018). At a minimum, this treatment may take place through dilution while mixing with native groundwater, but may also include various forms of sorption and biodegradation (Regnery *et al.* 2017). When considering the ability of an aquifer to remove organic contaminants, sorption and degradation are generally regarded as the most important treatment components (Regnery *et al.* 2017). It is common for laboratory methodologies, such as batch and column studies, to be employed to better understand how EOCs interact with the aquifer when recharged as part of MAR (Regnery *et al.* 2017).

Organic carbon and nutrient-rich waters are often routinely injected into groundwater environments at concentrations higher than those typically encountered in such systems. This injection can promote the formation of biofilm within the aquifer (Li *et al.* 2013). Numerous studies e.g., Page *et al.* (2014), Pavelic *et al.* (2011) and Thompson *et al.* (2015), have investigated the processes which lead to the clogging of aquifer materials during artificial recharge.

Despite the clear and well investigated impacts that biofilm can have on the viability of MAR schemes, comparatively scant attention has been paid to the role of biofilm in the attenuation of EOCs in managed aquifers.

Biofilms are fundamental to many water treatment processes. Biofilm dependent processes include slow sand and trickling filters, membrane reactors and aerobic and anaerobic fixed beds. In such processes, the immobilised microbial biomass in biofilm is responsible for the bulk of treatment (Pandit *et al.* 2018; van den Akker *et al.* 2011).

In spite of the common usage of biofilm in water treatment processes, the potential of biofilm in managed aquifers to naturally bioattenuate EOCs has been understudied. It is argued, via a brief review of relevant literature, that natural bioattenuation in MAR schemes could assist in mitigating the real and perceived risks posed by EOCs and warrants further research.

Biofilm and bioattenuation: Important processes for EOC attenuation in MAR?

It is widely recognised that natural biological processes are often key to organic contaminant removal in water environments, either directly through biodegradation (Petrie *et al.* 2015) or indirectly, by facilitating the establishment of suitable conditions for chemical degradation or adsorption to mineral substrates, for example by stimulating biological oxygen consumption (Dolfing *et al.* 2007; USEPA 2013). Herein, this conglomeration of natural treatment pathways are referred to as bioattenuation.

Biofilm represents a diverse microflora, which is often highly heterogeneous. The bacteria present in biofilms are more readily able to adapt to environmental change than the same bacteria in a non-sessile state and can indeed be more resistant to biocidal chemicals (Bricheux *et al.* 2013). This combination of characteristics means that biofilms have the potential to host a diverse, resilient and adaptable microflora, which has great potential to aid in the bioattenuation of pollutants from water.

In a number of MAR-typical situations, and during groundwater transport more generally, biodegradation has been shown to be the dominant factor controlling the transport of trace organic contaminants. For instance, Alidina *et al.* (2014) investigated the role of primary substrate composition and concentration on the attenuation of trace organic contaminants in a laboratory simulated MAR environment. Four sets of columns received varying ratios of the primary substrates peptone-yeast and humic acid. It was found that the composition of the primary substrate had a greater influence on the attenuation of the investigated compounds than concentration; more refractory carbon, in the form of humic acid, resulted in a greater attenuation of moderately degradable trace organic contaminants. The attenuation of both easily degradable and recalcitrant organics was unaffected by the primary substrate composition and concentration. These findings suggest different families of enzymes could be responsible for the degradation of different organic contaminants. Concurrently collected microbial data showed that greater refractory carbon resulted in a more diverse microbial community.

Onesios and Bouwer (2012) investigated the utility of biofilm-based removal of pharmaceutical and personal care products. Here, aerobic glass laboratory columns (2.5 x 30 cm), filled with 30-40 mesh sand were inoculated with wastewater treatment

plant effluent to stimulate biofilm growth and simulate conditions found in soil aquifer treatment-style MAR sites as well as slow sand filters. The effect of varying concentrations of acetate, included to act as an easily degradable substrate, was investigated. It was found that 10 of the 14 compounds were removed by at least 95% under all experimental conditions. The removal of three of the compounds was found to be dependent on acetate concentration, while three compounds showed no discernible removal pattern.

Kim and Corapcioglu (1997) investigated the effect of biofilm growth on bacteria-facilitated transport of contaminants in porous media. By developing a numerical model, which considered contaminant adhesion to biofilm and the role of such adhesion in the mobility of contaminants, it was found that the adsorption of contaminants to bacterial surfaces markedly reduced the mobility of contaminants in the presence of biofilm. They concluded that the injection of bacteria into subsurface environments could contribute substantially to the bioremediation of hydrophobic contaminants, irrespective of native microbial populations. Importantly, it was found that the substantial biofilm growth proximal to injection points hindered, rather than contributed to, the transport of contaminants, in spite of the increased rates of biofilm detachment in these zones.

Reflection and conclusion

Managed groundwater systems straddle the often-complex interface between engineered and natural environments. While the receiving aquifer of a MAR scheme is anthropogenically altered from the time it receives the first injection of water, processes considered ‘natural’ are likely to continue and be enhanced in the system’s new state of equilibrium. The presence of biofilm is widely recognised in managed groundwater environments. In the contexts of water treatment and remediation, biofilm forms an accepted backbone of many treatment processes. The authors contend that bioattenuation in managed groundwater environments, driven in part by attached growth in the form of biofilm, could be an integral and under-recognised component of natural treatment in these systems. Further research, framed in the context of bioattenuation, could be key to ensuring the continued and critical role of MAR in shoring increasingly scarce water supplies globally, while

simultaneously protecting human health and the environment from the real and perceived risks associated with EOCs.

References

Alidina, M, Li, D, Ouf, M & Drewes, JE 2014, 'Role of primary substrate composition and concentration on attenuation of trace organic chemicals in managed aquifer recharge systems', *Journal of Environmental Management*, vol. 144, pp. 58-66.

aus der Beek, T, Weber, F-A, Bergmann, A, Hickmann, S, Ebert, I, Hein, A & Küster, A 2016, 'Pharmaceuticals in the environment—Global occurrences and perspectives', *Environ Toxicol Chem*, vol. 35, no. 4, pp. 823-35.

Bekele, E, Page, D, Vanderzalm, J, Kaksonen, A & Gonzalez, D 2018, 'Water Recycling via Aquifers for Sustainable Urban Water Quality Management: Current Status, Challenges and Opportunities', *Water*, vol. 10, no. 4, p. 457.

Bricheux, G, Le Moal, G, Hennequin, C, Coffe, G, Donnadieu, F, Portelli, C, Bohatier, J & Forestier, C 2013, 'Characterization and evolution of natural aquatic biofilm communities exposed *in vitro* to herbicides', *Ecotoxicology and Environmental Safety*, vol. 88, pp. 126-34.

Dolfing, J, Eekert, Mv, Seech, A, Vogan, J & Mueller, J 2007, '*In Situ* Chemical Reduction (ISCR) Technologies: Significance of Low Eh Reactions', *Soil and Sediment Contamination: An International Journal*, vol. 17, no. 1, pp. 63-74.

Kim, S & Corapcioglu, MY 1997, 'The Role of Biofilm Growth in Bacteria-Facilitated Contaminant Transport in Porous Media', *Transport in Porous Media*, vol. 26, no. 2, pp. 161-81.

Li, D, Alidina, M, Ouf, M, Sharp, JO, Saikaly, P & Drewes, JE 2013, 'Microbial community evolution during simulated managed aquifer recharge in response to different biodegradable dissolved organic carbon (BDOC) concentrations', *Water Research*, vol. 47, no. 7, pp. 2421-30.

Onesios, KM & Bouwer, EJ 2012, 'Biological removal of pharmaceuticals and personal care products during laboratory soil aquifer treatment simulation with

different primary substrate concentrations', *Water Research*, vol. 46, no. 7, pp. 2365-75.

Page, D, Vanderzalm, J, Miotliński, K, Barry, K, Dillon, P, Lawrie, K & Brodie, RS 2014, 'Determining treatment requirements for turbid river water to avoid clogging of aquifer storage and recovery wells in siliceous alluvium', *Water Research*, vol. 66, pp. 99-110.

Pal, A, Gin, KY-H, Lin, AY-C & Reinhard, M 2010, 'Impacts of emerging organic contaminants on freshwater resources: Review of recent occurrences, sources, fate and effects', *Sci Total Environ*, vol. 408, no. 24, pp. 6062-9.

Pandit, S, Sarode, S & Chandrasekhar, K 2018, 'Fundamentals of Bacterial Biofilm: Present State of Art', in VC Kalia (ed.), *Quorum Sensing and its Biotechnological Applications*, Springer Singapore, Singapore, pp. 43-60.

Pavelic, P, Dillon, PJ, Mucha, M, Nakai, T, Barry, KE & Bestland, E 2011, 'Laboratory assessment of factors affecting soil clogging of soil aquifer treatment systems', *Water Research*, vol. 45, no. 10, pp. 3153-63.

Petrie, B, Barden, R & Kasprzyk-Hordern, B 2015, 'A review on emerging contaminants in wastewaters and the environment: Current knowledge, understudied areas and recommendations for future monitoring', *Water Res*, vol. 72, pp. 3-27.

Regnery, J, Gerba, CP, Dickenson, ERV & Drewes, JE 2017, 'The importance of key attenuation factors for microbial and chemical contaminants during managed aquifer recharge: A review', *Critical Reviews in Environmental Science and Technology*, vol. 47, no. 15, pp. 1409-52.

Thompson, AR, Stotler, RL, Macpherson, GL & Liu, G 2015, 'Laboratory Study of Low-Flow Rates on Clogging Processes for Application to Small-Diameter Injection Wells', *Water Resources Management*, vol. 29, no. 14, pp. 5171-84.

USEPA, United States Environmental Protection Agency 2013, *Introduction to In Situ Bioremediation of Groundwater*.

van den Akker, B, Holmes, M, Pearce, P, Cromar, NJ & Fallowfield, HJ 2011, 'Structure of nitrifying biofilms in a high-rate trickling filter designed for potable water pre-treatment', *Water Research*, vol. 45, no. 11, pp. 3489-98.

Managing the urban water cycle in Berlin: Implementing barriers for trace organic compounds (TOrCs) and antibiotic resistant bacteria (ARB)

R. Gnirss[1, 3,] A. Sperlich[1], D. Sauter[1], M. Jekel[2,3], C. Stange[4]

[1]Berliner Wasserbetriebe, Neue Jüdenstr. 1, 10179 Berlin, Germany

[2]Technische Universität Berlin[3,] Kompetenzzentrum Wasser Berlin gGmbH

[4]DVGW-Technologiezentrum Wasser Karlsruhe

Keywords: Trace organic compounds, antibiotic resistant bacteria, advanced wastewater treatment, urban water cycle, managed aquifer recharge

Introduction

Antibiotic resistance has become a worldwide problem. The global spread of antibiotic resistant bacteria (ARB) and antibiotic resistance genes (ARGs), as well as the acquisition of resistance genes by clinically relevant bacteria, are associated with increasing hospitalization and mortality rates of patients infected with such organisms [WHO (2014)]. Wastewater treatment plants (WWTPs) receiving sewage from various sources, including hospitals and households have been recognized as one of the most important routes for propagation of antibiotic resistance from humans to environments [Berendonk et al., (2015)]. The presence of ARB and ARGs in the effluent of WWTPs has been reported in a number of international studies [Rizzo et al. (2013); Rodriguez-Mozaz et al. (2015), Hembach et al., (2017)]. Conventional wastewater treatment processes do not completely remove trace organic compounds (TOrCs) and bacteria including ARB. As a consequence ARB, ARGs and some TOrCs are released to the receiving surface waters.

Berlin with 3.7 Mio inhabitants and an area of 900 km² is situated in the glacial valley of Berlin-Warsaw with a flat topography and unconsolidated glacial and fluvio-glacial sediments. However, groundwater availability as traditional source of potable water is limited because average precipitation is less than 570 mm/a. For this reason the water supply has been designed to be replenished by surface water through managed aquifer recharge (MAR) via infiltration ponds for more than 150 years. Due to low natural flow in its rivers, treated wastewater contributes significantly to the overall flow, thus generating a partially closed water cycle. Subsurface passage represents the main barrier towards pathogens for drinking water production. Crucial

factors for the functioning of this barrier towards pathogens are source water protection, sufficient travel times, a fine and homogeneous aquifer matrix and low flow velocities. The wells are designed to meet the criteria of 50 days minimum travel time [DVGW (1995)].

Long-term investigations in the catchment area of Lake Tegel have shown that MAR is an efficient barrier in the partly closed urban water cycle [Gruenheid et al. (2005); Heberer et al. (2004)]. Additional barriers to environmentally relevant chemicals and bacteria are an integral part of the protection of aquatic ecosystems and drinking water resources, particularly as drug concentrations might increase due to climate change and demographic trends [Jekel et al. (2016)]. In order to mitigate human health risks and following the precautionary principle of the German drinking water regulation, the implementation of additional advanced wastewater treatment steps such as powdered activated carbon (PAC) adsorption and ozonation, as well as optimization of the MAR schemes employed in Berlin are planned. The Berliner Wasserbetriebe, responsible for drinking water supply and wastewater discharge in Berlin, has invested considerable efforts in upgrading urban water cycle. Thus, the Berlin case can be seen as a demonstration site for indirect potable water re-use with long term experience from which other regions worldwide can profit.

Materials and Methods

The catchment area of Lake Tegel (Berlin) is shown in figure 1. WWTP Schönerlinde employs the conventional activated sludge process with nutrient removal (N/P removal) and secondary sedimentation. Treating both, effluent from WWTP Schönerlinde and surface water, a surface water treatment plant (OWA Tegel) with tertiary coagulation/filtration was installed in order to prevent eutrophication. For coagulation, on average 8 g/m³ of ferric chloride were dosed load proportionally into the filter inlet. In 2017, PAC dosing of about 20 mg/L was introduced as additional treatment step in the OWA Tegel. The filtration rate was constant at 7.5 m/h. The share of treated wastewater in the surface water of Lake Tegel is about 17%. Waterworks (WW) Tegel operate approximately 200 wells, situated along the banks of Lake Tegel. WW process includes aeration and subsequent rapid sand filtration, no further treatment is required to meet the German drinking water regulation.

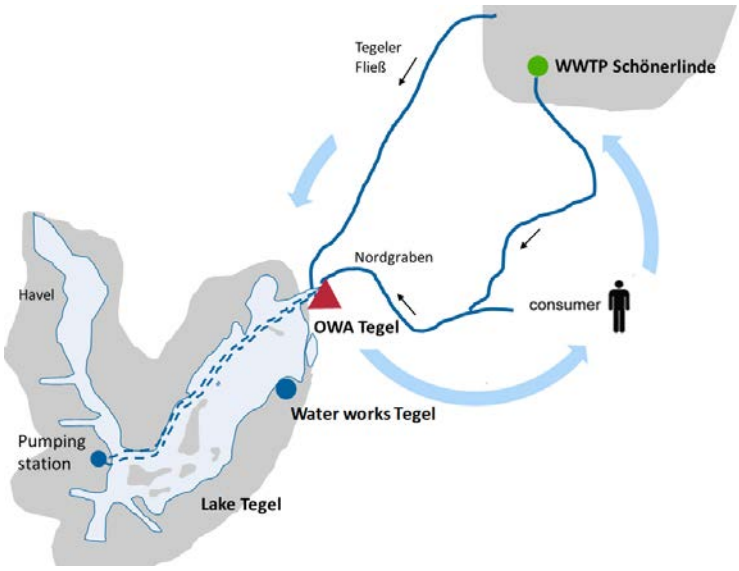


Figure 1: Urban water cycle around Lake Tegel in Berlin (Catchment Area)

Results

The high quality of the WWTP effluent is reflected in low average concentrations for dissolved organic carbon (DOC), total suspended solids (TSS), total inorganic nitrogen (TN) and total phosphorus (TP) with 11.6 mgDOC/L, 6 mgTSS/L, 13 mgTN/L, 0.5 mgTP/L, respectively. For selected TOrCs, dose-response relationships for the adsorption on activated carbon and the reaction with ozone were determined and confirmed in pilot plant operation [Altmann et al. (2015)]. Since PAC dosing was started, OWA effluent concentrations below 6.6 mgDOC/L, 1 mgTSS/L and 0.05 mgTP/L have been achieved.

Typical concentration ranges of selected TOrCs at different stages of the Tegel water cycle are given in Table 1. In technical processes TOrC removal is substance specific and varies between 50-80% for carbamazepine, and benzotriazole, but only 30-50% for valsartan acid and gabapentin (Table 1). Coupling natural and technical processes ensures removal above 95-99% for relevant TOrC. Results show that a wide range of TOrC are attenuated in the subsurface by biodegradation and/or adsorption as reported in Gruenheid et al. (2005), Grützmacher et al. (2007) and Massmann et al. (2008). Travel times as high as 3 months or several decades have been measured [Massmann et al. 2008]. These long travel times in the subsurface and mixing with ambient groundwater in the production wells enables the system to buffer quality fluctuations, e.g. TOrC concentration. On the other hand, after

advanced treatment was installed, lower concentrations were not immediately measured in drinking water (e.g. gabapentin).

Table 1. Concentrations of selected TOrC at different stages of the Berlin water cycle. Average values 2017-2018 and standard deviation.

Location	Benzotriazole (µg/L)	Valsartan acid (µg/L)	Gabapentin (µg/L)	Carbamazepine (µg/L)	Diclofenac (µg/L)
Effluent WWTPs	12.71 ± 4.09	9.25 ± 3.06	1.72 ± 0.93	1.96 ± 1.50	3.91 ± 1.9
Influent OWA	2.19 ± 1.8	2.15 ± 1.9	0.35 ± 0.3	1.96 ± 1.50	0.53 ± 0.6
Effluent OWA	1.15 ± 1.17	1.91 ± 1.62	0.35 ± 0.28	0.20 ± 0.22	0.35 ± 0.36
Surface water Lake Tegel	0.57 ± 0.16	1.15 ± 0.35	0.19 ± 0.05	0.11 ± 0.03	0.05 ± 0.05
Drinking water	0.27 ± 0.04	0.72 ± 0.13	0.38 ± 0.08	0.13 ± 0.03	0.01 ± 0.01

E. coli Extented spectrum β-lactamase (ESBL)-producing *E. coli* and vancomycin resistant enterococci (VRE) were quantified using cultivation on selective agar plates.

Table 2. Concentrations of *E. coli* and selected antibiotic resistant bacteria at different stages of the Berlin water cycle.

Location	n	*E. coli* (MPN/100 mL)		ESBL *E. coli* (CFU/100 mL)		VRE (CFU/100 mL)	
		mean value	concentration range	mean value	concentration range	mean value	concentration range
Effluent WWTP	10	14,022.2	1,480-23,820	383.2	80-700	305.0	20-700
Effluent ozonation*	10	90.4	15-219	5.0	0-16	1.2	0-7
Effluent fast filtration*	38	25.4	1-291	0.8	0-6	0.1	0-1
Influent OWA	7	373.2	0-1,125	19.3	1-60	1.4	0-10
Effluent OWA	7	30.9	1-68	2.3	0-12	0.4	0-3
Bank filtrate**	1	not detected		not detected		not detected	

* pilot plant operated with ozonation and fast filtration effluent; ** short passage, only single sample

Results show that only a small proportion of the *E. coli* bacteria are ESBL-producing bacteria (<6%). In the effluent of the WWTP concentrations of ESBL *E. coli* and VRE ranged between 80-700 and 20-700 CFU per 100 mL. By ozone treatment of the effluent a reduction of the ARB by about 2 log levels could be proven. Also, the

treatment in the OWA resulted in a reduction of the ARB (0.5-1 log levels). After bank filtration no ESBL *E. coli* and VRE could be detected.

Table 3. Concentrations of 16S rRNA gene and selected antibiotic resistance genes at different stages of the Berlin water cycle. (LOQ = limit of quantification)

Location	n	*16S rRNA* (gene copies/mL)		*sul1* (gene copies/mL)		bla_{TEM} (gene copies/mL)	
		mean value	concentration range	mean value	concentration range	mean value	concentration range
Effluent WWTP	10	4.1×10^6	5.6×10^5-9.7×10^6	6.8×10^4	1.4×10^4-2.8×10^5	2.6×10^2	<LOQ-1.7×10^3
Effluent ozonation*	10	4.5×10^6	8.2×10^5-1.2×10^7	1.9×10^4	2.4×10^3-7.9×10^4	4.0×10^1	<LOQ-3.3×10^2
Effluent fast filtration*	38	6.4×10^5	1.7×10^4-5.0×10^6	2.5×10^3	7.2×10^1-2.3×10^4	9.3×10^{-1}	<LOQ-3.5×10^1
Influent OWA	7	5.4×10^6	1.3×10^6-1.2×10^7	6.5×10^3	4.2×10^2-1.9×10^4	2.5×10^0	<LOQ-5.0×10^0
Effluent OWA	7	2.2×10^6	7.7×10^5-3.9×10^6	3.9×10^3	2.8×10^2-1.7×10^4	not detected	
Bank filtrate**	1	not detected		not detected		not detected	

* pilot plant operated with ozonation and fast filtration; ** short passage, only single sample

PCR analysis demonstrated the prevalence of the sulfonamide resistance gene *sul1* and the β-lactamase gene bla_{TEM} in the WWTP effluent as well as in the surface water. Concentrations were significantly higher for *sul1* than for bla_{TEM}. Previous studies have shown that the *sul1* gene is one of the most common ARGs in the environment [Xiong et al. (2015); Stoll et al., (2019)], and the high gene copy numbers and detection frequency found in our study might have been caused by the association with mobile genetic elements, in combination with the widespread use of sulfonamides.

The bla_{TEM} gene encodes TEM β-lactamase, conferring resistance to β-lactam-antibiotics such as penicillins and cephalosporins, and is responsible for a high proportion of ampicillin resistance in *E. coli* and in *Klebsiella pneumoniae* [Poole (2004)]. bla_{TEM} is also considered to be a precursor of ESBLs [Emery and Weymouth, (1997)]. The production of ESBLs is a significant resistance mechanism that impedes the antimicrobial treatment with third-generation cephalosporins (e.g. cefotaxime, ceftazidime) and monobactams (e.g. aztreonam), and the enzymes are not inhibited by β-lactamase inhibitors such as clavulanic acid [Rawat and Nair

(2010)]. The results of several studies show the wide distribution of bla_{TEM} in aquatic environments worldwide [Henriques et al. (2006); Hu et al. (2008); Böckelmann et al. (2009)].

Ozonation and fast filtration of WWTP effluent and OWA reduced the ARGs, but not to the same extent as the ARB. In this study DNA-based techniques are used to detect the ARGs in water samples. These methods are unable to discriminate between live bacteria and dead bacteria. Treatment processes can damage the bacteria so that they are no more cultivable, but the DNA is still intact. The dissemination of ARB and ARGs is facilitated by horizontal gene transfer, enabling the exchange of ARGs among different bacterial strains or species [Frost et al. (2005)] and beyond the habitat of the original host [Moore and Lindsay (2001)]. It is presumed that conjugation is the primary mechanism of horizontal gene transfer [von Wintersdorff et al. (2016)], but also transduction [Brown-Jaque et al. (2015)] and transformation [Lorenz and Wackernagel (1994)] have been observed. Therefore, there is always a potential risk of transfer of ARGs of dead bacteria to other bacteria in the environment. Nevertheless, after bank filtration concentration of the ARGs was below the limit of quantification (LOQ). First results show removal of ARB and ARGs in the treatment processes. However, additional sampling campaigns need to be conducted to understand occurrence of ARB and ARGs in the Tegel water cycle.

Conclusion

Berlin as a water-wise, sustainable city has been relying on its own water resource for decades, safely managing de-facto potable reuse. This study provides an overview on the results of applied research on TOrC and ARB/ARGs removal options in Berlin's urban water cycle and its implications for urban water management. A key objective was the evaluation of treatment alternatives including direct dosing of PAC and ozonation for TOrC and ARB/ARGs removal. The results show that both ozonation and PAC can be combined with coagulation/filtration and are suitable to significantly reduce TOrCs, ARB and ARGs. Additional sampling campaigns need to be conducted to understand occurrence of ARB and ARGs in the water cycle.

Combination of PAC adsorption or ozonation for TOrC removal with coagulation/ filtration for phosphorus removal represents the preferred planning variant for the future expansion of Berlin's wastewater treatment plants.

References

Altmann, J.; Sperlich, A.; Jekel, M. (2015). Integrating organic micropollutant removal into tertiary filtration: Combining PAC adsorption with advanced phosphorus removal. Water Research 84, 58

Berendonk T.U., Manaia C.M., Merlin C., Fatta-Kassinos D., Cytryn E., Walsh F., Bürgmann H., Sorum H., Norström M., Pons M.-N., Kruezinger N., Huovinen P., Stefani S., Schwartz T., Kisand V., Baquero F., Martinez J.L. (2015). Tackling antibiotic resistance: the environmental framework. Nature Rev. Microbio., 13 (5): 310–317.

Böckelmann, U., Dorries, H. H., Ayuso-Gabella, M. N., de Marcay, M. S., Tandoi, V., Levantesi, C., et al. (2009). Quantitative PCR monitoring of antibiotic resistance genes and bacterial pathogens in three European artificial groundwater recharge systems. Appl. Environ. Microbiol. 75, 154–163.

Brown-Jaque, M., Calero-Cáceres, W., Muniesa, M., (2015). Transfer of antibiotic-resistance genes via phage-related mobile elements. Plasmid 79, 1–7.

Frost, L.S., Leplae, R., Summers, A.O., Toussaint, A. (2005). Mobile genetic elements: the agents of open source evolution. Nat. Rev. Microbiol. 3 (9), 722–732.

DVGW (1995). Technische Regel Arbeitsblatt W 101: Richtlinien für Trinkwasserschutzgebiete. DVGW Eschborn

Emery, C.L., Weymouth, L.A. (1997). Detection and clinical significance of extended-spectrum beta-lactamases in a tertiary-care medical center. J. Clin. Microbiol. 35(8), 2061–2067.

Gruenheid, S.; Amy, G.; Jekel; M. (2005). Removal of bulk dissolved organic carbon (DOC) and trace organic compounds by bank filtration and artificial recharge. Water Research 39 (14), 3219

Grützmacher,G, Wiese, B., Hülshoff,I., Orlikowski, D., Hoa, E., Moreau-Le Golvan Y.(2007) Bank filtration and Aquifer recharge for drinking water production: application, efficiency and persepectives – an integration of Nasri outcomes and international experiences. published on https: //kompetenz-wasser.de/Nasri aufgerufen am 14.4.19.

Heberer T., Mechlinski A., Fanck B., Knappe A., Massmann G., Pekdeger, A., Fritz B. (2004). Field Studies on the Fate and Transport of Pharmaceutical Residues in Bank Filtration. Groundwater Monitoring & Remediation 24, 70.

Hembach N., Schmid F., Alexander J., Hiller C., Rogall E.T., Schwartz T. (2017). Occurrence of the mcr-1 colistin resistance gene and other clinically relevant antibiotic resistance genes in microbial populations at different municipal wastewater treatment plants in Germany. Front. Microbiol. 8: 1282

Henriques, I., Moura, A., Alves, A., Saavedra, M.J., Correia, A. (2006). Analysing diversity among beta-lactamase encoding genes in aquatic environments. FEMS Microbiol. Ecol. 56(3), 418–429.

Hu, J., Shi, J., Chang, H., Li, D., Yang, M., Kamagata, Y. (2008). Phenotyping and genotyping of antibiotic-resistant Escherichia coli isolated from a natural river basin. Environ. Sci. Technol. 42(9), 3415–20.

Jekel M., Baur N., Boeckelmann U., Duennbier U., Eckhardt A., Gnirss R. (2016). Anthropogene Spurenstoffe und Krankheitserreger im urbanen Wasserkreislauf: Bewertung, Barrieren und Risikokommunikation (ASKURIS). Eds. Jekel, M. and Ruhl, A.S. Technische Universität Berlin.

Jiang L., Hu X., Xu T., Zhang H., Sheng D., Yin D. (2013). Prevalence of antibiotic resistance genes and their relationship with antibiotics in the Huangpu River and the drinking water sources, Shanghai, China. Sci. Total Environ. 458–460: 267–272.

Lorenz, M.G., Wackernagel, W. (1994). Bacterial gene transfer by natural genetic transformation in the environment. Microbiol. Rev. 58 (3), 563–602.

Massmann, G., Dünnbier, U., Heberer, T. & Taute, T. (2008). Behaviour and redox sensitivity of pharmaceutical residues during bank filtration - Investigation of residues of phenazone-type analgesics . Chemosphere 71(8): 1476-1485

Poole, K. (2004). Resistance to beta-lactam antibiotics. Cell. Mol. Life Sci. 61(17), 2200–2223.

Rawat, D., Nair, D. (2010). Extended-spectrum β-lactamases in Gram-negative bacteria. J. Glob. Infect. Dis. 2(3), 263–274.

Rizzo L., Manaia C., Merlin C., Schwartz T., Dagot C., Ploy M.C., Michael I., Fatta-Kassinos D. (2013). Urban wastewater treatment plants as hotspots for antibiotic resistant bacteria and genes spread into the environment: a review. Sci. Total Environ., 447: 345-360.

Rodriguez-Mozaz S., Charmorro S., Marti E., Huerta B., Gros M., Sànchez-Melsío A., Borrego C.M., Barceló D., Balcázar J.L. (2015). Occurrence of antibiotics and antibiotic resistance genes in hospital and urban wastewaters and their impact on the receiving river. Water Res. 69: 234-242.

Stange C., Yin D., Xu T., Guo X., Schäfer C., Tiehm A. (2019). Distribution of clinically relevant antibiotic resistance genes in Lake Tai, China. Science of the Total Environment 655: 337-346.

Stoll, C., Sidhu, J.P.S., Tiehm, A., Toze, S. (2012). Prevalence of clinically relevant antibiotic resistance genes in surface water samples collected from Germany and Australia. Environ. Sci. Technol. 46 (17), 9716–9726.

von Wintersdorff C.H.J, Pender J., van Niekerk J.M., Mills N.D., Majumder S., van Alphen L.B., Sevelkoul P.H.M., Wolffs P.F.G. (2016). Dissemination of antimicrobial resistance in microbial ecosystems through horizontal gene transfer. Front. Microbiol. 7,

WHO. (2014). Antimicrobial resistance - Global report on surveillance.

Xiong W., Sun Y., Ding X., Zhang Y., Zeng Z. (2014). Antibiotic resistance gene occurrence and bacterial community composition in the Liuxi River. Front. Environ. Sci. 2 (61), 1–6.

Recharge Local Water Cycle From Surface Water And Wastewater Reuse

S. Donnaz*, P. Gislette*, Miguel-Angel Sanz*, Marlene Choo Kun*

* Suez Treatment Infrastructure, 183 avenue du 18 juin 1940, 92508 Rueil-Malmaison, France
(E-mail: sylvain.donnaz@suez.com ; philippe.gislette@suez.com; miguel-angel.sanz@suez.com; marlene.choo-kun@suez.com)

Abstract
Aquifers are more than ever the nexus of Indirect Potable Reuse to increase global Water Resource, recharge local water cycle, centralize water monitoring and provide sustainable solution for Reuse De Facto in many regions.
As water resources and energy became scarcer in some regions of the world, aggravated by the consequences of Climate Change and demography evolution, Water Reuse combined with Managed Aquifer Recharge is a remedy, that provides concrete solution which combines quantitative and qualitative benefits.
It secures and enhances water supplied at low cost by meeting seasonal peak demands thanks to aquifer storage. It reduces evaporation of stored water while reducing costly investments in traditional concrete water tanks. It improves water quality and prevents salt water from intruding into coastal aquifers.

Aquifers constitute the most sustainable environmental buffer for an indirect potable water reuse scheme. Environmental benefits are numerous, such as maintaining flows and groundwater-dependent ecosystems, which improves local amenity, land value and biodiversity. It improves coastal water quality by reducing urban discharges, it mitigates floods and flood damage and facilitates urban landscape improvements that increase land values.
Dams, treatment plants, canals and water feeders are man-made infrastructures. Groundwater and aquifers on the contrary are less visible and not well understood by the majority of water planners.
However, aquifers provide naturally a high level of “environmental services” such as: storage, purification and transport.

Management of Aquifer Recharge should be included in the design of water projects, on the basis of some simple drivers and three pragmatic points. Increasing water storage (Dam or concrete storage) by considering an advantage to natural groundwater storage. Need for additional Water Treatment Plant (including desalination) by taking advantage from aquifer recharge to benefit from better water quality or to restore naturally groundwater quality. Need more Water Resources to increase local water resources by reuse, soil aquifer treatment & aquifer storage.
Geologist and water treatment engineers from Suez are committed worldwide to design and provide fit-for-purpose water reuse solutions including the sustainable approach of Management of Aquifer Recharge.

This paper will detail three applications of surface water and wastewater reuse in the world: Paris Surface water augmentation through aquifer, Mexico City IPR aquifer recharge, Perth Beenyup IPR aquifer recharge Phase I and II.

Keywords
Management of Aquifer Recharge, Reuse, Indirect Potable Reuse

INTRODUCTION

Managed Aquifer Recharge (MAR) is the purposeful recharge of water to aquifers for subsequent recovery and/or environmental benefits. Under favourable geological conditions MAR is most of the time the lowest total expenditure cost (TOTEX) solution for water resources storage and soft treatment based on hydrogeological knowledge and operational know-how.

This paper covers the coupling of water infrastructure and aquifers by aiming to recharge local water cycle. Managed Aquifer Recharge (MAR) includes different applications such as wastewater reuse, surface water reuse and sea water barriers against salts intrusion. All schemes aiming at recharging the aquifer(s) of the water basins(s) of any given city. For such cities, project driver is to seek rainfall independence, by recycling water into aquifer replenishment, so that it can serve as seasonal storage for water management, further step of water treatment and in the end as an increased local water resource, such as for drinking water purposes.
After a brief overview of the various references already existing around the world of different MAR applications coupled with water infrastructure.

SUEZ is the one of the worldwide Group having built experience in all the project development stages of the overall water cycle practices among which MAR techniques are included. Furthermore, SUEZ Treatment Infrastructure “Métiers” deals with pre-treatment or post-treatment stages in operations where MAR is involved and quality control is needed.
SUEZ MAR skills focus on those regions with hydric stress counting non-regulated surface resources and/or treated waters liable to reuse.

These capabilities have been developed and integrated through the design & operation of more than 21 large projects established in France, Spain, USA, Australia and Mexico, as well as through the implementation of Research and Innovation programs and pilot projects all around the world.
Specifically, SUEZ takes advantage of the MAR systems as a powerful tool and component of an Integrated Water Resources Management approach. MAR are applied to local and regional scales.

Coupling reuse with MAR methodologies can be used to address water shortages and contribute to sustainable water resources management practices. The establishment of a MAR system depends on the source of recharge water, the selection of a recharge method and site, the type of water treatment system, and the ultimate purpose of recovered water, and these components are closely related and integrated.

Experiences of MAR using water from reuse in Spain, USA, Mexico and Australia are described in this paper.

COUPLING MANAGED AQUIFER RECHARGE WITH INDIRECT POTABLE REUSE

Coupling MAR with Indirect Potable Reuse is more than ever a sustainable and fit-for-purpose solution to face Water Scarcity and the challenges imposed by the Climate Change.

Climate Change does constitute one the main drivers and stakes that MAR can meet: as precipitations are progressively decreasing in most subtropical and lower mid-latitude regions and extreme events become more frequent worldwide, the enormous aquifers and soil storage capacity offers a buffering solution for flow regulation. To be prepared for a decrease of water availability and for an increase of flooding severity simultaneously, it should be aimed to build retention potential that can address them both. In addition to landscape retention areas and reservoirs, aquifers are one of the biggest water reservoirs at our disposal.

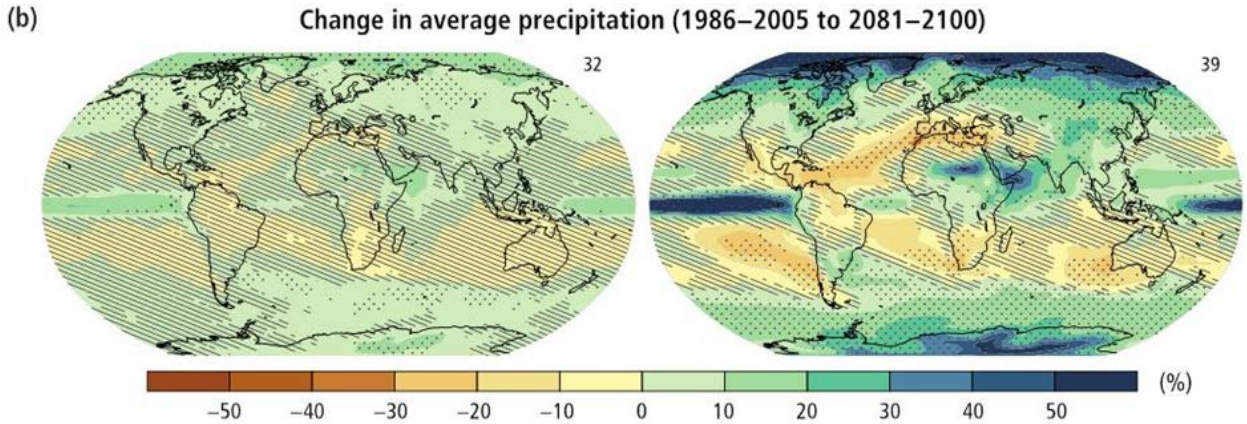


Figure 1: One of the consequences of climatic change is annual precipitation reduction accompanied by intensity increase during rainy season in many regions of the world where MAR techniques and water recycling will be a solution[1] (IPCC).

Other MAR drivers:

- Water scarcity: arid climate and prolonged dry periods are the major driver for MAR projects.
- Water resources protection: control seawater intrusion and migration of pollution through hydraulic barriers that are becoming an issue.
- Health protection: Potential for contaminant and pathogen attenuation and natural disinfection through natural filtering enhanced by long residential times. MAR can be assimilated to an additional sanitary protection barrier for water resources
- Environment protection: Chemical use and sludge byproducts are minimized.
- Land use & environmental impact: being underground processes, MAR projects reduce land use to a minimal extent.
- Cost effective tool: MAR CAPEX & OPEX are in general much less expensive than traditional storage, long distance transportation and treatment options.
- Additional economic benefits of water reuse coupled with MAR.

The Suez's Approach to Aquifer Recharge and References

There are numerous possibilities of MAR schemes depending on project requirements and local conditions to optimize storage capacity, water quality and environment protection. Technical expertise is needed to select the optimal one and develop tailor-made solutions adapted to local regulations.

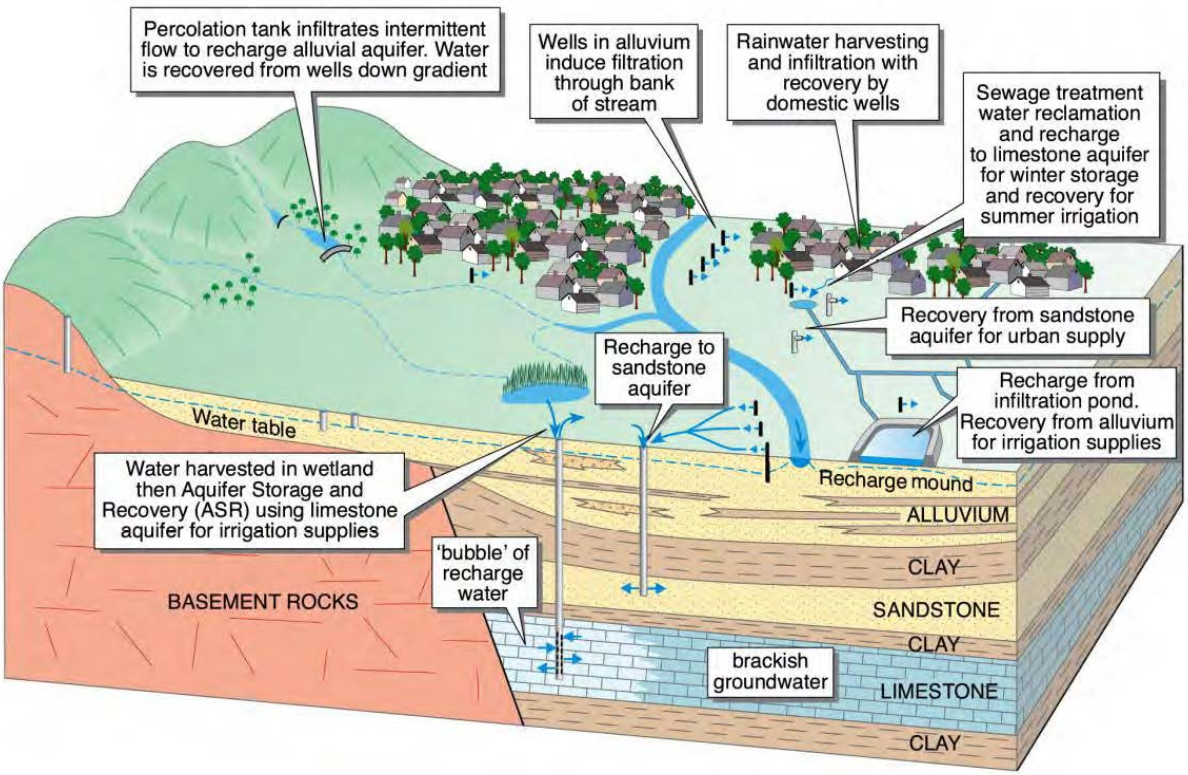


Figure 2: Aquifer Recharge Illustration

All different MAR arrangements could be simplified by the following scheme which features MAR process:

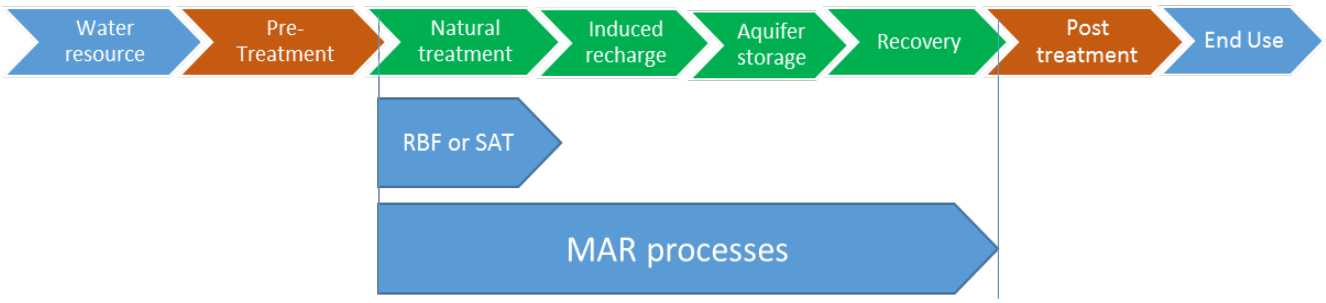


Figure 3. MAR processes include the integration of aquifer and non-saturated formations as components for natural treatment and water storage. RBF means River Bank Filtration, SAT means Soil Aquifer Treatment.

All processes are interrelated. In consequence pre and post treatment characteristics depend on the quality of the water resources, MAR processes features and end use purposes.
The aquifer recharge can be direct or indirect. If the aquifer is confined recharge will be only possible through direct injection wells and therefore limiting the scope of soil natural treatment. In this case the quality of water injected must be, at least, better than native groundwater, being pretreatment more complex and expensive for these cases where Soil Aquifer Treatment is minimized.
When the aquifer is an unconfined one, it may be recharged indirectly, through infiltration basins, galleries or uncompleted wells thus permeating through unsaturated formations or soil. In these cases soil acts as a biophysical reactor where water impurities are physically retained or transformed through bio energized redox processes, degassed and mitigated. Hence water

pretreatment before recharge could be simplified and cheaper.

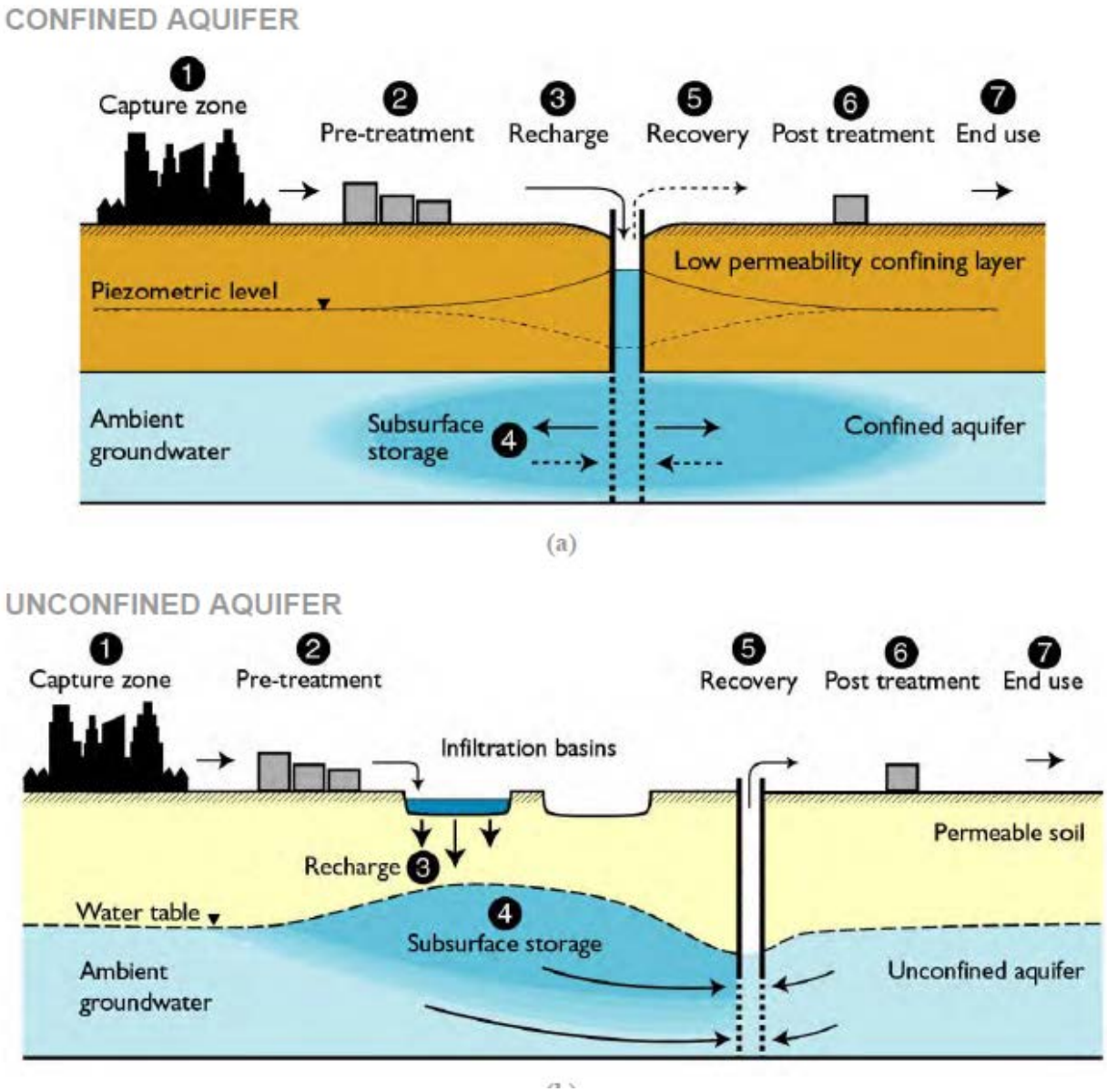


Figure 4: MAR arrangements scheme

SUEZ references in MAR have been developed since more than 50 years ago. Here below are listed the most significant projects carried out until present time. Eight cases have been selected to be described in this paper.

	Country	Site	Volume involved (m^3/year)	Scheme	Year	Remarks
1	USA	West Basin California	14,000,000	Injection of recycled water for preventing seawater intrusion	1990	
2	USA	Toms River	6,380,000	Supply Source/some water quality issues	2000	
3	USA	Delaware	1,800,000	Supply Source		
4	USA	Matchaponix (NJ)	7,200,000	Seasonal Supply/Salt avoidance		
5	USA	Idaho	8,400,000	Supply Source/contaminant plume control		
6	Spain	Barcelona - Llobregat	17,000,000	River bed scarification, ASR through wells and infiltration ponds	1960/70	Aguas de Barcelona,
7	Spain	Barcelona - Besós	4,000,000	Bank river filtration		Aguas de Barcelona: intermittent activity
8	Spain	Marbella - Estepona	200,000	ASTR		HIDRALIA
9	Spain	Agost _ Alicante	< 100,000	Lamination dams, infiltration		HIDRAQUA
10	Spain	Murcia	< 100,000	Reclaimed water infiltration for irrigation purposes.	1992-2000	EMUASA
11	Spain	Canary Islands	< 100,000	Treated wastewater infiltration	2014	CANARAGUA
12	Spain	Canary Islands	< 100,000	Rain water harvest and infiltration		CANARAGUA
13	Spain	Canary Islands	6,000,000	Desalinated brackish water infiltration		Aguas de Telde
14	France	Le Pecq-Croissy	50,000,000	Riverbank filtration, Pond infiltration,	1980	Water France / SUEZ Consulting
15	France	Flins-Aubergenville	40,000,000	Riverbank filtration, pond infiltration, ASR	2000	Water France / SUEZ Consulting
16	France	Moulle (Pas-de-Calais)	20,000,000	Pond infiltration		
17	France	Poncey (Dijon)	5,000,000	Trench infiltration		
18	France	Hyéres les Palmiers (Var)	TBI	Pond infiltration, seawater intrusion prevention	2015	Eau France / Well Services
19	France	Auxerre (Yonne)	TBI		2016	Eau France / Well Services
20	Mexico	Mexico City	2,518,500	Wastewater treatment plant for landscape and irrigation reuse and aquifer recharge for drinking usage.	2016	Design, Build & Operate (6 months).
21	Australia	Perth / Beenyup	14,000,000	Groundwater replenishment with treated wastewater	2016	Commissioning for October 2016

Table 1. Suez's References with regards to Managed Aquifer Recharge

Lessons learnt and Perspectives

Managed Aquifer Recharge alternatives are very interesting to couple with reuse, adding natural treatment and storage of water resources.

- Environmental:
  - Optimization of local hydric resources management
  - Improvement and increase of the surplus flows regulation
  - Saline intrusion in the coastal aquifers is under control
- Economic benefits for the population due to reliable water supply at moderated cost, increase in land and property value and positive impacts for the human wellbeing, sport and tourism
- Economic benefits for industry coming from avoided economic losses during drought periods and loss of a key industries to the region
- Environmental benefits for the improvement of groundwater quality, efficient control of seawater intrusion and preservation of the precious local groundwater resources
- Economic benefits for the population due to a climate resilient water supply source, with a more competitive cost than desalination
- Environmental benefit by controlling the water balance for the deeper groundwater resources, and limiting the abstraction from superficial aquifers;
- Social benefit by enabling cities growth and limiting the impact of the recurrent climate drought that do affect some parts of the world.

Water management plans should systematically consider the MAR alternative, at conceptual & feasibility stages. When coupled with Water Reuse, MAR offers a safe, sustainable and cost-effective solution for the benefits of the local water cycle management, the population and the territories or cities. Aquifer recharge from water reuse can only be one lever of a wider water management plan, which shall also include water conservancy measures (reduced water consumption, reduced water leakages/losses in distribution systems, …).

Key success factors for aquifer recharge from water reuse are long-term planning, public outreach & education, phased implementation.

Treatment solutions to be considered for Aquifer Pre-treatment & Post-treatment applications

Like Pr. Michael E. Campana pointed out in recent publication, we need to "refill the hidden tanks" to "take all benefits of managing the recharge of aquifers"[2].

While considering aquifer recharge, water treatment through Pre- or Post-treatment is key to ensure safe and sustainable Water Reuse. When coupling Aquifer Recharge with Indirect Potable Reuse, benefits from storage and water quality monitoring arise and give credits to Water Reuse treatment solutions.

Each case is specific and solution will vary depending on local regulation(s). However, treatment solutions can be summarized in 3 categories:

<u># Pre-treatment solutions for recharge of Confined Aquifer</u>

In this case, recharge will only be possible through direct injection wells and the quality of water injected shall be at least better than the native groundwater. Pre-

Treatment solution	***Suez degrémont™ solutions***
Settling	Pulsatube®, PulsaGreen®, Pulsazur®
Dissolved Air Flottation (DAF)	AquaDAF®
Sand filtration	Aquazur V® (sand)
Dual media filtration	Mediazur®
Filtration	Filter FH (DMPF), FV2B filters, Greenleaf®
Membrane Ultrafiltration	Ultrazur®, Ultramarine®
Reverse Osmosis for micropollutants removal, for Aquifers with brackish waters, sea intrusions)	Desalination membranes with pretreatment such as SeaClean®, SeaDAF®, Cartridge filter, Ultramarine®
Activated carbon filtration (GAC, PAC)	Carbazur®, PulsaGreen®
Disinfection	Chlorination, Aquaray® (UV)
Ozonation (disinfection, micropollutants)	Oxyblue®
Decarbonatation	Densadeg®
Mineralisation	Lime saturation Densadeg®, Gyrazur®

treatment will be more complex where Soil Aquifer Treatment is minimized.
The quality of the water injected into the aquifer will fulfil the standards for drinking water. The water treatment process line and technological products will be the ones used by Suez for drinking water and desalination projects.
Processes involved for confined aquifer and drinking water quality standards are the following:

Table 2. Confined aquifer Pre-treatment solutions

Pre-treatment solutions for recharge of Unconfined Aquifer

In this case, recharge may be indirect through infiltration basins, galleries or soils. In this case, soil acts as a biophysical reactor where water impurities are physically retained or transformed through bio energized redox processes, degassed and mitigated. Hence water pretreatment before recharge could be simplified and cheaper.
The quality of the water injected into the aquifer will be closer to

Treatment solution	*Suez Degrémont™ solutions*
Advanced Settling	Densadeg®
Dissolved Air Flotation (DAF)	GreenDAF®
Biofiltration	Biofor®
Micro-screening by mechanical sieve	Compakblue™
Sand filtration	Aquazur V® (sand)
Dual media filtration	Mediazur®
Activated carbon filtration (GAC, PAC)	Carbazur®, PulsaGreen®
Membrane Biological Reactor (MBR)	Ultrafor®, UltraGreen®
Membrane Ultrafiltration	Ultrablue®
Disinfection	Chlorination, Aquaray® (UV)
Ozonation (disinfection, micropollutants)	Oxyblue®

Table 3. Unconfined aquifer Pre-treatment solutions

the highest standards applied for the treated water obtained by the most advanced treatment from waste water treatment plants. The water treatment process line and technological products will be the ones used by Suez for advanced reuse projects including tertiary + quaternary treatment stages.
Processes involved for unconfined aquifer & high recycled water quality standards are the following:

The 3rd category is the Post-treatment (combined or not with Pre-treatment)

In specific cases, when a specific pollution shall be treated within a polluted aquifer and where Soil Aquifer Treatment is minimized or not possible, the following technological product might be used for specific treatment:

Treatment solution	*Suez degrémont™ solutions*
Iron removal	Ferazur®
Manganese removal	Mangazur®
Arsenic removal	Separation, chemical, biological or resin solutions
Heavy metals	Mining solutions

Table 4. Aquifer Post-treatment solutions

Think and move forward with Managed Aquifer Recharge

MAR utilize and take advantage of groundwater stores magnitudes, aquifer dynamics, physic-chemical processes as well as natural biological processes, in order to store and regulate surface resources, to fix problems derived from aquifer intensive exploitation, and even to purification water processes. Multiple solutions apply in the fields of hydrogeology and water treatment. MAR schemes and techniques are strongly dependent on local conditions.
Dams, treatment plants, canals, and water feeders are man-made water infrastructures that all engineers can see and imagine. They can also precisely design solutions. Groundwater and aquifers on the contrary are less visible, and not as well understood by the majority of water planners.
However, aquifers provide naturally and for free a high level of “environmental services” as water storage, water purification, water transport.

Even for a non-specialist, it is possible to include MAR in the design of many water projects, on the basis of 3 simple question marks:

1. Case 1: Increasing Water storage (Dam or concrete storage). Is it possible to take advantage of natural groundwater storage?

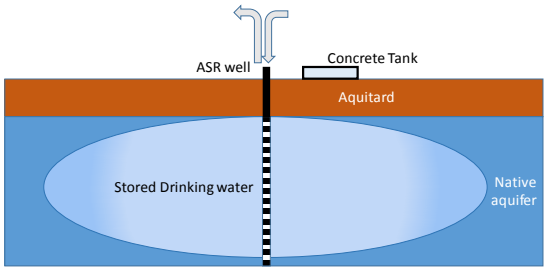


Figure 5. High cost civil engineering tank could be replaced by ASR scheme

2. Case 2: Need for additional Water Treatment Plant (including desalination/brackish)? Is it possible by aquifer recharge to benefit from better water quality, or to restore naturally groundwater quality?

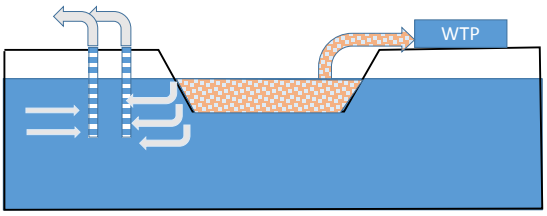


Figure 6. A WTP could be replaced or its treatment CAPEX & OPEX minimized by appropriated MAR arrangement like River Bank Filtration.

3. Case 3: Need more Water Resources? Is it possible to increase local water resources by reuse, soil aquifer treatment & aquifer storage?

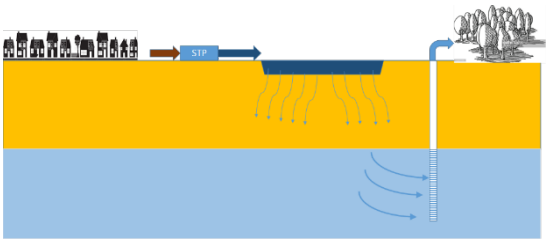


Figure 7. MAR infiltration system could complement water reuse to recharge aquifers reducing treatment costs.

Suez MAR Schemes bring a smart and inexpensive response to one of the above 3 questions. To illustrate this fact, here below 8 examples are highlighted:

CASE STUDIES	STORAGE BENEFITS	WATER QUALITY	LOCAL RESOURCES INCREASE
#1 : MARBELLA (SPAIN)	Yes		Yes
#2 : BARCELONA (SPAIN)		Yes	Yes
#3 : FLINS AUBERGENVILLE (FRANCE)	Yes	Yes	
#4 : CROISSY SUR SEINE (FRANCE)		Yes	Yes
#5 : WEST BASIN (USA)		Yes	Yes
#6 : PERTH (AUSTRALIA)		Yes	Yes
#7 : MEXICO CITY (MEXICO)			Yes
#8 : TOMS RIVER (USA)		Yes	Yes

Table 5. Case studies key benefits

Quantity benefits	Quality benefits	Environmental benefits
Securing and enhancing water supplies at low cost by meeting seasonal peak demands thanks to aquifer storage	Improving water quality	Maintaining environmental flows and groundwater-dependent ecosystems, which improve local amenity, land value and biodiversity

Reducing evaporation of stored water	Preventing salt water from intruding into coastal aquifers	Improving coastal water quality by reducing urban discharges
		Mitigating floods and flood damage
		Facilitating urban landscape improvements that increase land value

Table 6. Concrete benefits

CASE STUDY: Injection of recycled water to reduce water scarcity in the heart of Mexico City

Short description of the project: Water scarcity is a reality in Mexico City, in 2013 the National Water Commission of Mexico (CONAGUA) published that the pressure on the water resources in the Valley of Mexico was 136% coming from a deficit between the renewable water of the region, 3468 hm^3/year, vs the granted water for all uses, 4720 hm^3. In 2015, it was estimated that the aquifer from the metropolitan area of Mexico City is overexploited by 3.5 m^3/s, aquifer that is responsible for around 40% of the water supply to the area.

The Chapultepec WWTP project is a wastewater treatment plant that will provide water for recreational activities (the lakes of the Chapultepec Park), for irrigation of the forest of Chapultepec, and for groundwater recharge of the aquifer of Mexico City. The treatment line includes a biological reactor for carbonaceous and nutrient (N&P) removal as well as technologies like the **Ultrafor™** (biological membrane reactor, see chapter 8) to provide water for the lakes and irrigation. The water for groundwater recharge will go through an additional treatment including UF membrane filtration, reverse osmosis and UV disinfection. The project includes a total of 4, 250 meters depth, injection wells each with a capacity of 20 liters per second. A monitoring well network was also designed to follow-up piezometry and water quality. Although this capacity is small compared to the water demand of the city, it will be the first direct recharge case and an example to follow in the sustainable management of the water resources in Mexico.

Key Figures and Challenges

Key Drivers	Key Figures	Main Challenges
○ Water scarcity and overexploitation of the aquifer ○ Support of the local authorities to develop sustainable Water Supply ○ Demand long ago exceeded local water supply	○ Total treatment capacity of the wastewater treatment plant 576 m^3/h ○ Total recharge capacity 288 m^3/h ○ **4 injection wells with a capacity of 72 m^3/h each.** ○ **300 mm diameter and 250 meters deep**	○ The first direct recharge project in Mexico City ○ Meeting all the requirements of the Mexican law on treated wastewater recharge ○ Design and construction of the injection and monitoring wells ○ Aquifer modelling

Table 7. Key Projects Indicators

Client Expectations and Goals

- Meet rigorous water quality parameters and stringent footprint requirements
- Increase water demand and develop sustainable water supply

- Implement top technologies and monitoring tools
- Include reuse schemes as part of the water resource management

Tailored solutions

- Use of top technologies like the Ultrafor™ biological membrane reactor, Reverse Osmosis and UV disinfection to answer to the strict water quality demanded and the short footprint required
- Provide different treatment solutions for each water usage.
- Offer integrated management of aquifer recharge with injection and monitoring wells

Benefits

- Increase water supply and diminish water scarcity
- Develop sustainable management schemes for the water resource
- Improvement of groundwater quality

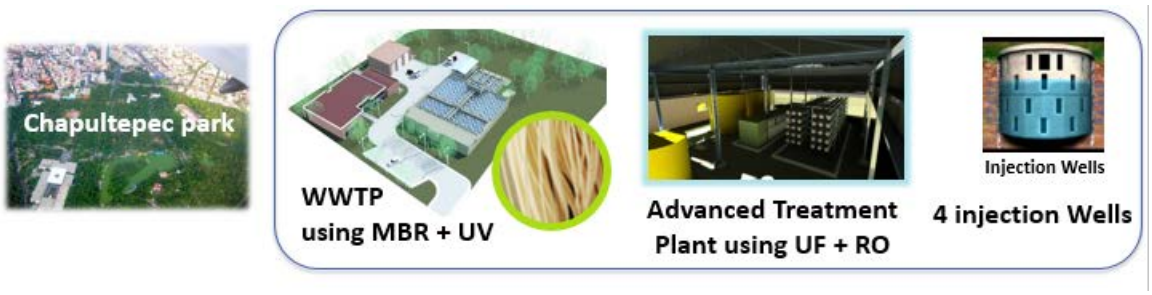


Figure 8. Technological solutions applied

Direct injection: Artificial Recharge	
Pathogens Microorganisms	Removal or total inactivation of whole pathogens
Contaminants regulated by drinking water standards	Limits by NOM-127-SSA1-1994
Contaminants not regulated by drinking water standards	COT ≤ 1 mg/L

Table 8. Direct injection in confined aquifer

REFERENCES

[1] IPCC, Intergovernmental Panel on Climate Change
[2] Michael E. Campana, Professor of Hydrogeology and Water Resources Management at Oregon State University [the 'other OSU'] in Corvallis, OR, and Technical Director of the American Water Resources Association, IWA website, October 2016

Novel Non-RO Direct Potable Reuse in the United States

Andrew Salveson, Eva Steinle-Darling, Jeff Mosher

Summary

Within the US, the one existing and two progressing DPR projects (Big Spring TX, El Paso TX, Ventura CA) have one major component in common: the use of RO. With the rising specter of prolonged drought and the limitations of RO (i.e., high cost, energy use and concentrate management), there is a clear and present need for purification approaches for potable reuse that do not rely on RO; which is the focus of this paper.

Full Abstract

At the municipal scale, there are two Direct Potable Reuse (DPR) facilities in operation in the world. One of those facilities is in United States (U.S.) in Big Spring, Texas. Other DPR facilities are under development in the U.S., including projects in Ventura, California and El Paso, Texas. These three U.S. facilities have one major component in common: the use of reverse osmosis (RO) for purification. With the rising specter of prolonged drought and water scarcity across large parts of the U.S., and the limitations of RO (i.e., high cost, energy use and concentrate management), there is a clear and present need for purification approaches for potable reuse that do not rely on RO. This paper will address the following key issues:

- Regulatory frameworks for the protection of public health associated with DPR in the U.S.
- The progress of DPR in the U.S. based upon case studies in Big Spring, Texas, Ventura, California, and El Paso, Texas.
- Methods to evaluate public health risk with Quantitative Microbial Risk Analysis (QMRA).
- The latest novel research of DPR using non-RO technology, focusing upon the IWA (Tokyo, 2018) and WateReuse Association (Phoenix 2017) award winning project in Altamonte Springs Florida; called PureAlta (https://www.altamonte.org/754/pureALTA).

In 2015, the National Water Research Institute (NWRI) published a 173-page "how to" document on DPR, titled *Framework for Direct Potable Reuse* (NWRI, 2015). Subsequent to that publication, several expert panels have produced DPR guidance in the U.S. for New Mexico, Florida, Arizona, and Colorado. ***These regulatory and public health efforts have converged upon a common theme of multiple barriers, pathogen log reduction, and risk minimization***.

The DPR system in Big Spring, Texas has now been successfully running for more than 4 years. For the first two years of that project, the Texas Water Development Board sponsored a study of the facility that included extensive water quality analysis for chemical and biological agents. That work, now final, robustly demonstrates the safety of DPR with the tested treatment train. Big Spring, through its success, helped prepare for the Ventura, California and El Paso, Texas DPR projects to progress. Each of these projects, however, involve RO-based treatment trains.

While robust, RO comes at a high capital cost, a high energy cost, and produces a high strength waste (RO concentrate or brine). While appropriate for some locations, RO brine disposal can be extremely challenging for inland projects. With this challenge in mind, the City of Altamonte Springs Florida launched the PureAlta project, a non-RO permanent and full-scale DPR demonstration system involving ozone, biologically active filtration, and advanced oxidation. PureAlta has been awarded the 2017 Innovative Project of the Year by the WateReuse Association and the 2018 Project Innovations Award from IWA. These awards were given due to the innovative treatment process, use of advanced online monitoring, and the use of novel offline analytical methods (such as bioanalytical tools using cell or protein-based test systems or bioassays) to document the safety and quality of the purified water.

In addition, understanding risk and using risk assessment for DPR is essential in the regulation and design of projects. . In 2018, the Water Research Foundation published a report that includes a thorough Quantitative Microbial Risk Analysis for potable water reuse, based upon the use of both RO-based and non-RO based treatment systems.

This work, recently published in Environmental Science and Technology, describes the hazards of off-spec performance and the use of diversion and multiple barriers to maintain public health protection.

This abstract is a proposal by the key authors of the referenced projects, Andrew Salveson, Eva Steinle-Darling, and Jeff Mosher, to detail the latest science and regulations related to DPR in the United States.

Potable Reuse and Public Health: QMRA from The DPR Demonstration Project

Brian Pecson, Trussell Technologies, Oakland, USA; Shane Trussell, Trussell Technologies, Solana Beach, USA; Sarah Triolo, Trussell Technologies, Oakland, USA; Adam Olivieri, EOA, Oakland, USA; Rhodes Trussell, Trussell Technologies, Pasadena, USA

Introduction

The ability of DPR treatment trains to provide consistent public health protection remains uncertain, largely due to the lack of existing DPR projects. This study developed an extensive dataset on DPR performance to assess whether redundancy and enhanced monitoring could be used to achieve reliable potable reuse. The 1.5-MGD DPR Demonstration Project was developed at the City of San Diego's North City Water Reclamation Plant and consisted of ozone (O_3), biologically active carbon (BAC), membrane filtration (MF), reverse osmosis (RO), and UV with advanced oxidation (UV/AOP).

The DPR Demonstration Project synthesized findings from multiple past research efforts to create a system providing continuous protection against public health threats. *Robustness*, or the use of multiple barriers with different removal mechanisms, enhances reliability by reducing the probability that contaminants can pass through treatment trains and impact public health. Robustness was added to the standard MF, RO, UV/AOP train by including two pre-treatment steps: ozone and BAC. These barriers also provide enhanced *redundancy*, the application of treatment barriers beyond the minimum requirements. Through high-frequency data collection, we developed an extensive data set to assess treatment reliability.

One additional knowledge gap is the uncertainty related to the concentration of pathogens in raw wastewater. Treatment requirements are frequently based on the difference between pathogen concentrations in the source water and what is acceptable in the treated water. In the absence of raw wastewater data, the most common approach has been to use conservative assumptions about the levels that may potentially be present.

In this study, we integrated two key pieces of information: (a) the extensive performance dataset from the DPR Demonstration Project and (b) new raw wastewater pathogen datasets developed by the Cities of Oceanside and San Diego. By integrating both the performance and the pathogen monitoring datasets, we more accurately assessed the reliability of a future DPR system.

Results

High-frequency performance data were used to develop performance distribution curves for individual unit processes and the entire treatment train, illustrating the consistency of performance and the probability with which the treatment train can meet various pathogen reduction requirements.

The yearlong pathogen sampling campaigns conducted at the City of Oceanside and the City of San Diego provided approximately 20 new data points to further characterize raw water concentrations. Enteric virus, *Giardia*, and *Cryptosporidium* were enumerated and used as inputs to QMRA. The QMRA assessed the ability of the DPR train to meet two risk targets: (a) the US target of 1 in 10,000 infections per person per year and (b) the WHO's risk target of 1e-6 disability-adjusted life years (DALYs).

The QMRA demonstrated that both goals could be reliably achieved both under typical operating conditions, as well as highly conservative failure conditions. These findings demonstrate that DPR can reliably achieve its stated risk goals and provide a source water that is equivalent or more protective than conventional drinking water supplies.

Conclusions

As the State of California continues to pursue DPR regulations, improved understanding of pathogen concentrations in raw and treated wastewaters is a top priority. Regulators have advocated the use of QMRA to better understand the risks and appropriate pathogen control measures for DPR. This study directly addressed both knowledge gaps by utilizing the expanded pathogen datasets in the QMRA. Additional insights will be provided regarding the benefits of redundancy and robustness, and how treatment barriers can be used in combination with other non-

treatment barriers—including source control, environmental or engineered buffers, and enhanced monitoring—to create safe DPR systems.

Direct Potable Reuse Research Update: DPR-4, Treatment for Averaging Chemical Peaks

Jean Debroux, PhD, Kennedy Jenks Consultants, San Francisco, CA, USA;
Stephen A. Timko, Kennedy Jenks Consultants, Seattle, WA;
Shane Trussell, PhD, PE, Trussell Technologies, San Diego, CA, USA;
Aleks Pisarenko, PhD, Trussell Technologies, San Diego, CA, USA
Rodrigo Tackaert, Trussell Technologies, San Diego, CA, USA
Megan H. Plumlee, PhD, PE, Orange County Water District, Fountain Valley, CA

Abstract:

Recycled water is a resource that the state of California relies upon to meet its water supply needs. To maximize the benefits associated with using recycled water, California is moving towards developing Direct Potable Reuse (DPR) regulations to guide projects in the future. An Expert Panel was convened to review the feasibility of DPR and although they deemed DPR feasible, they recommended that additional research address key technical questions which remain. DPR-4: Treatment for Averaging Chemical Peaks (DPR-4) is the fourth of five (5) DPR research projects funded by the California State Water Resources Control Board and managed by the Water Research Foundation. DPR-4 began in December of 2018 and focuses on three main elements: 1) Literature Review, 2) Case Study Investigation, and 3) Targeted Analyses at pilot or full-scale facilities. The researchers will provide an update on the progress of their work and how it may impact DPR in California.

Keywords: Direct Potable Reuse; DPR; Chemical Peaks; Advanced Treatment; Total Organic Carbon, Source Control

Introduction

Water reuse is a droughtproof, reliable water resource that has been successfully incorporated into many communities in California. Water reuse can benefit a community by offsetting often more expensive imported surface waters, relieving stress on over-drafted groundwater basins, and/or reducing discharge to sensitive receiving waters. In the case of non-potable reuse, implementation is challenged by the costly installation of an often-large secondary distribution system (i.e. purple pipe) within a community.

Indirect potable reuse, via groundwater replenishment, is currently a significant use of recycled water in California and has been occurring since 1962. California Groundwater Replenishment Regulations require that residence time of at least six (6) months is needed in the subsurface (i.e. environmental buffer) prior to extraction for potable purposes. This requirement makes recharge limited to locations with larger, suitable groundwater basins.

To extend the opportunity for communities without usable groundwater basins to incorporate potable reuse, California is moving towards regulating Direct Potable Reuse (DPR) via Raw Water Augmentation (RWA) and Treated Water Augmentation (TWA). Surface Water Augmentation (SWA) is considered indirect potable reuse, but projects that do not meet a minimum hydraulic retention time and/or minimum dilution requirements will be regulated as RWA, a form of DPR per California codes. Table 1 indicates the general differences between these three (SWA, RWA, and TWA). A commonality between the three modes of DPR, as compared to IPR, is the reduction of the environmental buffer between water purification and consumer. An environmental buffer can provide treatment and response time for a utility and reduction, or removal, of that buffer requires greater controls on the quality of purified water.

The California Division of Drinking Water (DDW) of the State Water Resources Control Board (SWRCB) is charged with developing the regulations for DPR projects in California. As part of Senate Bill (SB) 918, enacted in 2010, the state was required to convene an Expert Panel to study the technical and scientific issues associated with DPR. In 2013, SB 322 additionally required the DPR Expert Panel to assess whether additional research was needed to establish DPR criteria.

To address the knowledge gaps identified by the expert panel, six research projects were identified and funded by SWRCB. DPR-4: Treatment for Averaging Potential Chemical Peaks is the fourth of the five research projects and is managed by the Water Research Foundation (WRF).

Table 1 – Pending Potable Reuse Modes in California

Mode of Potable Reuse	Receiving Water Body	Key Characteristics
Surface Water Augmentation (SWA)	Surface Water Impoundment prior to Drinking Water Treatment Plant (DWTP)	-Minimum of two (2) months Hydraulic Retention Time (HRT) -Minimum of 100:1 (or 10:1 when subjected to additional treatment) dilution 99% of the time determined by hydraulic modeling -Projects that do not meet HRT or dilution requirements may be considered DPR -Final SWA Regulations adopted in 2017
Raw Water Augmentation (RWA)	Source Water of DWTP	-Water will be retreated in DWTP -Draft regulations pending response to DPR Expert Panel recommendations
Treated Water Augmentation (TWA)	Finished Water from the DWTP or directly into Distribution System	-No additional treatment beyond recycled water purification -Draft regulations pending response to DPR Expert Panel recommendations

Full advanced treatment (FAT), although not mandatory for all potable reuse projects in California, has become customary and will likely be the centerpiece of the treatment process train of early DPR projects in California. FAT consists of high-pressure membrane filtration (i.e. reverse osmosis, RO) followed by ultraviolet light (UV) application in conjunction with oxidant addition (e.g., hydrogen peroxide) to produce hydroxyl radicals (i.e. advanced oxidation processes, AOP). RO is typically preceded by low-pressure membrane filtration (i.e. micro- or ultra-filtration, MF or UF) as pretreatment. Although typically there are other supporting processes in FAT (e.g. pre-treatment filtration, decarbonation, stabilization), the core contaminant removal processes of advanced purification are considered MF-RO-UVAOP.

Although FAT does an excellent job of removing organic contaminants of concern, typically low levels (< 0.5 mg/L) of total organic carbon (TOC) reside in FAT product waters. It has been observed that larger compounds (MW > 200) and/or charged compounds are typically very well removed by RO membranes (Drewes et al., 2006; Howe et al., 2019), and UVAOP is an effective process to oxidize key contaminants (i.e. NDMA and 1,4-dioxane) that pass through RO filtration, and likely others (Plumlee et al., 2008, Mestankova et al., 2016).

Short-duration chemical peaks have been observed in RO feed and FAT product waters at full scale facilities (Olivieri et al., 2016) due to certain low molecular weight, non-polar compounds that are not fully removed by FAT. These compounds were detected by measuring Total Organic Carbon (TOC) online (Figure 1). TOC is considered the most appropriate surrogate for organic contaminants that escape FAT.

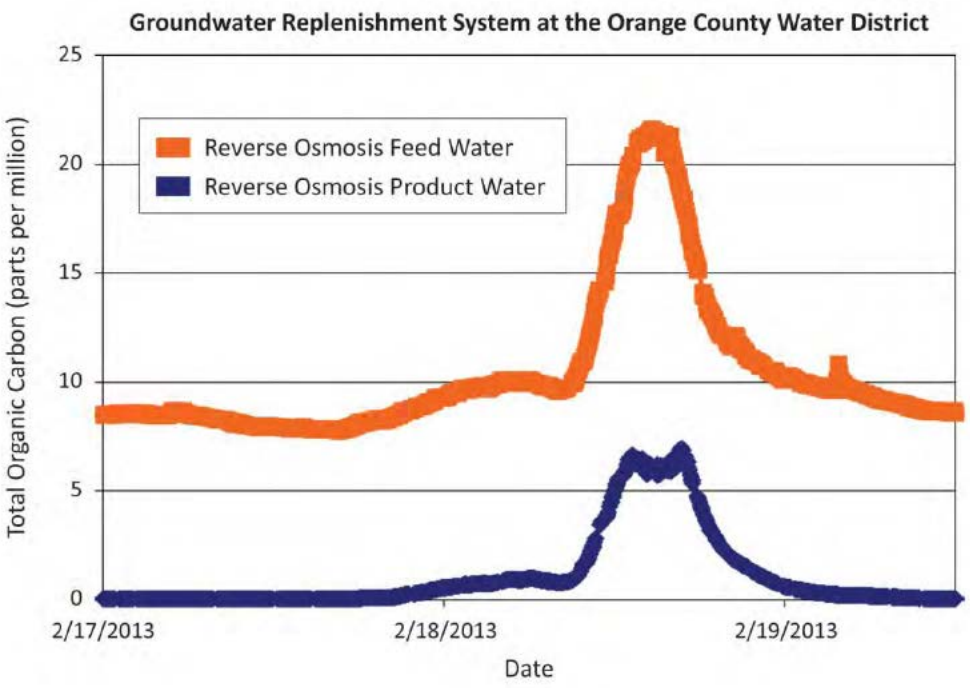


Figure 1 – Chemical Peak at Full-Scale Potable Reuse Facility (Figure 4-1: Results from online monitoring of total organic carbon before and after reverse osmosis (RO) at the Orange County Water District's Groundwater Replenishment System in February 2013 (Dadakis and Dunivin, 2013) from Olivieri et al. (2016))

Research Approach

DPR-4 investigates chemical peaks that can occur at full-scale potable reuse facilities and what can be done to address them. The research is comprised of three main components: 1) a Literature Review, 2) Case Study Investigation, and 3) Targeted Analyses at pilot or full-scale facilities. The Literature Review includes a listing of chemical families that can escape FAT, evaluation of real-time TOC data to determine the definition of a TOC peak beyond baseline, and treatment technologies and/or blending that average potential chemical peaks. The Case Study Investigation will contain technology descriptions, evaluation of illicit chemical discharges, source control programs and operational protocols for three full-scale FAT facilities. The Targeted Analyses will be focused on the efficacy of TOC as a surrogate for compounds that escape FAT and will include testing of spiked RO feed and permeate waters using different TOC analyzers.

Interim Results

DPR-4 was initiated in December 2018 and is scheduled to be completed in February 2020. The research team will present results of the literature review, including target contaminant identification, peak identification and potential treatment/blending strategies. Progress made on the Case Study Investigation and the Target Analyses will be presented as appropriate.

References

Drewes, J.E., Xu, P., Bellona, C., Oedekoven, M., Macalady, D., Amy, G. and Kim, T.-U. (2006). Rejection of Wastewater-Derived Micropollutants in High-Pressure Membrane Applications Leading to Indirect Potable Reuse, Report WateReuse Foundation, Alexandria, Virginia, USA.

Howe, K.J., Minakata, D., Breitner, L.N. and Zhang, M. (2019). Predicting Reverse Osmosis Removal of Unique Organics, Report The Water Research Foundation, Denver, Colorado and Alexandria, Virginia, USA.

Mestankova, H., Parker, A.M., Bramaz, N., Canonica, S., Schirmer, K., von Guten, U. and Linden, K.G. (2016). Transformation of Contaminant Candidate List (CCL3) compounds during ozonation and advanced oxidation processes in drinking water: Assessment of biological effects. Water Research, 93 (15 April), 110-120.

Olivieri, A., Crook, J., Anderson, M., Bull, R., Drewes, J., Haas, C., Jukubowski, W., McCarty, P., Nelson, K., Rose, J., Sedlak, D. and Wade, T. (2016). EXPERT PANEL FINAL REPORT: Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse, Report State Water Resources Control Board Division of Drinking Water, Sacramento, California, USA.

Plumlee, M.H., López-Mesas, M., Heidlberger, A., Ishida, K.P., and Reinhard, M. (2008). N-nitrosodimethylamine (NDMA) removal by reverse osmosis and UV treatment and analysis via LC-MS/MS. Water Research, 42(1-2), 347-355.

Characterization of Microbial Community in Pre-Ozonation and Biofiltration for Potable Water Reuse Reclamation

Lin Li, M.S., Reno, U.S.; Tatiana Guarin, M.S., Reno, U.S.; Vijay Sundaram, PE, Rocklin, U.S.; Lydia Peri, PE, Washoe County CSD, Reno;
[*]Krishna Pagilla, PE, Ph.D. Reno, U.S.
[*] Corresponding author: Dr. Krishna Pagilla. Email Address: pagilla@unr.edu

Abstract

Present study combined pre-ozonation and biofitration in indirect potable water reuse process development and analyzed the microbial community in the biofilters. Four operating strategies under different ozonation/TOC ratios have been applied during the study. 16S rRNA (V4 zone) of the biofilter biomass was sequenced on Illunima MiSeq platform. Bioinformatics analysis was performed by QIIME2 pipeline and PICRUSt2 pipeline. The results show that *proteobacteria* on phylum level was always dominant in all the samples; bacterial groups displayed different community composition at different sampling locations as well as different operating strategies. The biomass composition in water phase was significantly different with that in bio-filtration media. However, the bacterial functional pathway structure is quite stable in the process.

Keywords: Ozone-BAC; 16S rRNA sequencing; QIIME2; PICRUSt2; Microbial characterization; Indirect potable water reuse

Introduction

Potable water reuse has attracted significant public attention in recent years. Multiple studies have combined physical-chemical and biological treatment to remove contaminants of emerging concerns (CECs) in water reuse in order to meet the water quality requirements. Previous studies have proved that Ozone-biofiltration is an inexpensive and highly efficient method for degradation of CECs, however, the mechanisms still remain unknown, especially with respect to microbial community in the biofilter biofilms. Present study applied ozonation to enhance biological activated carbon filtration (Ozone-BAC) system for TOC and CEC removal. The development of next generation sequencing provides us a promising method to decipher the function/mechanism in biofiltration. Here, we aimed to test how the ratio of ozone dose/TOC influence the performance of Ozone-BAC system, and also cause the generation of bromate and Nitrosodimethylamine (NDMA). Microbial communities

vary in different steps of the system; and the community structures are correlated to the water quality in effluent, which means the characterization of microbial community is a crucial factor to decode the mechanisms of Ozone-BAC system (Gerrity et al., 2018).

This pilot project for production of potable water reuse quality is one of the very few to combine physical-chemical and biological treatment. The focus is on the correlation between ozone conditions and the function variation causing the change of microbial community, and hence the water quality in effluent. The results from this study will provide guidance for full scale implementation.

Material and Methods

Water and media samples were collected in November 2018 to Jan 2019 in South Truckee Meadows Water Reclamation Facility (STMWRF, Washoe County, NV, USA). The main influent water is the secondary effluent after granular media filtration in STMWRF. The schematic of Ozone-BAC system is shown in Figure 1. Present study consisted of four sampling events (SE1, SE2, SE3, and SE4 respectively) under different ozone/TOC ratio conditions. Sampling conditions are shown in Table 1. 2 L water samples were collected from influent, ozonation effluent and two BAC towers using sterilized amber bottles. Water samples were filtered by 0.2 um sterilized PES membrane filters and total DNA on the filters were extracted by DNeasy PowerWater Kit (QIAGEN, USA). 30 g BAC media were collected from BAC filter and DNA was extracted by DNeasy PowerSoil Kit (QIAGEN, USA). Total DNA samples were sent to RTL genomics (TX, USA) for 16S rRNA (V4 region) sequencing on Illumina MiSeq platform. DNA samples were amplified using universal bacterial primers 515F (5′-GTGCCAGCMGCCGCGGTAA-3′) and 806R (5′-GGACTACHVGGGTTC TAAT-3′) (Caporaso et al. 2011). Microbial community diversities of different water and media samples were analyzed by QIIME2 pipeline (Bolyen et al. 2018). Predicted functional profile by 16S rRNA sequencing data was performed by PICRUSt2 pipeline (Ye and Doak 2009).

Results and Discussion

1. Sequencing quality control

High throughput sequencing yielded more than 780,000 raw sequences in total of 20 samples. More than 99% sequences had an average read length of 280 bp. The total number of assigned reads ranged between 48,746 and 15,813, with a mean of

37,245 for all samples reads. The sequence number of each sample was normalized based on the minimum reads after taxonomic classification with a threshold of 0.95.

2. Analysis of bacterial community dynamics at different sampling location under different ozone/TOC ratio.

Overall, the most abundance groups include *proteobacteria, actinobacteria, bacteroidetes, and planctomycetes* on phylum level, which have been proved to be of high abundance in water and soil samples (Tamaki et al., 2005). However, addition of chlorine to secondary effluent can affect the relative bacterial community compositions. For example, influent samples in SE2 and SE3 shows the highest abundance in *beta-proteobacteria* (~83%). However, with chlorine, the relative abundance of *beta-proteobacteria* was decrease to 40%. After ozonation (in SE2, SE3, and SE4), *beta-proteobacteria* decreased more and with the increase of ozone/TOC ratio, which means ozonation may inhabit the growth of *beta-proteobacteria*, whereas, *alpha-proteobacteria* relative abundance showed an increase with more ozone dose. In media samples, the abundances of *beta-proteobacteria* was dominant in BAC1 filters but were all lower than that in water samples, which ranged from 24% to 36%. *Gamma-proteobacteria* were dominant in BAC2 filters in SE2 and SE3 (42% and 24%). Figure 2 showed overall results of relative microbial profiling on class level. Top 8 classes are selected. Figure 3 indicates the correlation between different samples according to abundance profiling in 21 samples. All of the media samples from different biofilters were all clustered compared with profiles in water samples. The results also indicate different filter with different EBCT tend to culture different microbial communities. With ozonation, SE2 and SE3 samples showed similar microbial abundance results, whereas a big difference was present in SE4, under the condition of the highest ozone/TOC ratio of 2.0. *Sphingobacteria* and *clostridia* are more abundant than that in the other samples. The highest ozone dose may be an important factor of this change. For effluents from two biofilters, no significant effect on microbial community change are found in both effluent samples.

3. Analysis of bacterial functional predictions at different sampling locations under different ozone/TOC ratio

MetaCyc ontology predictions were performed by PICRUSt2 pipeline in QIIME2, which can be comparable with common shotgun metagenomics outputs. Figure 4 shows the results of heatmap of inferred pathway abundance to predict absolute

functional gene families that can be linked to reactions within pathways. BAC1 media sample in SE3 shows the highest abundance of predicted gene families, whereas BAC2 media sample shows the lowest under sample ozone dose. Influent samples (SE1) shows the lowest gene family abundance, which is because of the adding of chlorine in the sampling day. With ozone dose increase, effluent samples from both biofilters tend to decrease, especially, no DNA was amplifiable after BAC2 in SE4.

Conclusions

The present study has revealed top four dominant bacteria group on phylum level in pre-ozonation and biofiltration system. *Proteobacteria* is dominant across the whole water line in four sampling events. Microbial community in water phase and media phase have shown different patterns. Abundance of predicted functional gene families in biomass showed BAC media samples tend to have more functional genes than water samples. The effluent samples from two biofilters did not show a significant trend, but under ozone/TOC of 1.5, the least abundance of functional genes in final effluents have been predicted.

References

Bolyen, E., Rideout, J. R., Dillon, M. R., Bokulich, N. A., Abnet, C., Al-Ghalith, G. A., ... & Bai, Y. (2018). QIIME 2: Reproducible, interactive, scalable, and extensible microbiome data science (No. e27295v1). PeerJ Preprints.

Caporaso, J. G., Lauber, C. L., Walters, W. A., Berg-Lyons, D., Lozupone, C. A., Turnbaugh, P. J., ... & Knight, R. (2011). Global patterns of 16S rRNA diversity at a depth of millions of sequences per sample. Proceedings of the national academy of sciences, 108(Supplement 1), 4516-4522.

Gerrity, D., Arnold, M., Dickenson, E., Moser, D., Sackett, J. D., & Wert, E. C. (2018). Microbial community characterization of ozone-biofiltration systems in drinking water and potable reuse applications. Water research, 135, 207-219.

Tamaki, H., Sekiguchi, Y., Hanada, S., Nakamura, K., Nomura, N., Matsumura, M., & Kamagata, Y. (2005). Comparative analysis of bacterial diversity in freshwater sediment of a shallow eutrophic lake by molecular and improved cultivation-based techniques. Appl. Environ. Microbiol., 71(4), 2162-2169.

Ye, Y., & Doak, T. G. (2009). A parsimony approach to biological pathway reconstruction/inference for genomes and metagenomes. PLoS computational biology, 5(8), e1000465.

Figures and Tables

Table 1 Sampling Conditions in Four Events

Sampling Event	Sampling Date	Ozone/TOC	Influent TOC	Flowrate
SE1[a)]	Oct 22 2018	0	7.0 mg/L	13 GPM
SE2	Dec 17 2018	0.9	8.1 mg/L	13 GPM
SE3	Jan 14 2019	1.5	7.5 mg/L	13 GPM
SE4	Jan 22 2019	2.0	7.3 mg/L	13 GPM

a) No ozonation applied in this sampling event, but with chlorination in the pilot influent, for regular algae control in STMWRF.

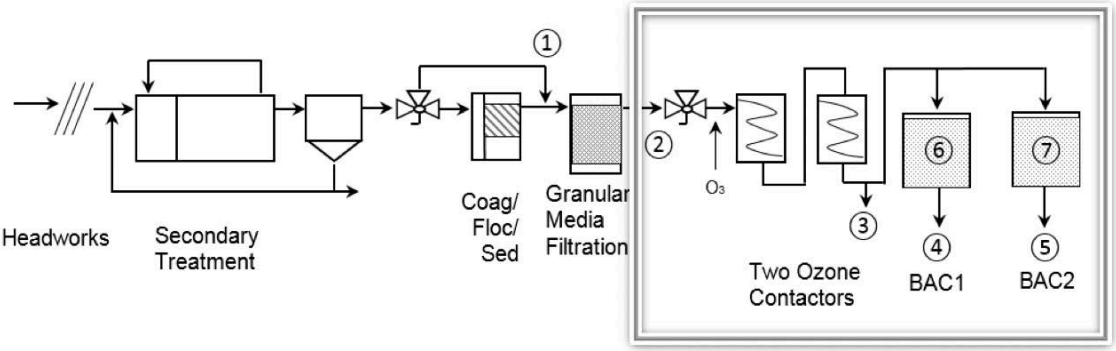


Figure 1. Schematic of Ozone-BAC system in present study. The pre-ozone oxidation includes two zone contactors in series, following by two BAC filtration towers in parallel with flow rates of 16 LPM/20 min EBCT and 32 LPM/10 min EBCT, respectively. The number indicating the sampling points. ① is the effluent from STMWRF; ② is the influent to the pilot; ③ is the effluent after ozonation; ④ and ⑤ are the effluents from two BAC towers. ⑦ and ⑥ indicate the media sampling location, for the study of bacteriology.

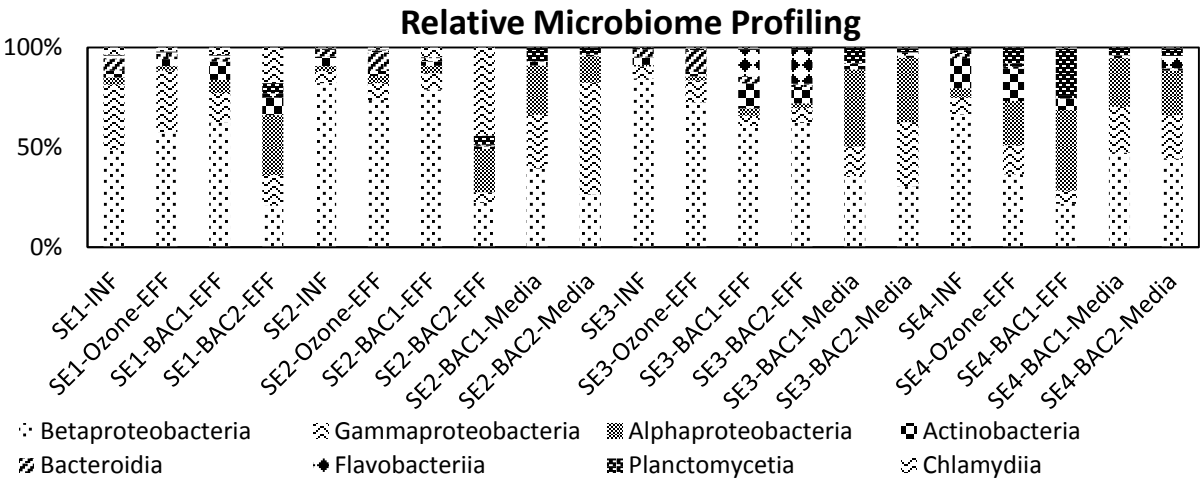


Figure 2. Relative microbiome profiling on class level. 8 high abundance class group are presented. SE1 to SE4 indicated four sampling events. INF means influent water sample, O3-EFF means the effluent after ozonation, BAC1-EFF and BAC2-EFF means two effluents after bioflitrations. BAC1-Media and BAC2-Media means two activated carbon media samples.

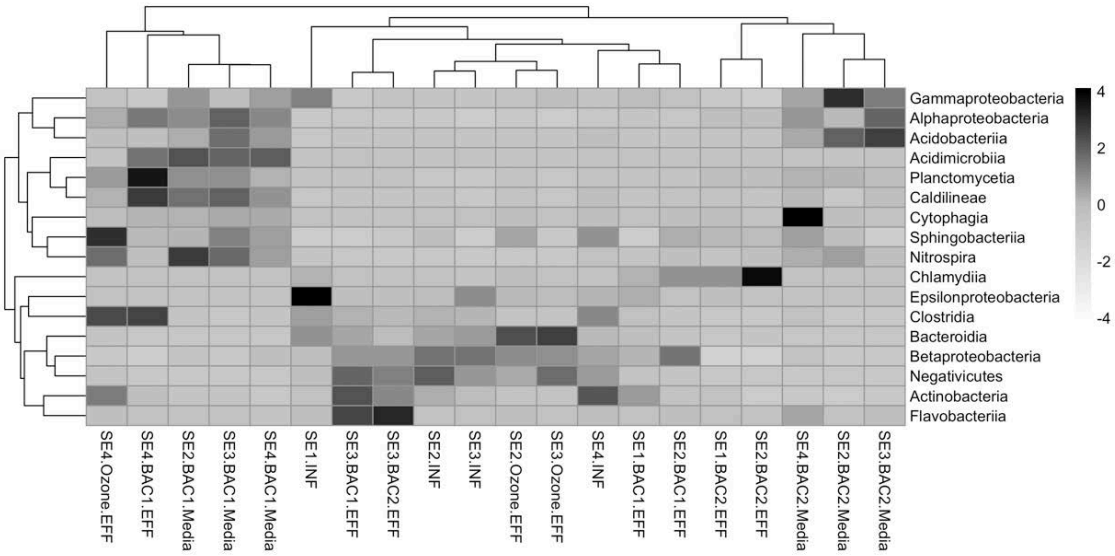


Figure 3. Heatmap showing the clustering samples, based on relative abundance and samples correlations of microbiome profiling on class level.

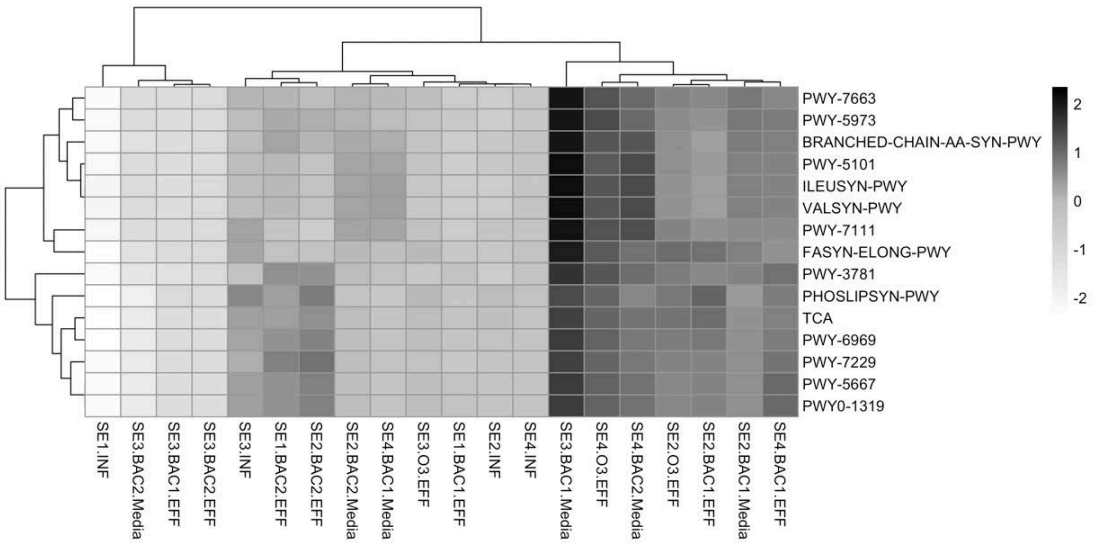


Figure 4. Heatmap showing the clustering of samples, based on infer pathway abundance according to predict absolute functional gene families that can be linked to reactions within pathways (numbers regrouped to MetaCyc reactions be default).

Reclamation of secondary effluents from the municipal wastewater plant – A pilot test and economic evaluation

Chen-Hua Ni, Eco-digital Technology Inc.,Taipei, Taiwan, (E-mail: frankni@ecod.com.tw);
Yu-Chung Lin, EigenGreen International Inc., Taipei, Taiwan, (E-mail: murphyyclin@eigengreen.com)
Chia-Yuan Chang, Department of Environmental Engineering and Science, Chia Nan University of Pharmacy and Science, Tainan 71710, Taiwan, (E-mail: chadjamei@yahoo.com.tw)
Justin C.T. Lin , Department of Environmental Engineering and Science, Feng Chia University, Taichung,Taiwan, (E-mail: jlin0623@gmail.com)

Abstract

A containerized Mobile Wastewater Recycling System (MWRS) was built to demonstrate technical as well as economic feasibility to reclaim secondary effluent from a large municipal wastewater treatment plant in southern Taiwan. The MWRS consisted of three units, including an auto-cleaning filter, a pressured ultrafiltration (UF) and subsequent two-stage reverse osmosis (RO) membranes which were installed in a 20” container. Performing test shows that the treated water is much better than current quality of portable water and can be adopted for supplying manufacturing water in the neighbourhood industrial factories. The system stability was validated through three-months continuous operation. Based on the pilot study and obtained operation parameters, a full-scale reclamation plant with 45,000 CMD was deigned accordingly. Economic evaluation was estimated. The unit cost including CAPEX & OPEX was estimated to be USD 0.28 & 0.29 per cubic meter of water.

Keywords: containerized mobile pilot, secondary effluent, municipal sewage reclamation, ultrafiltration, reverse osmosis

Introduction

A new law entitled "Reclaimed Water Resources Development Act" was announced in 2016. It is aimed to promote the development, supply, use and management of reclaimed water in Taiwan and to provide a clear legal framework for the recycling/reuse of wastewater/sewage effluents. Taiwan is earmarking a multi-billion dollars budget to start the action. In the future, total capacity of reclaimed water is expecting to achieve 1.32 million CMD in 2031 which is about 10% of the supply of the public water supply system. Taiwan will enter a new era of diversified water resources. (Chen , 2018)

As effluent from municipal wastewater treatment plants (WWTPs) is the major source of reclaimed water, Taiwan plans to clean up municipal wastewater. Targeting reclaimed capacity from WWTPs is estimated to contribute more than half (0.77million CMD) (Chiou et al, 2007). In addition to the water from reservoirs, rivers, underground aquifers, underflows and seawater desalination, reclaimed of effluent from wastewater treatment plant will be included as a new alternative in Taiwan. (Huang et al, 2016)

In Taiwan, only few pilot plant tests are performed to demonstrate the technical and economic feasibility to reclaim the biological secondary effluent(BSE) in the past few years. Chen et al (2005) conducted a 50 m3 /day pilot plant test with UF/RO membranes

and biological systems in an industrial park WWTP located north of Taiwan. The cost was estimated at USD 0.54 dollar per cubic meter of water including CAPEX & OPEX cost for a production capability of 10,000 m3/day full-scale plant. Ni et al.(2017) performed a pilot system combined with submerged micro-filtration and RO membranes to reclaim the biological secondary effluents of WWTP from the petrochemical industry. Excellent water quality still fulfils the requirements for cooling water make-up or process water. The unit cost was estimated at USD 0.73 dollar per cubic meter of water for a production capability of 1,400 m3/day reclamation plant.

In this study, a containerized Mobile Wastewater Recycling System (MWRS) was built to demonstrate technical as well as economic feasibility to reclaim secondary effluent from a large municipal wastewater treatment plant in southern Taiwan. It aims to indentify the real performance and stability of the UF+RO processes, and then obtain the datas for further design of the full-scale wastewater reclamation plant with producing 45,000 CMD capacity of reclaimed water. The economic feasibility such as OPEX & CAPEX costs should be also evaluated for considering the possibility to sale the reclaimed water to the manufacturing factory located in the neighbourhood industrial park.

Material and Methods

Characteristics of Biological Secondary Effluent (BSE)

A containerized Mobile Wastewater Recycling System (MWRS) was built for testing on-site to reclaim secondary effluent from a large municipal sewage wastewater treatment plant in southern Taiwan. Figure 1 shows the process scheme of the existing plant. The treatment capacity is 75,000m3/day and the processes includes coarse/fine screen, aeration grit, preliminary settler, trickling tower, aeration activated sludge, secondary sedimentation and disinfection. BSE was taken from the outlet of sedimentation and pumped to the MWRS to treat. Characteristics of BSE in the WWTP were examined as shown in Table 1. The water parameters were persued analytical guideline of standard methods.

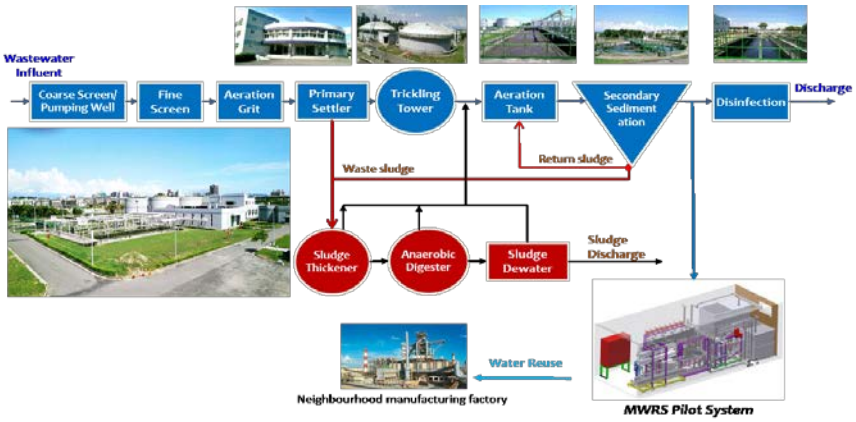


Figure 1 Process scheme and BSE source of the existing municipal sewage treatment plant

Mobile Wastewater Recycling System (MWRS)

Figure 2 shows the process scheme of Mobile Wastewater Recycling System (MWRS) for this test. The MWRS equipped with wastewater storage tanks, an auto-cleaning filter(ACF), a pressured ultrafiltration (UF) membrane unit and subsequent two-stage reverse osmosis (RO) membranes. Operational parameters such as flow, pressure, level with running settings for UF/RO membrane processing and cleaning are easy to access

and adjust via a human-machine interface(HMI) panel. All components were installed on a movable 20” container (L: 6 m, W: 2.4 m, H: 2.6 m). Therefore, it can be used to conduct demonstration tests in different wastewater treatment sites.

The MWRS capacity of producing reclaimed water is 36 CMD under the system recovery being operated between 65 and 78%. The UF membrane was hollow-fiber ultra-filtration PES membrane (model: Pentair Xiga module) with average pore size of 0.2 μm and surface area of 64 m2 per module. The Flux kept at 60~70 LMH with average permeate flow at 3~5 m3/hr. Operation modes of the UF unit include filtration, backwash and CEB with recovery rate at 90~92% RO unit was equipped with two low-pressure, antifouling polyamide spiral wound modules (Model: Nitto Denko, PRO-20 Module, Size 8040, 37.8 m2 per module). RO configuration was designed as one pass with two stages, whereas overall RO water recovery rate was tested at 65-75%. The RO unit can produce water in capacity of 1.5~1.8 m3/hr with flux at 18~20 LMH.

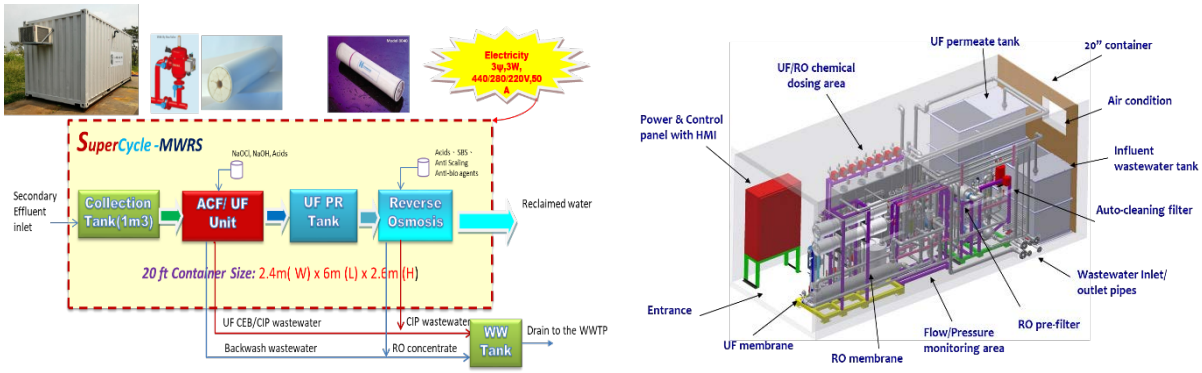


Figure 2 Process scheme and layout of the Mobile Wastewater Recycling System (MWRS)

Results and Discussion

Water quality performance validation

Table 1 indicates the biological secondary effluent and treated water quality. The feed secondary effluents with slight alkaline (pH 7.0~7.4) become slight acidic (pH 5.6~6.8) in the outflow of pilot unit. Turbidity and suspended solids were respectively decreased from 1.1~11.0 to 0.2 NTU and from 1.6~32.4 to below 1 mg/L, which showed a promising capability even fluctuations of feed effluent. For organic contaminants, original chemical and biochemical oxygen demands were respective between 5~20 mg/L (COD) and 2~5 mg/L (BOD); however, total organic carbon (TOC) in the reclaimed water was below 1 mg/L. For hardness, conductivity, SiO2 content and ammonia nitrogen, significant removals were achieved as high as 97.1%, 95.1%, 91.3% and 90.8%, respectively. Such results were all much better than current quality of portable water and can be adopted for supplying manufacturing water in the neighbouring industrial factories.

Operating stability validation

Variation of UF flow &TMP

UF system stability was validated through three-months continuous operation. Figure 3 indicates the variation of UF flowrate and trans-membrane pressure (TMP) during

operating period. The UF permeate can be consistently produced as flux of the UF unit set at 60~67

Table 1 Comparison of treated water BSE and quality

Item	Unit	BSE Inlet (Ave.)	UF Filtrate (Ave.)	RO Permeate (Ave.)	Reclaimed Water Required
Temp.	˚C	28.2	28.5	28.6	15~35
pH		7.1	7.2	6.1	5.5~8.0
Turbidity	NTU	2.8	≦0.5	≦0.2	≦0.2
SS	mg/L	4.5	≦1.0	≦1.0	≦3
COD	mg/L	15.1	14.1	≦3.6	
TOC	mg/L	3.6	--	≦1.1	≦5
Conductivity	µS/cm	950	940	≦60	≦100
T. Hardness	mg/L asCaCO3	245	---	≦7.1	≦20
Calcium	mg/L	189	---	≦5	---
M-Alkalinity	mg/L asCaCO3	132	---	≦30	---
Ammonia	mg/L	10.1	---	≦1.05	≦0.5
SiO2	mg/L	16	---	≦1.0	---
T. Iron	mg/L	0.03	---	≦0.02	---
Manganese	mg/L	0.13	---	≦0.02	---
Chloride	mg/L	58	---	≦3.0	---
Sulphate	mg/L	120	---	≦0.5	---
Phosphate	mg/L	7.5	---	≦0.5	---

LMH. Backwash of the UF unit was set 40 seconds every 30-min filtration, and maintenance chemical enhanced backwash was carried out every 27 hours. For the earlier two months running. the resulting TMP of the UF unit was kept constantly between 0.2 and 0.7 kg/cm2, which were still lower from the setting scenario (TMP over 0.8 kg/cm2) for chemical cleaning-in-place (CIP). After two months running, the UF membrane was removed out for checking fouling issues and off-site CIP cleaning with oxalic acid (2000 mg/L). After CIP cleaning, the UF TMP kept 0.18~0.4 kg/cm2 running until the end of testing.

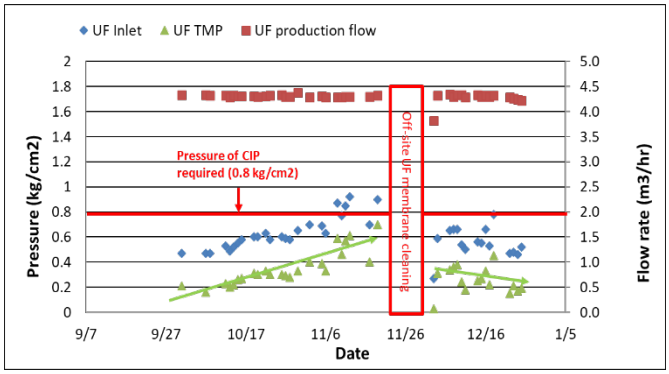


Figure 3 Variation of UF flowrate and trans-membrane pressure (TMP) during operating period.

Maintenance Enhanced Cleaning(CEB) of UF system

For the UF unit operation mode, filtration (flux:67LMH) was kept every 30 min and 40 seconds backwash (flux:88LMH). On-line Maintenance Enhanced Cleaning(CEB) was automatically done after 28 times of filtration-backwash cycles to reduce the UF fouling. Figure 4 shows the another record cleaned by CEB1(NaOCl: 500mg/L+NaOH:1000mg/L) then followed by CEB2(HCl: 1000mg/L). The result indicates that the TMP drops from 0.32 to 0.18kg/cm2 by (CEB+CEB2). The result shows that the major foulants of UF

membrane are bio-mass colloid and algae caused from secondary effluent and with slight inorganic substances.

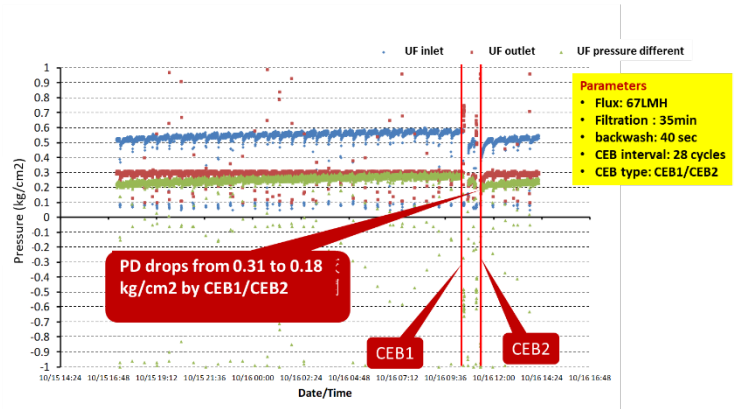
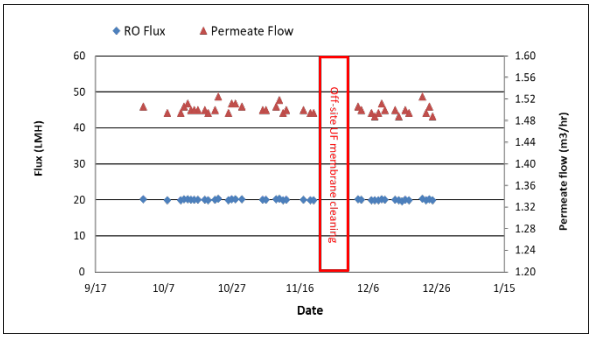
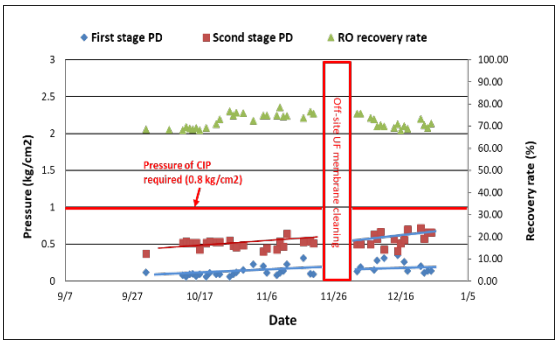


Figure 4 UF fouling cleaned by CEB1 (NaOCl: 1000mg/L+NaOH:500mg/L) and CEB2(HCl: 1000mg/L).

Variation of RO flow & operating pressure

Figure 5 shows the variation of flow and average flux for RO unit. The RO unit was kept running stably under the flux and permeate flow at 20 LMH and 1.48~1.52m3/hr respectively. Figure 6 shows the variation of RO pressure difference (first and second stage) and RO system recovery. During the three months period, the RO system recovery was tested for the range of 65~78% where pressure difference of the first stage (0.05~0.4 kg/cm2) and the second sage (0.4~0.8 kg/cm2) were both below the suggesting value of over 1 kg/cm2 for CIP. It shows a promise result that RO fouling/scaling issues can be under control and RO CIP interval is more





than 2 months

Figure 5 Variation of flow and average flux for RO unit...**Figure 6** Variation of RO pressure difference (first and second stage) and RO recovery.

CAPEX & OPEX estimation for a full-scale plant

Based on the three-months pilot study of the MWRS and obtained operation parameters, a full-scale reclamation plant with production of 45,000 CMD reclaimed water was deigned accordingly. The full-scale plant was pre-design using the process units including the disc-filter unit (as an energy saving tertiary filter instead of sand filter), hollow fibre ultra-filtration and reverse osmosis (one pass two stage). The layout including a disc-filter treatment zone, a UF facility building, a RO facility building, management and control rooms and an exhibition centre.

Moreover, economics evaluation can then be estimated. Table 2 shows the estimated CAPEX & OPEX result. OPEX includes the electricity, chemicals, consumable parts and labor/management fee. The unit cost of OPEX is estimated to be USD 0.28 per cubic meter of reclaimed water. The unit cost of CAPEX is estimated to be USD 0.29 by considering the hardware amortization at 15 years. The total unit cost is estimated to be USD 0.57 per cubic meter of reclaimed water.

Table 2 CAPEX & OPEX estimation for the full-scale plant.

Item	Disc-filter + UF + RO	Remark
Feed flow (CMD)	67,000	
Recovery rate (%)	≧ 67	For the whole plant
Reclaimed water flow(CMD)	≧ 45,000	
Recycled water grade/ reuse purpose	As portable water / Cooling make-up & Process water for manufacturing	
OPEX (USD/m^3)	0.28	
1. Electricity fee	0.11	Unit electricity fee: 0.084USD/kwh
2. Chemicals fee	0.04	Chemicals for membrane cleaning
3. Consumable parts	0.05	• Including filter : Every one month • Membranes: UF life time 4 years, RO life time 4 years, Off-site cleaning every one year
4. Labor & Management	0.03	Man power, administration, water analysis, equip. maintain and others
CAPEX (USD/m3)	0.29	Amortization for 15 years
OPEX & CAPEX (USD/m3)	0.57	Price accepted by factory≦0.6

Conclusions

A containerized Mobile Wastewater Recycling System (MWRS) was built and successfully demonstrate technical as well as economic feasibility to reclaim secondary effluent from a large municipal wastewater treatment plant in southern Taiwan. Reclaimed water quality are better than current quality of portable water and can be adopted for supplying manufacturing water in the neighbouring factories. A full-scale reclamation plant with producing 45,000 CMD reclaimed water was deigned accordingly. The estimated OPEX & CAPEX costs are USD 0.57 per cubic meter of water.

References

Chen J.W. (2018). The Introduction of Wastewater Reclamation in Taiwan. Proceeding of Taipei International Water Environment Forum, Taipei, Taiwan

Chiou RJ, Chang TC, Ouyang CF. (2007). Aspects of municipal wastewater reclamation and reuse for future water resource shortages in Taiwan. *Water Sci Technol.* , 55(1-2):397-405.

Huang Y.D. ,Chu C.P. , Liu S.R. (2016). The Current Status of Wastewater Reclamation/Reuse in Taiwan, Proceeding of the 12th International Conference on Hydroscience & Engineering Hydro-Science & Engineering for Environmental Resilience, Tainan, Taiwan.

Chen H.H., Yeh H.H., Shiau S. (2005). The membrane application on the wastewater reclamation and reuse from the effluent of industrial WWTP in northern Taiwan, *Desalination*,185(1~3), pp 227-239

Huang L., Development of Reclaimed Water Resources – the Reclaimed Water Resources Development Statute and its Ancillary Laws(Taiwan)
Ni C.H., Lin Y.C., Chang C.Y., Lin J. C.T., (2017). Recycling of Biological Secondary Effluents in Petrochemical Industry Using Submerged Microfiltration and Reverse Osmosis- Pilot Study and Economic Evaluation", *Journal of Desalination and Water Treatment,* 96: pp 45-54

Real-time bacteriological counting for integrity monitoring of reverse osmosis treatment for potable reuse

Takahiro Fujioka, Nagasaki University, Nagasaki, Japan; Menu Leddy, Essential Environmental and Engineering Systems, Huntington Beach, CA, USA; fujioka@nagasaki-u.ac.jp

Abstract:

Monitoring water quality of recycled water plays a critical role for ensuring public health protection for potable reuse. This study assessed the efficacy of online bacterial counting for monitoring the integrity of reverse osmosis (RO) membrane process for the removal of bacteria. This pilot-scale study was conducted by monitoring bacterial counts in RO feed and permeate using real-time bacteriological commercial counters. During a 7-day test, online bacterial counts in the RO permeate were below 15 counts/mL. In contrast, bacterial counts in the RO feed ranged from approximately 2,500 to 10,000 counts/mL. These data enabled to continuously determine bacterial removal rates at 2.6–3.1-log. Overall, online monitoring of bacteria provides greater assurance of microbial water quality by RO treatment.

Keywords: bacteriological counter; bacterial removal; RO; water reuse

Introduction

Rigorous monitoring of microbial water quality is essential to ensure the safety of recycled water for potable reuse. Among advanced wastewater treatment processes, reverse osmosis (RO) membrane process plays an important role in removing microorganisms and pathogens in wastewater. However, the credibility of RO membranes for the removal of microorganisms remains low. This is due to the fact that current RO membrane integrity monitoring methods are based on the removal of surrogate substances (e.g., electrical conductivity); thus, it can provide up to a 2-log (i.e., 99%) pathogen reduction. To improve the credibility of RO process performance for contaminant removal, this study evaluated the efficacy of a real-time bacteriological counting technology for continuous monitoring the integrity of RO membranes for the removal of bacteria.

Material and Methods

A pilot-scale RO filtration system used in this study was comprised of a 4-inch spiral wound RO membrane element (ESPA2-LD-4040) provided by Hydranautics/Nitto (Oceanside, CA, USA). The RO feed was a membrane bioreactor (MBR) effluent. The RO system was operated at a permeate flux of 19–20 L/m^{2}h and a transmembrane pressure of 0.7 MPa. Two real-time bacteriological counters (IMD-WTM, Azbil Corporation, Tokyo, Japan) were installed in the RO feed and permeate. The analytical system is based on the identification of (a) scattered light for counting particles in water and (b) auto-fluorescence emission light emitted from total bacteria. Further information of the analytical instrument in previous studies (Fujioka et al., 2018; Fujioka et al., 2019). Bacterial counts in the RO feed exceeded the capacity of the instrument; therefore, prior to the entry of the instrument the RO feed underwent a 50-fold dilution using RO permeate that was subsequently filtered with MF filter.

Results and Discussion

Over the course of the 7-day test, online bacterial counts in RO permeate were continuously monitored below 10 counts/mL **(Figure 1)**. The results indicate that bacteria in RO permeate can be identified at low concentrations. However, the mechanisms underlying the bacterial passage still remains unclear. In contrast to the RO permeate, bacterial counts in the RO feed were monitored at approximately 2500 to 10,000 counts/mL. There were large variations in bacterial counts in the RO feed due to the operational events (e.g., system halt) and changes in wastewater quality during the pilot-scale test. The bacterial counter measurements were verified by comparing with three other established methods: flow cytometry, epi-fluorescence microscopy, and plate counting (data not shown here).

Bacterial removal rates calculated by online bacterial counts were approximately 2.3–3.7-log **(Figure 2)**, which corresponds to 99.40–99.98%. The removal rate was greater than a 2-log reduction, which is the maximum log removal rate determined using conventional surrogates (i.e., electrical conductivity). This is important because bacterial counts and their removal are directly related to pathogen control and management. The results here suggest that online bacterial monitoring in the RO feed and permeate can be applied to ensure RO membrane integrity, providing greater assurance for recycled water.

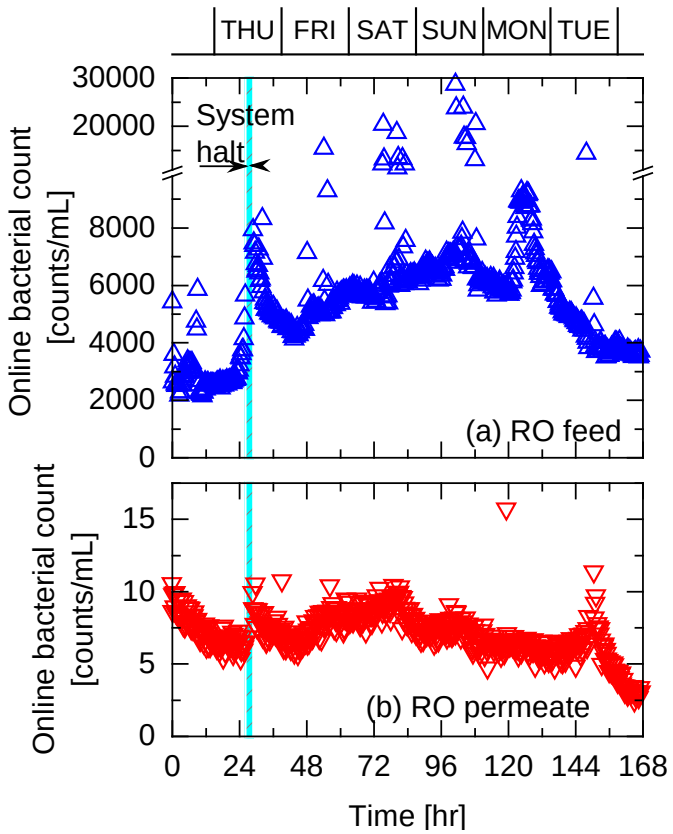


Figure 1 Bacterial counts of (a) RO feed and (b) RO permeate every 5 min during RO treatment of MBR effluent at the pilot scale.

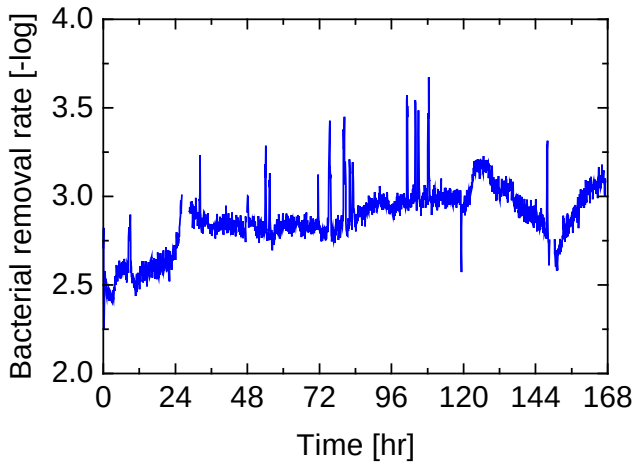


Figure 2 Bacterial removal rates determined by online bacteriological counters.

Conclusions

Online monitoring using real-time bacteriological counters continuously provided bacterial counts in RO feed and permeate. The bacterial count data enabled to

continuously provide bacterial removal rates, which were greater than the conventionally determined bacterial removal rates (e.g., 2-log). The high bacterial removal rates through online bacterial counting can provide higher credibility for bacterial removal by the RO process. Overall, the results in this study suggest that an online bacterial counter can be used for the integrity monitoring of RO treatment performance for bacterial removal.

References

Fujioka, T., Hoang, A.T., Aizawa, H., Ashiba, H., Fujimaki, M. and Leddy, M. (2018) Real-Time Online Monitoring for Assessing Removal of Bacteria by Reverse Osmosis. Environ. Sci. Technol. Letters 5(6), 389-393.

Fujioka, T., Makabe, R., Mori, N., Snyder, S.A. and Leddy, M. (2019) Assessment of online bacterial particle counts for monitoring the performance of reverse osmosis membrane process in potable reuse. Sci. Total Environ. 667, 540-544.

Validation of ceramic membrane filtration for removing enteric viruses in tertiary treated wastewater

Takashi Yonetani, METAWATER co., ltd., Tokyo, Japan; Akihiko Hata, the University of Tokyo, Tokyo, Japan; Yasuhiro Matsui, METAWATER co., ltd., Tokyo, Japan; Luisa A. Ikner, The University of Arizona, Tucson, AZ, USA; Charles P. Gerba, , The University of Arizona, Tucson, AZ, USA; Hiroyuki Katayama, the University of Tokyo, Tokyo, Japan

Background

In California and other states in the U.S., it is recommended that enteric virus levels in raw wastewater be reduced by 12-$\log_{10}$ based on the log credit approach for direct potable reuse. Log_{10} reduction values (LRVs) have been determined for several established water reclamation processes. The sequential treatment process of coagulation-microfiltration can be applied for the removal of pathogens including small viruses (20-100 nm in diameter) when ceramic membranes characterized by a uniform pore size distribution are employed. However, $\log_{10}$ reduction values for coagulation-microfiltration (CMF) as an advanced water treatment process have yet to be formally established for infectious viruses at a level acceptable for practical use. In general, reduction efficiencies for treatment technologies are determined using a specific target virus spiked into a specified water quality matrix. Bacteriophages including MS2 and Phi-X174 are generally employed for this purpose as they can be readily propagated to high titers (>10^{10} PFU/mL), thereby allowing for the determination of virus reduction from large volumes of test waters (e.g. >100 L). Of concern, however, is whether the spiked viruses accurately reflect the condition and reduction capacity of viruses indigenous to wastewater. Recent studies have demonstrated that Pepper Mild Mottle Virus (PMMoV), a pathogenic plant virus, is present more consistently and at greater concentrations in raw and treated wastewaters than many human enteric viruses (Symonds et al., 2018; Kitajima et al., 2018). The objectives of the study described herein are to calculate LRVs, and to validate the use of spiked bacteriophages and indigenous PMMoV as indicators of human enteric virus removal during coagulation-CMF as a direct potable reuse water treatment process.

Materials and Methods

Viral removal efficiencies from tertiary wastewater effluent using coagulation-CMF were evaluated by bench-scale units in both Japan and the U.S. The tertiary effluent underwent coagulation with high-basicity poly-aluminum chloride (PACl, 6.2 mg-Al/L) immediately prior to CMF at 500 mL/min. The coagulation was conducted via an in-line mixer, and a ceramic membrane (0.08 m^2 filtration area) was operated at 145 mL/min (corresponding flux = 100 lmh).

Infectious bacteriophages MS2, fr, and Phi-X174 were spiked during separate batch experimental runs into the tertiary effluent feed water at target densities of 6.0 to 6.5 $\log_{10}$ PFU/mL. Concentrations of the spiked viruses in both the feed and filtrate samples were determined using double-layer overlay agarose plaque assays in conjunction with permissive bacterial host culture strains.

For indigenous PMMoV testing, 100 L of tertiary effluent was subjected to coagulation-CMF over a 18-hour operational period via a sequential filtration run and backwash procedure, during which the filtrate volume was collected for further concentration. Quantification of indigenous PMMoV was conducted using 2 L and ~100 L of the feed and filtrate, respectively, by way of the VIRADEL (virus adsorption elution) method employing electronegative MF followed by centrifugal ultrafiltration for secondary concentration (Katayama et al., 2002; Hata et al., 2015). PMMoV levels in the feed and filtrate were determined by RT-qPCR using the virus concentrates. The sample volumes applied to RT-qPCR were equivalent to 150 mL and 7500 mL of feed and filtrate, respectively, assuming 100% recovery through the entirety of the process.

Results and discussion

Indigenous PMMoV in feed water sample concentrations ranged from 10^5 to 10^9 genomic copies/L (N = 21). Reduction efficiencies of PMMoV by the coagulation-CMF process were evaluated six times, and the $\log_{10}$ reduction values ranged from 4.5 to 4.8 $\log_{10}$. Four test runs resulted in values below the limit of detection for PMMoV in the filtrate; for these experimental runs, the $\log_{10}$ reduction values measured from >3.4 $\log_{10}$ to >4.7 $\log_{10}$, which were in agreement with the values obtained from the tests during which PMMoV was detected in the filtrate. The batch tests utilizing the spiked bacteriophages were conducted four times for each of the three strains. MS2 and fr bacteriophage levels were below the limit of detection (1 PFU per 10 mL) in the filtrate volumes for all four tests, while Phi-X174 was

consistently detected in the filtrate. Overall $\log_{10}$ reduction values for MS2, fr, and Phi-X174 measured as > 7 $\log_{10}$, > 7 $\log_{10}$, and 3.3 ± 0.2 $\log_{10}$, respectively. The results indicate that viral reduction efficiency by coagulation-CMF is dependent on morphology and viral surface properties including surface charge, hydrophobicity, and isoelectric point. Further studies are required to identify the cause(s) of the observed type/strain-dependent viral removal. In this study, the removal efficiency of indigenous viruses by the coagulation-CMF process was successfully estimated by using PMMoV. However, the concentration of PMMoV in the filtrate was close to the detection limit during many experiments. Therefore, measures to improve the sensitivity for PMMoV detection are under evaluation to better evaluate the actual LRVs achieved during coagulation-CMF treatment.

Anaerobic secondary treatment and potable reuse: RO fouling and DBP formation

Aleksandra Szczuka, Department of Civil and Environmental Engineering Stanford University, Stanford, CA, USA; aszczuka@stanford.edu

William A. Mitch, Department of Civil and Environmental Engineering Stanford University, Stanford, CA, USA; wamitch@stanford.edu

Abstract

This study evaluates the effect of various disinfection schemes applied to anaerobic effluent (from a pilot-scale anaerobic membrane bioreactor) on organic fouling of reverse osmosis (RO) membranes alongside expected disinfection by-product (DBP) formation and DBP associated toxicity in final potable reuse effluents (evaluated at lab scale). The results show that ozonation reduces the organic fouling potential. Regardless of the disinfection used, the total DBP concentration in final potable reuse trains was below 5μg/L and the calculated DBP associated toxicity was at least 4-fold lower than previously observed for aerobic secondary treatment based potable reuse trains. The results of this study demonstrate that anaerobic secondary treatment is promising for potable reuse applications.

Keywords: RO Fouling, DBP Formation, Anaerobic Treatment

Introduction

Water utilities are increasingly turning to energy efficient technologies to reduce treatment costs and meet sustainability goals. Anaerobic secondary treatment reactors are promising replacements to aging aerobic secondary treatment infrastructure, as they have the potential to substantially reduce the energy cost and footprint of wastewater treatment (McCarty et al., 2011). While aerobic systems require significant energy input for aeration and generate significant quantities of secondary biosolids for disposal, anaerobic systems avoid aeration, generate methane that can be harvested for energy generation (energy recovery conservatively estimated at 0.14 kWh/m^3 for medium strength wastewater), and can reduce secondary biosolids generation and associated disposal costs by up to 90% (Shin et al., 2014; McCarty et al., 2011). One such anaerobic technology, the Staged Anaerobic Fluidized Membrane Bioreactor (SAF-MBR), has been demonstrated to achieve standard effluent limitations for surface water discharge (i.e., BOD5 and

TSS) at ~6hr hydraulic retention times in temperatures as low as ~10°C during pilot-scale treatment of authentic sewage over a year-long period (Shin et al., 2014). This pilot-scale evaluation has shown that SAF-MBR treatment is a promising alternative to current aerobic secondary treatment.

However, for utilities who seek to meet future water demand through potable reuse, the compatibility of anaerobically treated secondary effluent with full advanced treatment (FAT) trains has not been evaluated. The energy cost of FAT, which traditionally consists of microfiltration (MF), reverse osmosis (RO), and a UV based advanced oxidation process (AOP), is closely tied to the operational energy costs of membrane treatment units (Gerrity et al., 2014). In particular, fouling of RO membranes, caused largely by effluent organic matter and biofilm growth, can increase the cost of treatment (Guo et al., 2012). In order to control biofilm growth, disinfectants, such as chloramines, are applied upstream of RO treatment units. Applied disinfectants can alter the sorption characteristics of the organic constituents in RO influent, rendering them more or less likely to sorb to RO membranes (Lee et al., 2006). Once biofilm growth is controlled through disinfection, organic fouling can be the major fouling mechanism of RO membranes (Xu et al., 2010). Hence, disinfectants that reduce the fouling propensity of organic matter can help lower energy costs of water production.

At the same time, when secondary effluent that contains effluent organic matter is disinfected upstream of RO units, disinfection by-products (DBPs) may form. DBPs are important contaminant classes for potable reuse effluents because some of these classes are regulated, and because previous research has indicated that their concentrations in potable reuse effluents may be far closer to those of human health concern than some other contaminant classes (e.g., pharmaceuticals (NRC, 2012)). Low molecular weight halogenated DBPs can pass through RO membranes and AOP treatment and can be present in concentrations of concern in reuse train effluents (Zeng et al., 2016). Unregulated DBPs classes, such as haloacetonitriles, are of increased concern: they have been shown to contribute more to DBP-associated toxicity than regulated DBP classes (Zeng et al., 2016). Much like the fouling propensity of RO membranes can be dependent on the disinfectant used, regulated and unregulated DBP formation can be dependent on the type of disinfectant used upstream of RO membranes.

The goal of this study is to assess the effect of disinfectants on RO membrane fouling alongside DBP formation and DBP associated toxicity. Anaerobically treated bioreactor effluent was collected from a pilot-scale SAF-MBR and treated with various combinations of chloramines, ozone, and biological activated carbon (BAC) filtration. The RO fouling potential of each disinfection scheme was evaluated and correlated to changes in properties of the organic matter. DBP formation and toxicity was evaluated at lab scale across a treatment train that included RO, an UV/H_2O_2 AOP, and chloramination.

Material and Methods

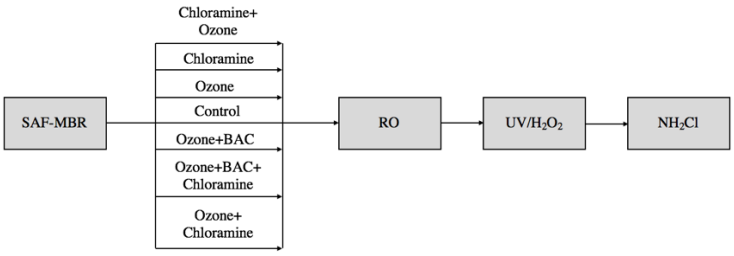


Figure 1. Treatment train used in the study.

Anaerobically treated effluent was collected from a pilot scale SAF-MBR, filtered with a propylene cartridge filter (1 μm, Culligan, USA) and 0.7 μm glass fiber filter (Whatman GF/F) and stored at 4°C prior to use. Samples were treated with various combinations of 0.8 mg O_3/mg DOC of ozone, 3.5 mg-Cl_2/L chlorine (forming chloramines in situ), or passed through a 30 min empty bed contact time of BAC (Figure 1). The RO membrane fouling potential of the pretreated effluent was evaluated using a lab scale crossflow RO membrane unit described previously in Steinle-Darling et al. (2005) by adapting techniques to measure flux decline through the membrane described previously in Lee et al. (2006). The changes in properties of the organic matter caused by disinfection were evaluated using a polarity rapid assessment method (PRAM) described previously in Rosario-Oritz et al. (2007). Briefly, polarity of the organics was assessed by passing the disinfected effluent through a C18 (hydrophobic bead) or Diol (hydrophilic bead) cartridge.

As can be seen in figure 1, RO effluent samples were treated by a UV/H_2O_2 AOP. 3 mg/L of H_2O_2 was added to the samples and a germicidal fluence of 700 mJ/cm^2 was targeted. After AOP treatment the pH of the samples was adjusted to 8 with 4mM borate buffer. Samples were then treated with 5 mg/L of monochloramine, and held

in the dark at room temperature for 3 days to mimic distribution system conditions. After 3 days, residual monochloramine was quenched with 33 mg/L ascorbic acid. At the end of treatment train in figure 1, samples were collected for DBP analyses. 43 DBPs were analyzed in the same fashion as previously described in Zeng et al. (2016). DBP associated toxicity was calculated as described in Zeng et al. (2016).

Results and Discussion

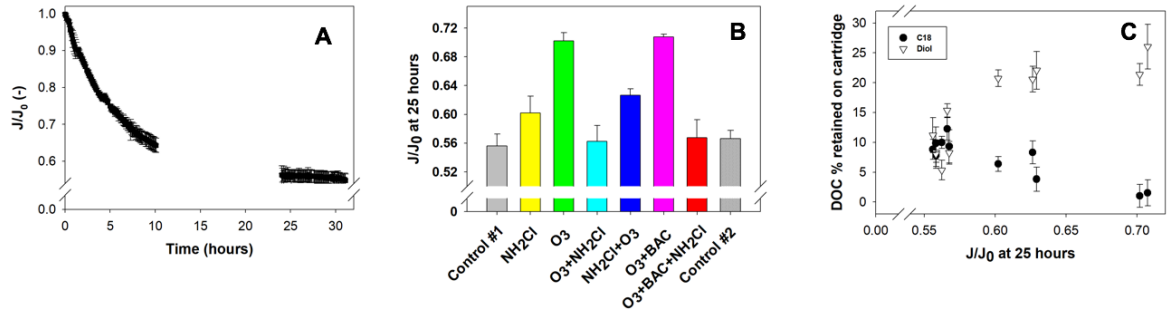


Figure 2. (A) Normalized flux decline in the RO treatment for an untreated control, (B) normalized flux after 25 hours of RO operation for the conditions tested, and (C) the percent of dissolved organic carbon (DOC) retained on C18 and Diol cartridges vs. the normalized flux after 25 hours of RO operation. Error bars represent standard deviations of triplicate (A,B) and duplicate (C) measurements.

As can be seen in figure 2a, the flux decline in the lab scale RO treatment unit treating anaerobic effluent stabilized after approximately 25 hours. At this time scale, biofouling can be ignored, and the majority of the flux decline can be attributed to organic fouling. The effect of disinfectants on organic fouling can be qualitatively compared by assessing the differences in normalized flux between a given condition and an untreated control after 25 hours of RO operation. Figure 2b shows that chloramine addition decreases the normalized flux decline through the RO membrane slightly, whereas ozonation results in the greatest normalized flux decline decrease. BAC treatment does not have an effect on flux decline. When ozonation and chloramination are combined, the difference between the flux decline of the treated sample and untreated control is negligible.

One explanation for the difference in normalized flux decline between the conditions is the difference in hydrophobicity of the organics caused by disinfectant application. As can be seen in Figure 2c, where the dissolved organic carbon (DOC) retention on

hydrophobic (C18) and hydrophilic (Diol) cartridges are plotted against the normalized flux measured after 25 hours of RO operation, the higher normalized flux values correlate with higher DOC retention percentages on Diol cartridges and lower DOC retention percentages on C18 cartridges. This implies that the more hydrophilic the DOC is, the lower the decline in flux through the RO membrane.

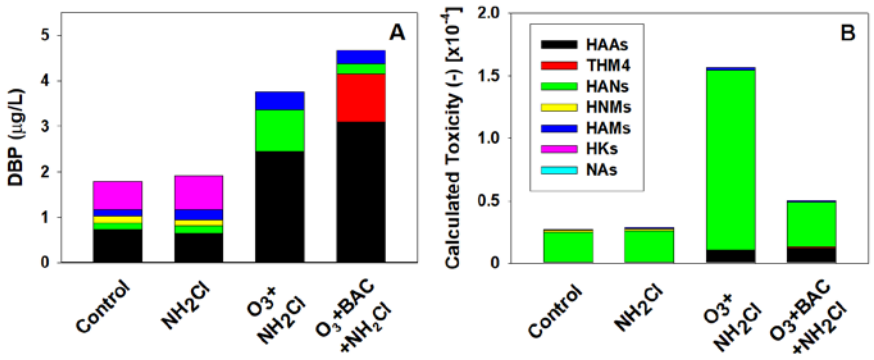


Figure 3. (A) DBP concentrations and (B) DBP associated calculated toxicity in final effluents. HAAs= haloacetic acids, THM4= trihalomethanes, HANs= haloacetonitriles, HNMs= halonitromethanes, HAMs= haloacetamides, HKs= haloketones, NAs= nitrosamines.

The regulated and unregulated DBP formation and calculated DBP associated toxicity in final treatment train effluents for chloramine based disinfection schemes upstream of RO are shown in Figure 3. Given that a disinfectant residual must be maintained through the RO treatment unit to prevent biofilm regrowth, chloramine based disinfection schemes were selected as most relevant to potable reuse applications. Here, the total DBP concentrations present in the final effluents are below 5 µg/L regardless of the disinfection scheme used, and are dominated by haloacetic acids (HAAs). For comparison, in the United States, regulated trihalomethanes (THM4) in drinking water may not exceed 80 µg/L. When the concentrations of DBPs are normalized by their toxic potency, unregulated haloacetonitriles (HANs) are the dominant DBP class. The combined ozonation and chloramination treatment upstream of RO displays the higher toxicity compared to the control, chloramine and ozone/BAC/chloramine disinfection schemes, however, this toxicity is still at least 4-fold lower than previously observed for aerobic secondary treatment based potable reuse trains (Zeng et al., 2016).

Conclusions

This study demonstrated that anaerobic membrane reactors can be compatible with potable reuse trains from the perspective of RO membrane fouling and DBP formation. Anaerobic membrane reactors are particularly attractive for utilities that look to lower the energy costs and biosolid disposal cost of their treatment. The use of bioreactors with built in membranes forgoes the need for a separate microfiltration unit, further lowering treatment train footprints for utilities that seek to reuse their water. However, additional research concerning methane recovery, mitigating sulfide production, and system scale up is necessary prior to implementation of anaerobic secondary treatment technologies in reuse applications.

References

Gerrity, D., Pecson, B., Trussell, R.S. and Trussell, R.R. Potable reuse treatment trains throughout the world. *Journal of Water Supply: Research and Technol.-AQUA*, 2014, 62, 321-338.

Guo, W., Ngo, H.H. and Li, J. A mini-review on membrane fouling. *Bioresource Technol.*, **2012**, 122, 27-34.

Lee, S., Ang, W.S. and Elimelech, M. Fouling of reverse osmosis membranes by hydrophilic organic matter: implications for water reuse. *Desalination*, 2006, 187, 313-321.

McCarty, P.L., Bae, J. and Kim, J. Domestic wastewater treatment as a net energy producer–can this be achieved?. *Environ. Sci. Technol.,* **2011**, 45, 7100-7106

National Research Council, 2012. *Water Reuse: Expanding the Nation's Water Supply through Reuse of Municipal Wastewater*; The National Academies Press: Washington, DC.

Rosario-Ortiz, F.L., Snyder, S.A. and Suffet, I.M. Characterization of dissolved organic matter in drinking water sources impacted by multiple tributaries. *Water Res.*, **2007**, 41, 4115-4128.

Shin, C., McCarty, P.L., Kim, J. and Bae, J. Pilot-scale temperate-climate treatment of domestic wastewater with a staged anaerobic fluidized membrane bioreactor (SAF-MBR). *Bioresource Technol.*, **2014**, 159, 95-103.

Steinle-Darling, E., Zedda, M., Plumlee, M.H., Ridgway, H.F. and Reinhard, M. Evaluating the impacts of membrane type, coating, fouling, chemical properties and water chemistry on reverse osmosis rejection of seven nitrosoalklyamines, including NDMA. *Water Res.*, **2007**, 41, 3959-3967.

Xu, P., Bellona, C. and Drewes, J.E. Fouling of nanofiltration and reverse osmosis membranes during municipal wastewater reclamation: membrane autopsy results from pilot-scale investigations. *Journal of Membrane Sci.*, **2010**, 353, 111-121.

Zeng, T.; Plewa, M.J.; Mitch, W.A. N-Nitrosamines and Halogenated Disinfection Byproducts in U.S. Full Advanced Treatment Trains for Potable Reuse. *Water Res.*, **2016**, 101, 176-186.

Online monitoring of N-nitrosodimethylamine for assessing the removal of trace organic chemicals by reverse osmosis

Takahiro Fujioka, Nagasaki University, Nagasaki, Japan; Haruka Takeuchi, Kyoto University, Otsu, Japan; Hiroaki Tanaka, Kyoto University, Otsu, Japan; Long D. Nghiem, University of Technology Sydney, Sydney, Australia; Hitoshi Kodamatani, Kagoshima University, Kagoshima, Japan; fujioka@nagasaki-u.ac.jp

Abstract:

Confidence in the safety of recycled water for potable water reuse can be enhanced by continuously ensuring the removal of trace organic chemicals (TOrCs). This study evaluated the efficacy of *N*-nitrosodimethlyamine (NDMA) as a conservative indicator for ensuring TOrC removal by reverse osmosis (RO) treatment. Results of this study revealed that NDMA rejection by an RO membrane was lower than the rejection values of 26 other TOrCs. In addition, NDMA rejection was linearly correlated with TOrC rejection across varied operating conditions. The linear correlation was also found for an RO membrane damaged with chlorine. This study suggests that NDMA rejection can be a conservative surrogate indicator capable of predicting changes in TOrC removal.

Keywords: TOrCs; CECs; Potable reuse; Reverse osmosis

Introduction

Reliable water quality assurance for the removal of trace organic chemicals (TOrCs) by advanced water treatment processes is critical to ensure the safety of recycled water in potable reuse. Reverse osmosis (RO) membrane process is capable of removing most contaminants in wastewater. However, the credibility of its performance for small TOrCs, particularly *N*-nitrosodimethylamine (NDMA, disinfection by-product), still remains a challenge because of the limited monitoring technologies for ensuring their removal. Continuous measurement of NDMA at concentrations relevant to water reuse applications in RO feed and permeate by newly developed analyzers—high-performance liquid chromatography followed by photochemical reaction and chemiluminescence detection (HPLC-PR-CL)—provides an online NDMA monitoring capability, which can be used as a surrogate indicator for

TOrC removal. This study aimed to demonstrate the validity of online-monitored NDMA rejection as a surrogate indicator of TOrC removal by RO treatment.

Material and Methods

The pilot system in this study was equipped with a 4-inch spiral-wound ESPA2 or HYDRAPro RO membrane element (Hydranautics, Oceanside, CA, USA). The standard operating conditions were a permeate flux of 20 L/m^{2}h and a feed temperature of 20 °C, whereas the conditions were varied to provide changes in TOrC rejection. A treated wastewater prepared by ultrafiltration (UF) membrane was used as the RO feed. Concentrations of *N*-nitrosamines in RO feedwater and permeate were determined by HPLC-PR-CL analyzers (Fujioka et al., 2018; Fujioka et al., 2016; Kodamatani et al., 2016). Concentrations of other TOrCs were determined using solid phase extraction followed by an ultra-performance liquid chromatography equipped with atmospheric pressure ionization and tandem mass spectrometer.

Results and Discussion

Pilot-scale experiments revealed that the online NDMA analyzers connected to the RO feed and permeate were able to determine NDMA concentrations every 22 min. NDMA rejection by RO varied considerably in response to changes in operating conditions (permeate flux and feed temperature). A high linear correlation between NDMA rejection and the rejection of six other TOrCs was observed for brand new RO membrane element (e.g. R^2 = 0.97 for acetaminophen) **(Figure 1)**. A high correlation was also identified for chlorine-treated RO membrane. In contrast, the rejection of another potential surrogate indicator (conductivity rejection) was not highly correlated with TOrC rejection.

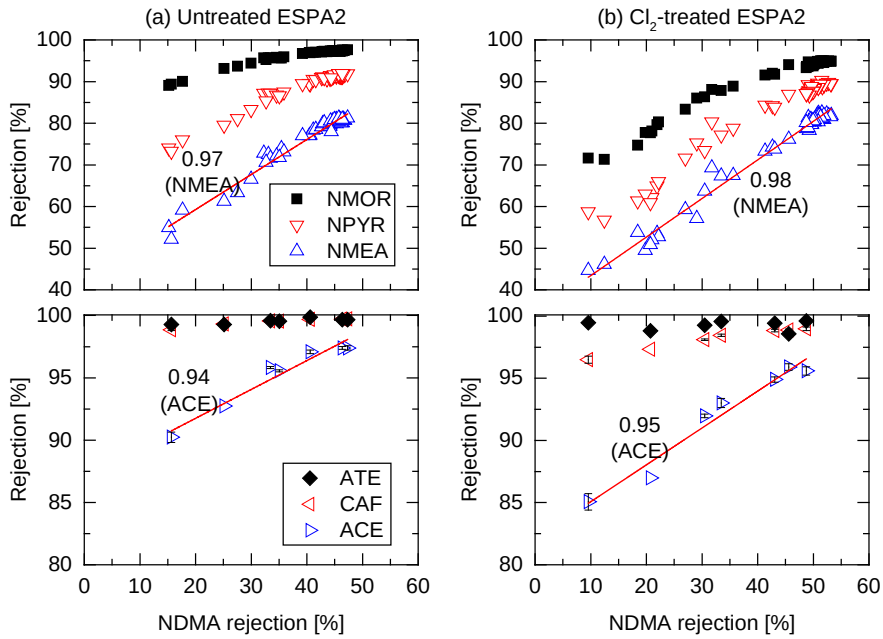


Figure 1 The rejection of TOrCs as a function of NDMA rejection by an (a) untreated and (b) Cl_2-treated ESPA2 RO membranes (R-squared values are shown for *N*-nitrosomethylethylamine (NMEA) and acetaminophen (ACE); Values reported for atenolol (ATE), caffeine (CAF) and ACE are the average and ranges of triplicate samples.)

Another tests using a commercial high-rejection RO membrane (i.e., HYDRAPro) revealed that the RO treatment of ultrafiltration-treated wastewater at a permeate flux of 20 L/m^{2}h and a feed water temperature of 13–34 °C resulted in a high NDMA rejection (65–87%). The NDMA rejection values were consistently lower than the rejection values of 23 other TOrCs regardless of their physicochemical properties (e.g., hydrophobicity and charge). More importantly, a linear correlation of NDMA rejection with the rejection of the 23 TOrCs using the high-rejection RO membrane was observed **(Figure 2)**. However, the high-rejection RO membrane required a transmembrane pressure that was greater than that of a conventional low-pressure RO membrane (i.e., ESPA2). Despite this disadvantage, this study suggests that NDMA, as a conservative indicator for TOrC removal, can determine the removal of TOrCs using an RO membrane with high rejection values of >65%.

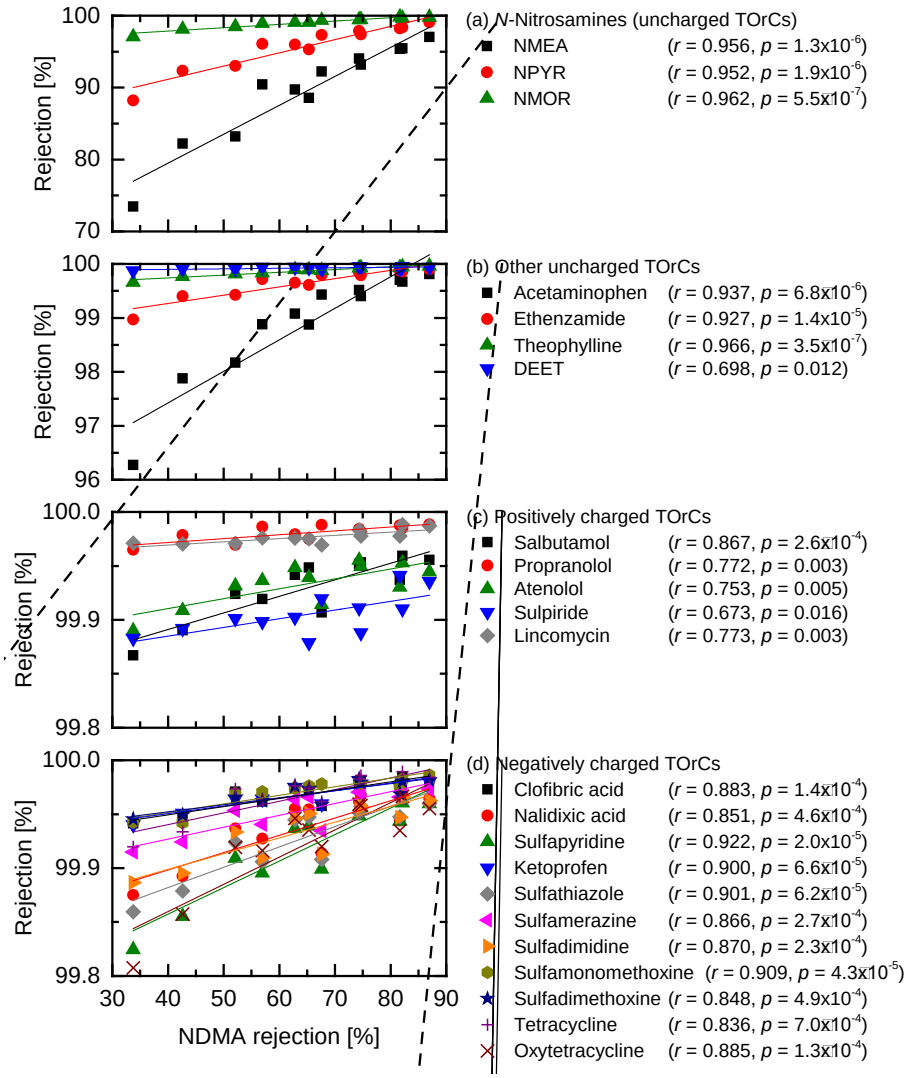


Figure 2 The rejection of TOrCs by the HYDRApro RO membrane as a function of NDMA rejection over the varied operating conditions: (a) *N*-Nitrosamines (uncharged TOrCs), (b) other uncharged TOrCs, and (c) positively and (d) negatively charged TOrCs. The dot line is the equality line with a slope of 1.0.

Conclusions

This study demonstrated the potential of NDMA as a conservative indicator for ensuring a certain level of TOrC removal by an RO membrane. In the first test, *N*-nitrosamine concentrations in RO feed and permeate were successfully monitored using two online HPLC-PR-CL analyzers during RO treatment of a UF-treated wastewater. A high and linear correlation between NDMA rejection and the rejection of six other TOrCs by RO was identified. Another pilot-scale test demonstrated that the HYDRApro RO membrane can achieve a 65–87% NDMA rejection over a feed

water temperature of 13–34 °C and a permeate flux of 20 L/m^{2}h. A linear correlation of NDMA rejection with the rejection of the 23 TOrCs was also observed. This study suggests the viability of NDMA as a conservative indicator for ensuring a high level of TOrC removal using an RO membrane.

References

Fujioka, T., Takeuchi, H., Tanaka, H. and Kodamatani, H. (2018) Online monitoring of N-nitrosodimethylamine rejection as a performance indicator of trace organic chemical removal by reverse osmosis. Chemosphere 200, 80-85.

Fujioka, T., Takeuchi, H., Tanaka, H., Nghiem, L.D., Ishida, K.P. and Kodamatani, H. (2016) A rapid and reliable technique for N-nitrosodimethylamine analysis in reclaimed water by HPLC-photochemical reaction-chemiluminescence. Chemosphere 161, 104-111.

Kodamatani, H., Yamasaki, H., Sakaguchi, T., Itoh, S., Iwaya, Y., Saga, M., Saito, K., Kanzaki, R. and Tomiyasu, T. (2016) Rapid method for monitoring N-nitrosodimethylamine in drinking water at the ng/L level without pre-concentration using high-performance liquid chromatography-chemiluminescence detection. J. Chromatogr. A 1460, 202-206.

Evaluating disinfection byproduct regulations for limiting human health risk after ozone-biofiltration-GAC treatment for potable reuse

Eric Peterson, Sierra Johnson, Steven Shiokari, Yun Yu, Sherri Cook & R. Scott Summers, University of Colorado Boulder, USA; eric.peterson@colorado.edu

Abstract

This study systematically evaluated disinfection byproduct (DBP) control by ozone-biofiltration-GAC at bench-scale for four treated wastewaters. This treatment approach was able to meet global drinking water DBP standards and reduce the calculated cytotoxicity health risk associated with unregulated DBPs. Many reuse standards reduced health risks of the treated wastewater effluents, but do not focus on the DBPs that contributed the greatest toxicity. The level of treatment needed to meet DBP standards is discussed and was consistently driven by trihalomethane limits.

Keywords: Biofilter; granular activated carbon; toxicity; regulations

Introduction

Ozone-biofiltration-granular activated carbon (O_3-BioF-GAC) treatment is emerging as an attractive option for potable water reuse treatment. It is a competitive alternative to reverse-osmosis systems because it does not generate brine waste and has lower costs and energy usage (Gerrity et al., 2014). However, a key roadblock to O_3-BioF-GAC adoption is the limited understanding of disinfection byproduct (DBP) control. DBP standards, which include regulations and non-regulatory guidelines, are used to limit DBP formation to reduce chronic health risks associated with drinking water (Wang et al., 2015). However, it is unknown if O_3-BioF-GAC can meet these standards especially when disinfectant residuals are required (Alexandrou et al., 2018).

Existing DBP standards were developed for conventional drinking waters. A common approach is establishing mass concentration limits on trihalomethanes (THM) and haloacetic acids (HAA); these compounds form at the highest concentrations and are thought to be associated with adverse health effects (Wang et al., 2015). However, there is variation between standards on which DBPs are targeted (individual compounds, collective limits on a class of compounds, or both) and the allowable concentrations. For example, the total THM limit in the United States (U.S.) is 80

μg/L, which is much lower than Australian limit of 250 μg/L. The chloroform limit in China of 60 μg/L is much lower than the World Health Organization (WHO) guideline of 300 μg/L. HAA standards in the U.S. and Canada limit the sum of five HAA compounds (HAA5) while other standards have individual limits for 2 to 3 chlorinated compounds only. Haloacetonitriles (HAN), another class of halogenated DBPs, are included only in WHO guidelines. Standards that target individual compounds sometimes have higher limits for bromide-substituted DBPs (e.g., bromoform) because they are heavier than their chlorinated analogues. This study systematically evaluated the use of O_3-BioF-GAC to meet global DBP standards, and the level of treatment needed to meet the standards, when a chlorine residual is required.

The existing DBP regulation approach is being questioned as many unregulated DBPs, particularly nitrogenous compounds (e.g., HANs), have recently been found to be more toxic than regulated DBPs (Plewa et al., 2017). Also, it is unknown if DBP standards that were developed for conventional drinking water are appropriate for potable reuse due to differences in source water quality. Formation of the unregulated and more toxic DBPs is of particular concern for potable reuse because wastewater effluents can have much higher levels of nitrogen-rich effluent organic matter and bromide than conventional source waters; this can result in higher nitrogenous DBP (e.g., HAN) formation and higher bromide substitution and therefore greater human health risks associated with the drinking water. However, the amount of unregulated DBP formation and associated toxicological risk are unknown (Krasner et al., 2009). Therefore, this study also evaluated the effectiveness of O_3-BioF-GAC to control unregulated DBPs and reduce the overall associated health risk when operated to meet current DBP regulations. The results can help inform regulatory decisions in the reuse context.

Materials and Methods

Bench-scale O_3-BioF-GAC treatment was conducted with four fully-nitrified secondary wastewater effluents collected from three full-scale facilities before disinfection. They had a range of water quality including dissolved organic carbon (DOC) of 6.1-9.4 mg/L and Br^- 190-250 μg/L. Ozonation was conducted in semi-batch reactors at a 1:1 mg O_3/mg DOC dose. Flow-through biofilters were operated using the recirculation/single pass method with inert anthracite media at 15-min and 30-min empty bed contact times (EBCTs) (Terry et al., 2019). GAC adsorption was

evaluated with rapid small-scale column tests using a 10 min EBCT and bituminous GAC with the proportional diffusivity method. DBP formation was assessed by sampling along the O_3-BioF-GAC treatment train and chlorinating under uniform formation conditions (Summers et al., 1996). Twenty organic DBPs (4 THMs, 9 HAAs, 4 HANs, 2 haloketones, 1 halonitromethane) were measured per U.S. EPA methods 551 and 552. Calculated cytotoxicity and genotoxicity were determined by first multiplying each measured DBP concentration with its toxic potency, as found in the literature, and then assuming effects are additive and summing all values for a given sample (Chuang and Mitch, 2017).

Results and Discussions

The O_3-BioF-GAC treatment train was effective for meeting each DBP standard assessed: Australia, Canada, China, EU directive, Japan, U.S., and WHO. The THM standards were the drivers for the level of treatment needed. THM formation in the source waters was 1.5-3.6 times higher than allowable limits for various standards but all source waters were below the higher Australian standard (Table 1). On average, ozonation reduced THMs by less than 10%, which was not enough to meet THM limits. Subsequent biofiltration, with 30 min EBCT, reduced THMs by an average of 31%, which was still not enough to meet THM limits (THM formation was still 1.1-2.5 times higher than allowable limits). The final GAC adsorption step reduced THMs enough to meet all standards until a 2 mg/L DOC breakthrough; some standards (Canada, EU directive, Japan) were also met at 3 mg/L DOC. For the THMs, bromodichloromethane (BDCM) formation was the driver compound in meeting the standards.

HAA standards were comparatively easier to meet. Many standards (Australia, China, Japan, WHO) were met in two of the four source waters without treatment. Ozone alone did not substantially improve HAA control, however ozone-biofiltration with a 30 min EBCT was able to meet all assessed HAA standards for all waters. GAC adsorption further reduced HAA formation to well below allowable limits. For example, HAA5 formation after biofiltration was 61-95% of the U.S. limit and then was below 30% after GAC. Similarly, dichloroacetic acid (DCAA) formation after biofiltration was 35-67% of the WHO limit and then was below 13% after GAC. Of all the HAAs, DCAA was the driver DBP for meeting the standards, and for the U.S. regulatory limit dibromoacetic acid (DBAA) was also a driver compound.

Analyzing these results with literature data on four additional wastewater effluents treated by O_3-BioF-GAC yielded a linear correlation between DOC and HAA5 (R^2=0.84) and between DOC and TTHM (R^2=0.85) (Figure 1). The relationships are similar to trends found with 10 conventional drinking water sources (Summers et al., 1996). The relationships predict that typical TTHM regulations in European countries (e.g., 25-50 µg/L) can be met when treated water effluent TOC is 1 mg/L if chlorine residual were required.

Table 1: Observed THM and HAA formation normalized to the allowable limit for multiple worldwide DBP standards. Values in bold meet the respective standard.

				[THM] / [THM allowed]					[HAA] / [HAA allowed]			
									WHO			USA
Treat-ment	**WWTP**	**DOC** (mg/L)	**TTHM** (µg/L)	**China**	**USA**	**WHO**	**Australia**	**HAA5** (µg/L)	MCAA	DCAA	TCAA	HAA5
Source	1a	7.7	219	3.25	2.74	2.35	**0.88**	104	**0.31**	**0.80**	**0.23**	1.73
	1b	7.2	230	3.62	2.87	1.98	**0.92**	119	0.00	1.14	0.26	1.99
	2	9.4	208	3.30	2.60	1.85	**0.83**	135	0.38	1.08	0.34	2.26
	3	6.1	157	2.42	1.96	1.51	**0.63**	75.7	**0.00**	**0.69**	**0.17**	1.26
O_3	1a	7.4	213	3.09	2.66	2.22	**0.85**	90.0	**0.38**	**0.91**	**0.12**	1.50
	1b	7.0	185	2.89	2.32	1.58	**0.74**	87.8	0.00	1.11	0.12	1.46
	2	9.0	185	2.86	2.31	1.68	**0.74**	112	0.50	1.03	0.21	1.87
	3	6.0	159	2.43	1.98	1.44	**0.63**	77.6	**0.40**	**0.82**	**0.10**	1.29
O_3 + BioF	1a	5.2	190	2.53	2.38	2.14	**0.76**	38.5	**0.00**	**0.35**	**0.04**	**0.64**
	1a	4.6	176	2.27	2.20	2.00	**0.70**	30.7	**0.00**	**0.25**	**0.03**	**0.51**
	1b	5.3	149	2.22	1.87	1.42	**0.60**	57.2	**0.00**	**0.67**	**0.07**	**0.95**
	2	7.0	141	2.08	1.76	1.45	**0.56**	64.4	**0.25**	**0.59**	**0.11**	1.07
	2	6.2	131	1.90	1.63	1.37	**0.52**	54.8	**0.25**	**0.49**	**0.09**	**0.91**
	3	5.1	136	2.02	1.70	1.29	**0.54**	62.5	**0.00**	**0.69**	**0.10**	1.04
	3	4.4	108	1.54	1.34	1.13	**0.43**	36.4	**0.00**	**0.36**	**0.05**	**0.61**
O_3 + BioF + GAC	1a	2.1	76.8	**0.82**	**0.96**	**0.80**	**0.31**	10.8	**0.00**	**0.04**	**0.00**	**0.18**
	1b	1.0	20.0	**0.22**	**0.25**	**0.21**	**0.08**	4.4	**0.00**	**0.03**	**0.00**	**0.07**
	1b	2.0	51.5	**0.59**	**0.64**	**0.56**	**0.21**	10.7	**0.00**	**0.06**	**0.00**	**0.18**
	1b	3.0	93.0	1.16	1.16	1.04	**0.37**	19.3	**0.00**	**0.13**	**0.01**	**0.32**
	2	2.0	53.0	**0.60**	**0.66**	**0.57**	**0.21**	9.6	**0.00**	**0.05**	**0.00**	**0.16**
	3	1.0	25.6	**0.28**	**0.32**	**0.27**	**0.10**	7.0	**0.00**	**0.08**	**0.00**	**0.12**
	3	2.0	57.7	**0.67**	**0.72**	**0.63**	**0.23**	10.1	**0.00**	**0.06**	**0.00**	**0.17**
	3	3.0	92.7	1.17	1.16	1.04	**0.37**	17.8	**0.00**	**0.13**	**0.01**	**0.30**

The results also provide examples that targeting DOC removal to meet THM and HAA regulations with O_3-BioF-GAC treatment can be effective for controlling unregulated DBP formation (Table 2). HAA9 formation was reduced by biofiltration and GAC in the same manner as HAA5 formation; furthermore, HAA9 formation was

well below the U.S. HAA5 limit after GAC despite targeting 4 additional DBPs. Haloketone and TCNM (chloropicrin) formation increased after ozonation but GAC treatment was able to reduce formation of these DBPs to below 1 µg/L. HAN formation was reduced by both ozone and GAC; when treating to the USA THM regulation (DOC 2 mg/L), HAN formation was reduced by 79% on average into the range of typical drinking waters.

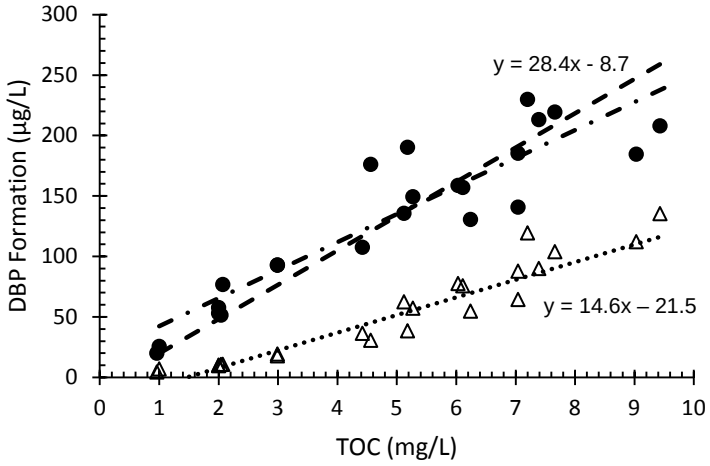


Figure 1: Relationship between TOC and regulated DBP formation for TTHM (filled dots) and HAA5 (open triangles).

Regressions include data from (Arnold et al., 2018), (Chuang and Mitch, 2017) & (Krasner et al., 2016). TTHM drinking water regression (dot-dash line) from (Summers et al., 1996).

Table 2: Effect of treatment processes on unregulated DBP formation and resulting calculated toxicity. Values are the average (range) of waters evaluated.

Treatment	DOC (mg/L)	HAN4 (µg/L)	HAA9 (µg/L)	HKs (µg/L)	TCNM (µg/L)	Calc. Cytotoxicity ($x10^3$)	Calc. Genotoxicity ($x10^3$)
Source	7.6 (6.1-9.4)	10.8 (4.5-15)	151 (101-178)	4.9 (3.4-6.3)	0.2 (0-0.3)	9.4 (5.7-13.9)	2.1 (1.7-2.8)
O_3	7.4 (6.0-9.0)	6.7 (5.4-8.4)	121 (100-150)	6.9 (1.2-14)	3.6 (0-10)	7.5 (5.3-9.1)	2.2 (1.6-2.8)
O_3 + BioF	5.4 (4.4-7.0)	6.4 (3.4-13)	74 (56-94)	4.1 (2.1-7.5)	0.7 (0-2.2)	7.3 (5.1-13.2)	1.3 (1.2-1.7)
O_3 + BioF + GAC	3.0	3.9 (2.7-5.2)	31 (29-34)	0.5 (0.4-0.6)	ND	5.3 (3.4-7.2)	0.8 (0.7-1.0)
	2.0	2.3 (1.0-3.3)	17 (15-20)	ND	ND	3.6 (1.6-4.8)	0.6 (0.5-0.7)
	1.0	0.6 (0.5-0.7)	8 (6-10)	ND	ND	1.1 (1.0-1.3)	0.3 (0.3-0.3)

Control of unregulated DBP formation resulted in control of calculated cytotoxicity and genotoxicity because the toxicity drivers, which were the compounds accounting for greater than 90% of total cytotoxicity and genotoxicity, were brominated DBPs not

addressed by most standards: monobromacetic acid (MBAA), bromochloroacetonitrile (BCAN) and dibromoacetonitrile (DBAN). Cytotoxicity was mostly driven by HANs, therefore ozone and GAC were the effective treatments. Conversely, genotoxicity was more driven by MBAA, therefore biofiltration and GAC were effective treatments. Significant reduction was achieved for both cytotoxicity (61%) and genotoxicity (70%) at the 2 mg/L DOC breakthrough level, however the reduction in toxicity was slightly lower than reduction in unregulated DBP concentrations overall, due to a shift toward more brominated DBPs.

Conclusions

The O_3-BioF-GAC treatment train was effective for meeting DBP regulations and reducing calculated toxicity for range of wastewater effluent source waters when chlorine residual is required. The DBPs addressed by most drinking water standards (THM, chlorinated HAA) are not the DBPs that contributed significantly to calculated toxicity (brominated, nitrogenous DBPs); however, simultaneous control of both groups of compounds resulted in existing regulations being useful targets for controlling health risks associated with unregulated DBPs in potable reuse.

Acknowledgements

The authors gratefully acknowledge funding support from the University of Colorado Dean's Graduate Fellowship, and the WWTP operators for providing water samples.

References

Alexandrou, L.; Meehan, B. J.; Jones, O. A. H. Regulated and Emerging Disinfection By-Products in Recycled Waters. *Science of the Total Environment*. October 2018, pp 1607–1616.

Arnold, M.; Batista, J.; Dickenson, E.; Gerrity, D. Use of Ozone-Biofiltration for Bulk Organic Removal and Disinfection Byproduct Mitigation in Potable Reuse Applications. *Chemosphere* 2018, *202*, 228–237.

Chuang, Y. H.; Mitch, W. A. Effect of Ozonation and Biological Activated Carbon Treatment of Wastewater Effluents on Formation of N-Nitrosamines and Halogenated Disinfection Byproducts. *Environ. Sci. Technol. Technol.* 2017, *51* (4), 2329–2338.

Gerrity, D.; Owens-bennett, E.; Venezia, T.; Stanford, B. D.; Plumlee, M. H.; Debroux, J.; Trussell, R. S. Applicability of Ozone and Biological Activated Carbon for Potable Reuse. *Ozone Sci. Eng.* 2014, *36* (2), 123–137.

Krasner, S. W.; Westerhoff, P.; Chen, B.; Rittmann, B. E.; Amy, G. Occurrence of Disinfection Byproducts in United States Wastewater Treatment Plant Effluents. *Environ. Sci. Technol.* 2009, *43* (21), 8320–8325.

Krasner, S. W.; Lee, T. C. F.; Westerhoff, P.; Fischer, N.; Hanigan, D.; Karanfil, T.; Beita-Sandí, W.; Taylor-Edmonds, L.; Andrews, R. C. Granular Activated Carbon Treatment May Result in Higher Predicted Genotoxicity in the Presence of Bromide. *Environ. Sci. Technol.* 2016, *50* (17), 9583–9591.

Plewa, M. J.; Wagner, E. D.; Richardson, S. D. TIC-Tox: A Preliminary Discussion on Identifying the Forcing Agents of DBP-Mediated Toxicity of Disinfected Water. *J. Environ.*

Sci. 2017, *58*, 208–216.
Summers, R. S.; Hooper, S. M.; Shukairy, H. M.; Solarik, G.; Owen, D. Assessing DBP Yield: Uniform Formation Conditions. *J. / Am. Water Work. Assoc.* 1996, *88* (6), 80–93.
Terry, L. G.; Pruisner, P.; Peterson, E.; Dickenson, E.; Wang, J.; Summers, R. S. Scale-Up Methodology for Biological Filtration Removal of Dissolved Organic Matter. *Environ. Eng. Sci.* 2019, *36* (4), 405–412.
Wang, X.; Mao, Y.; Tang, S.; Yang, H.; Xie, Y. F. Disinfection Byproducts in Drinking Water and Regulatory Compliance: A Critical Review. *Front. Environ. Sci. Eng.* 2015, *9* (1), 3–15.

Development of A Group Contribution Method to Predict the Mass Transfer Coefficients of Small Molecular Weight Neutral Organics through RO Membranes for Potable Reuse Application

Ryan Kibler, Michigan Technological University, Houghton, MI USA;
Muxue Zhang, Michigan Technological University, Houghton, MI USA;
Lauren Breitner, Trussell Technologies, Inc. San Diego, CA USA;
Kerry J. Howe, University of New Mexico, Albuquerque, NM USA;
Daisuke Minakata, Michigan Technological University, Houghton, MI USA;

Abstract:

Reverse osmosis (RO) is applied for the removal of chemicals of emerging concern in wastewater reclamation where neutral organic compounds whose molecular weights are less than 200 g/mol are poorly rejected. We develop a group contribution method by fragmenting the structure of an organic compound into segments that represent a base structure and functional groups for a wide variety of organic compounds. Assuming each base and functional group interacts independently with a polyamide RO membrane, the mass transfer coefficients were parameterized with a free energy of interaction. In all, 297 organics were used to calibrate 231 parameters for 6 membranes with more than 86.5% of calibrated mass transfer coefficients within 20% of experimentally determined mass transfer coefficients.

Keywords: reverse osmosis; group contribution method; DPR; organics;

Introduction

With over 85,000 chemicals in production and use today, experimental investigations of the most effective treatment methods to remove these compounds are not feasible. In particular, reverse osmosis (RO) has been employed as a barrier for removal of chemicals of emerging concern and pathogens in wastewater reclamation processes. Yet, RO poorly rejects neutral organic compounds with a molecular weight less than 200 g/mol. To identify for which chemicals of emerging concern that RO may be a robust treatment method, a comprehensive model is needed to predict the rejection efficiencies.

Several quantitative structure activity relationships (QSARs) models have attempted to predict the rejection efficiencies for chemicals of emerging concern such as pharmaceuticals and personal care products based on the physicochemical

properties, membrane properties, feed water characteristics, and operating conditions. These QSARs have been developed for several nanofiltration membranes, but have been limited in their application to RO. Those that have been developed for RO have often become entangled in the complexities using difficult to obtain and understand physicochemical properties of organic compounds and membranes such as Drewes *et al* (2013). This QSAR lacks mechanistic basis for rejection as it is difficult to quantitatively identify the contribution of each property based off regression analysis. The QSARs also lack broader impact as they are developed for one particular membrane and operating conditions used at the experiment. Consequently, there is a need to develop a comprehensive model that predict the rejections of a wide variety of organic compounds at any operational conditions through any RO membrane products that are commercially available.

In this study, we focus on the mass transfer coefficients of organic compounds and develop a proof-of-concept model based on only structural information of organic compounds. We develop a process model to predict the rejection of those organic compounds at any operational conditions through RO membrane products.

Material and Methods

For 70 neutral organic compounds whose molecular weight is less than 300 g/mol, bench scale experiments were performed with 6 brackish water and seawater RO membrane products at 3 operational pressures to determine the organics' mass transfer coefficients and rejection efficiencies.

A group contribution method (GCM) was developed by fragmenting the structure of a given organic into groups. The group parameters that represent the free energies of interaction between each fragmented part (both base structure and functional group) and RO membrane were determined by minimizing the objective function that calculates the normalized difference between the experimental and calculated mass transfer coefficients using genetic algorithms. The free energy of interaction for each segmented group of a given compound indicates the structural contribution to the overall mass transfer coefficient. For alkanes, the free energies of interaction were determined based on minimum carbon-based structures with functional groups (e.g., alkyl or halogenated groups). For alkenes and aromatic compounds, the free energies of interaction were determined by a base carbon-carbon double bond or a benzene ring structure with the functional group(s). The

different treatment of a base structure (cis/trans C-C double bond or mono-, di-, or tri-substituted aromatic ring) by the number and positions of functional groups successfully differentiated the effects of isomers.

In selecting compounds for prediction, a range of mass transfer coefficients were used for brackish water and seawater membrane. The mass transfer coefficients' lower limit was set to 0.1 L/m^2-h and 1.0 L/m^2-h for seawater and brackish water membranes, respectively. This lower limit corresponds to greater than 97% rejection thus eliminating the need for prediction. Similarly, an upper limit of 100 L/m^2-h was set corresponding to 20% rejection meaning a different treatment option should be employed for those organics. The error goal (EG) was set to calculate the MTC in order to predict the corresponding rejection efficiencies within ±5% from experimental values.

Results and Discussion

Among the 70 mass transfer coefficients determined by our bench-top experiments through 6 RO membranes, 54 compounds including 26 halo and oxygenated alkanes and alkenes, and 20 alkyl and halobenzenes were selected based on the applicable range of rejection efficiencies. Figure 1 compares the calibrated mass transfer coefficients as a function of experimentally obtained mass transfer coefficients. Overall, 92% of best calibrated mass transfer coefficient values were within EG for TMG(D) membrane. Similarly, 84% of mass transfer coefficient values (n=53) for BW30XFRLE, 76% (n=54) for ESPA2-LD, 69% (n=48) for AG LF, 100% (n=46) for SW30XHR, and 98% (n=46) for TM800M were obtained.

Figure 2 compares the calibrated rejection values of organic compounds against the experimentally obtained rejection ones. Taking into account the rejection data, 85% of compounds were within ± 5% of the experimentally measured rejection efficiencies and about 95% are within ± 10% of the experimentally determined rejection efficiencies showing its promise as a useful model.

Comparing the free energy of interactions between functional group parameters for each membrane, several trends were identified that were found to be consistent with physicochemical properties. For example, compounds containing more halogenated groups (i.e., Cl or Br) have a higher free energy of interaction leading to a lower mass transfer coefficient, thus higher rejection. In this case, the free energy of interaction quantitatively represents the hydrophilic/hydrophobic

effects of each functional group to the overall free energy of interaction. Several other trends were discerned that require further investigation and incorporation of more data points to determine their significance.

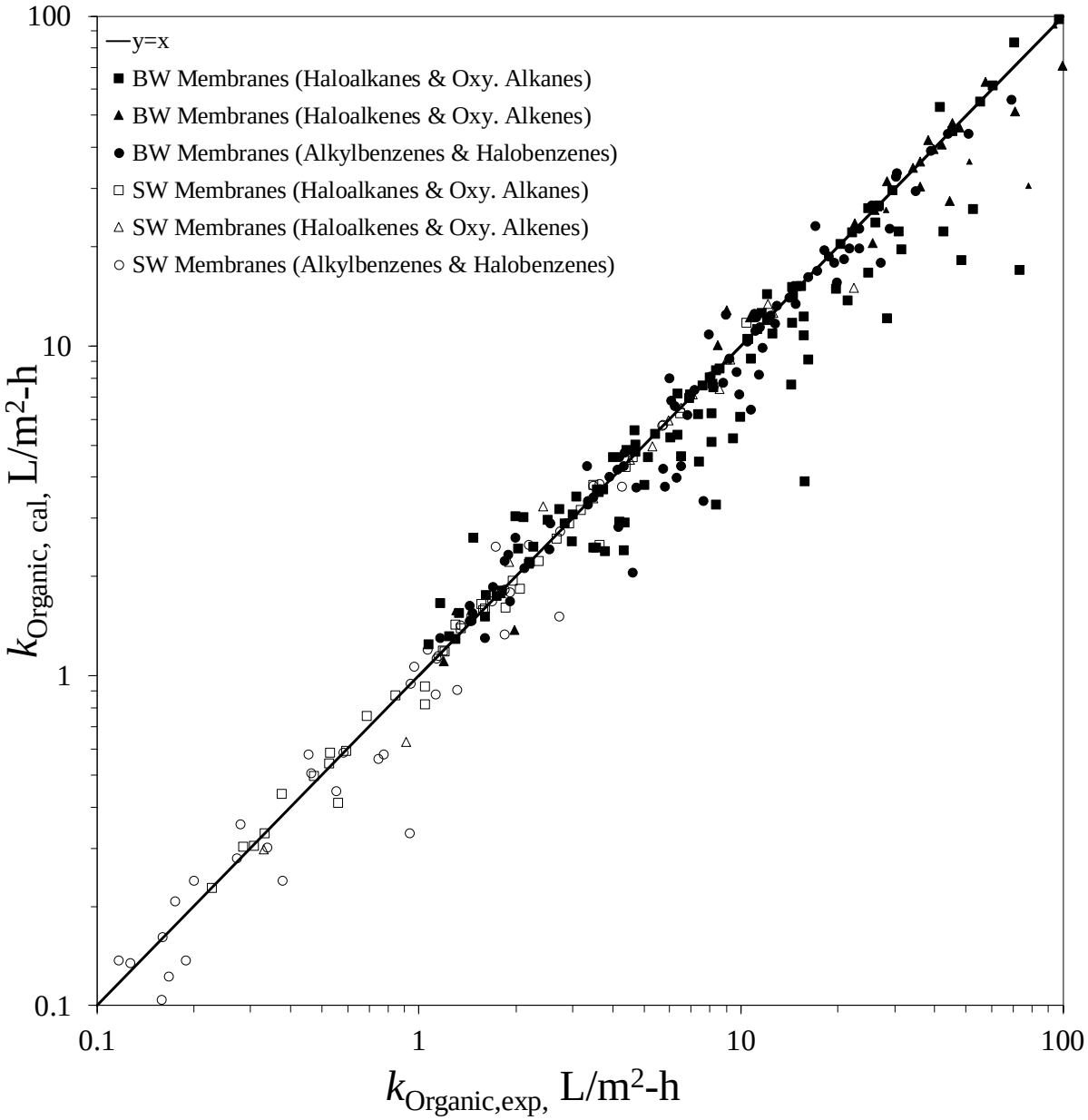


Figure 1. Plot of calibrated mass transfer coefficients ($k_{Organic,cal}$) against experimentally obtained mass transfer coefficient ($k_{Organic,exp}$).

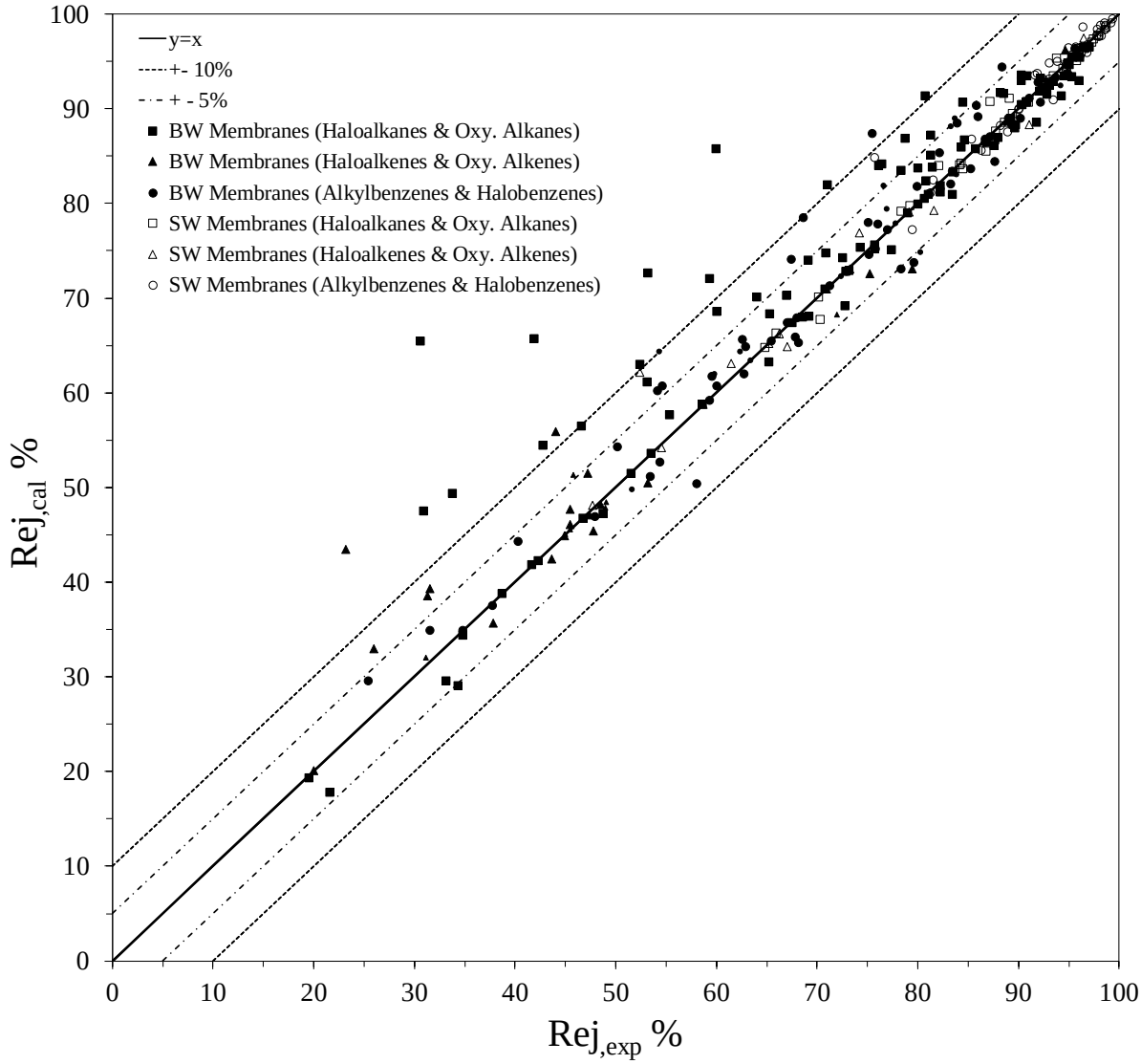


Figure 2. Plot of calibrated rejection ($Rej_{,cal}$) against experimentally determined rejection ($Rej_{,exp}$).

Conclusions

Presented in this paper, a GCM was developed to predict the mass transfer coefficient of a wide variety of organic compounds based solely on the chemical structure of the compounds. As more compounds are included in the model calibration, the GCM will be able to predict more complicated structures and other functional groups including oxygenated, nitrogen- and sulfur-containing groups. With this capability, the model is particularly useful to water utilities and industries. As an outcome of this project, a process model was developed that allows a user to split an organic compound into its functional group parameters and predict the rejection with

varying operating conditions. Still, it is critical to note that this model still acts as a proof-of-concept, since it used all experimental data for its calibration. Therefore, model validation with external data sources must be completed to fully confirm the model.

References

Drewes, J. E.; Bellona, C.; Eberhart, M.; Chellam, S. Predictive Models to Aid in Design of Membrane Systems for Organic Micropollutant Removal, WRRF Report 06−09; WateReuse Research Foundation: Alexandra, VA, 2013.

Howe, K. J.; Minakata, D.; Breitner, L. N.; Zhang, M. Predicting Reverse Osmosis Removal of Unique Organics, WRRF Report 14−19; Water Research Foundation: Alexandria, VA, 2018.

Advances in forward osmosis to combine desalination and reuse

G. Blandin, LEQUIA, Institute of the environment, University of Girona, Girona, Spain
J. Comas, Catalan Institute for Water Research, Girona, Spain
A. Verliefde, PaInT Group, Ghent University, Ghent, Belgium
P. Le-Clech, UNESCO Centre for Membrane Science and Technology, School of Chemical Engineering, The University of New South Wales, Sydney, Australia
I. Rodriguez-Roda, Catalan Institute for Water Research, Girona, Spain

In several densely populated (dry) coastal regions, seawater desalination represents a large share of the water supply. In these cases, typically wastewater (WW) treatment plant effluents and seawater intake points are in a relatively close geographic area. Sometimes, water reuse and seawater desalination are both implemented, but considered as separate and independent streams to solving water shortage. Implementing forward osmosis (FO) is a promising way to combine water reuse and desalination as this membrane technology takes advantage of the salinity gradient in-between the two streams for permeation of high quality water ((Cath et al., 2009, Yangali-Quintanilla et al., 2014) and Figure 1). In a FO-reverse osmosis (RO) hybrid process, high quality water recovered from the wastewater stream is used to dilute seawater before RO treatment. On one hand, lower desalination energy needs and/or water augmentation can be obtained while delivering safe water for potable reuse thanks to the double dense membrane barrier protection (FO-RO). On the other hand, thanks to the concentration process, FO may facilitate downstream treatment as well as energy and nutrients recovery.

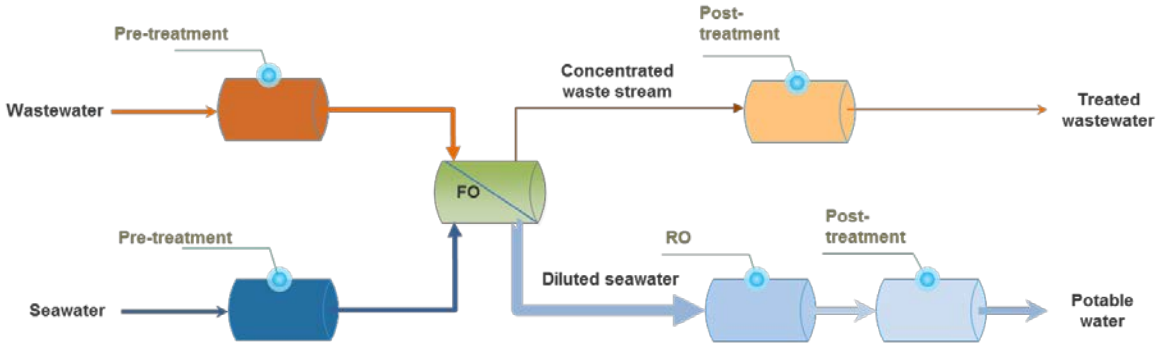


Figure 1: FO implementation to combine desalination and water reuse

The work presented will describe main findings of 6 years of research dedicated to the assessment of new generation of commercial FO membranes, the development

and assessment of submerged FO modules and implementation at various stage and applications of the WW treatment lines. Main findings are:

- Recent developments in FO membranes and modules allowed for substantial improvement in water flux and selectivity so to close the economics gap as well as high rejection of trace organic compounds (TrOCs, >90%) in order to assure safe water reuse (Blandin et al., 2015). However, flux improvement is associated with drawbacks, such as increased fouling behaviour, and thin FO membranes can suffer from mechanical constraint/stretching/abrasion affecting rejection and resilience of the process that should be further studied.

- Pilot scale testing and CFD modelling demonstrated that pressure drop and draw channel compaction due to current module design are key factors affecting FO module operation and mass transfer (Kim et al., 2017, Lian et al., 2018). Fouling, clogging and adapted strategies were also assessed; osmotic backwashing proved to be a promising cleaning strategy but is still to be tested during large scale operation.

- FO, unlike RO, does not rely on hydraulic pressure and therefore limiting design restrictions to high pressure vessels no longer stands; novel submerged (Sub-FO) modules were developed (up to 0.4 m^2). Sub-FO is of high potential interest to tackle clogging limitations in cross flow FO as well as for bioreactors operations. Specific mass transfer limitations challenges of Sub-FO such as external concentration polarization (ECP) in the submerged tank and module design for optimized draw circulation were identified (Blandin et al., 2018b). Recommendations of straight channel draw circulation combined with turbulences promotion (air scouring, stirring) were successfully tested.

- FO (cross flow and Sub) was successfully tested for several applications such as concentration before and after anaerobic digestion, concentration of raw wastewater, for concentration of microalgae and finally in osmotic membrane bioreactor (OMBR) (Blandin et al., 2017, Blandin et al., 2018a).

- Preliminaries studies demonstrated the interest to integrate FO in desalination schemes especially to combine it with water reuse (Blandin et al., 2015, Teusner et al., 2016). Refined economics assessment based on large scale operation, should integrate fouling and other maintenance costs/savings of the FO-RO hybrid systems, but also cost savings from treatment steps avoided in water recycling.

BLANDIN, G., COMAS, J. & RODRIGUEZ-RODA, I. Potential and Challenges of Osmotic Membrane Bioreactor (OMBR) for (Potable) Water Reuse: A Pilot Scale Study. Frontiers International Conference on Wastewater Treatment and Modelling, 2017. Springer, 188-192.

BLANDIN, G., GAUTIER, C., SAUCHELLI TORAN, M., MONCLÚS, H., RODRIGUEZ-RODA, I. & COMAS, J. 2018a. Retrofitting membrane bioreactor (MBR) into osmotic membrane bioreactor (OMBR): A pilot scale study. *Chemical Engineering Journal,* 339**,** 268-277.

BLANDIN, G., RODRIGUEZ-RODA, I. & COMAS, J. 2018b. Submerged Osmotic Processes: Design and Operation to Mitigate Mass Transfer Limitations. *Membranes (Basel),* 8**,** 72.

BLANDIN, G., VERLIEFDE, A. R. D., TANG, C. Y. & LE-CLECH, P. 2015. Opportunities to reach economic sustainability in forward osmosis–reverse osmosis hybrids for seawater desalination. *Desalination,* 363**,** 26-36.

CATH, T. Y., DREWES, J. E. & LUNDIN, C. D. 2009. A Novel Hybrid Forward Osmosis Process for Drinking Water Augmentation using Impaired Water and Saline Water Sources. *WERC.*

KIM, J., BLANDIN, G., PHUNTSHO, S., VERLIEFDE, A., LE-CLECH, P. & SHON, H. 2017. Practical considerations for operability of an 8″ spiral wound forward osmosis module: Hydrodynamics, fouling behaviour and cleaning strategy. *Desalination,* 404**,** 249-258.

LIAN, B., BLANDIN, G., LESLIE, G. & LE-CLECH, P. 2018. Impact of module design in forward osmosis and pressure assisted osmosis: An experimental and numerical study. *Desalination,* 426**,** 108-117.

TEUSNER, A., BLANDIN, G. & LE-CLECH, P. 2016. Augmenting water supply by combined desalination/water recycling methods: an economic assessment. *Environ Technol***,** 1-32.

YANGALI-QUINTANILLA, V., OLESEN, L., LORENZEN, J., RASMUSSEN, C., LAURSEN, H., VESTERGAARD, E. & KEIDING, K. 2014. Lowering desalination costs by alternative desalination and water reuse scenarios. *Desalination and Water Treatment*.

FO-NF treatment of municipal wastewater for customized agricultural reuse and AnMBR pretreatment

Ana María Álvarez, Acciona Agua, El Prat de Llobregat, Spain;
Teresa de la Torre, Acciona Agua, El Prat de Llobregat, Spain;
Jorge Malfeito, Acciona Agua, El Prat de Llobregat, Spain;
teresa.torre.garcia@acciona.com

Abstract:

The direct filtration of municipal wastewater using a forward osmosis (FO) - nanofiltration (NF) hybrid system was evaluated at pilot scale with the final goal of: 1. to preconcentrate the wastewater using FO for posterior anaerobic treatment of reduced digester volume and 2. to obtain an NF permeate of high-quality for reclamation. A pilot-scale FO plant (30.6 m^2 membrane area) including the nanofiltration DS recovery step was used for filtering wastewater after pretreatment for SS removal. Different cleaning strategies (flushing, osmotic cleaning and chemical cleaning) and different pretreatments (flotation-coagulation, settling tanks + filtration, disc filtration) were evaluated. The selected conditions for operating the demonstration plant achieving a sustainable operation were sedimentation and mesh filtration as feed pretreatment and physical cleaning every 20 minutes of filtration. Sustainable operation was achieved but significant membrane fouling was observed when operating at 50% recovery in the FO. The FO-NF system showed a high quality permeate for reuse, which can be customized for fertigation according to the soil needs. The removal of nutrients and micropollutants analyzed was greater than 90% for most of the studied compounds. Regarding to wastewater concentration by FO to be treated by anaerobic digestion (AD), the study showed operating at higher water recovery is required to achieve an acceptable concentration, however, parameters like sulfate concentration and conductivity that may affect posterior steps must be taken into consideration.

Keywords: Forward osmosis; hybrid FO-NF system; membrane fouling, water reclamation, anaerobic digestion

Introduction

The double membrane barrier concept is gaining popularity for reuse applications, as it provides high confidence regarding water quality not only from the technological but also from the public perception point of view. However, MF/UF-RO is not the exclusive existing double membrane barrier process. Forward osmosis has appeared in the last years as a low-fouling technology (Schneider et al., 2019), capable of treating highly complex waters. In forward osmosis (FO), a solution of high osmotic pressure, called draw solution (DS), is used to induce a flow of water through a semipermeable membrane. Afterwards, a separation step is needed to recover the DS and obtain as a product the water that have passed the FO membrane. The combination of forward osmosis and nanofiltration (FO-NF process) (Fig. 1.) has proven to be a robust process that can achieve a high-quality permeate for reuse (Corzo, 2018). Since a FO system run without hydraulic pressure, there is a significant opportunity for energy savings. Despite of the lack of applied hydraulic pressure, forward osmosis processes still face the challenge of membrane fouling. In order to reduce the impact of membrane fouling in water flux several strategies such membrane modifications including materials and spacers, cleaning methods (flushing, air-sparging, osmotic backwashing, chemical cleaning) (Ansari et al., 2018) and feed pretreatment have been evaluated in literature. However, so far, most studies has been developed at lab-scale, with synthetic feed, and in batch conditions (Ansari et al., 2017) and more research is needed to achieve a complete understanding and development of the process. Furthermore, an advantage of this process compared to the UF-RO process would be the possibility of customization of the permeate, as this will be mainly conformed by water and a draw solution (DS) which can be selected depending on the water reuse purposes.

Additionally, FO technology is able to concentrate municipal wastewater to feed an anaerobic digester. In general treating municipal wastewater is not feasible since it requires at least a concentration of 1000mg COD/L (Ansari et al., 2017) to ensure process efficiency. However, it was expected that FO wastewater process would allow concentrating organic matter to make municipal wastewater suitable for direct anaerobic treatment and generate clean water for different uses.

In this study, the FO-NF has been evaluated for a novel application: direct filtration of municipal wastewater with the final goal of: 1. to concentrate the wastewater using FO to be treated in an anaerobic digester of reduced volume and 2. to obtain an NF permeate of high-quality for reclamation.

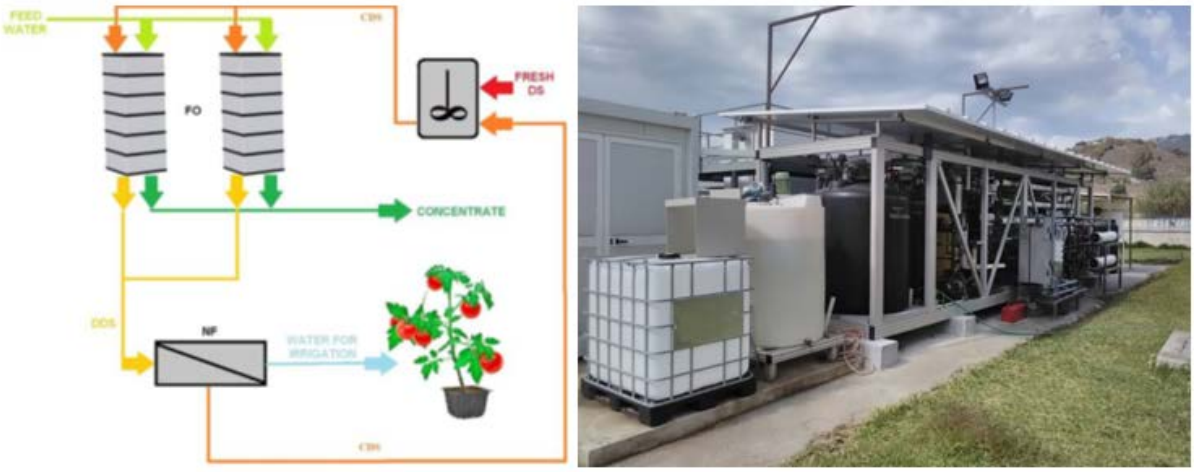


Fig. 1. Scheme of the FO-NF technology.

Material and Methods

A FO-NF demonstration plant located next to the wastewater treatment plant (WWTP) of Almuñécar (Granada) was used. Two different FO membrane configurations were evaluated: a rack of six FO commercial TFC flat-sheet membrane modules (84 m^2 PFO 100, Porifera, USA) and 2 spiral wounded membranes with an area of 30.4 m^2 of TFC (FO8040, Toray, Korea). Two NF membranes NF 90 4040 (Filtech, high rejection) were used, with an area of 60.8 m2. As feed water, the FO-NF demonstration plant used the influent obtained directly from the WWTP, after sand and grit removal. Experiments were conducted at a constant flow of 100 l/h using magnesium chloride as draw solution. Recirculation of wastewater coming out of the FO membranes was set at 90% in order to increase both recovery and cross-flow velocity along the FO membranes. Recovery was set at 50% in order to avoid excessive concentrate conductivity, which would limit the final application of the concentrate for irrigation, if this for instance would feed an anaerobic membrane bioreactor afterwards. Different pretreatment systems were

experimentally evaluated: settling, disc filtration (0.4 mm), settling and filter mesh (0.1 mm) and no pretreatment. Water quality parameters of the primary effluent, concentrate and permeate were measured according to standard methods (Clesceri et al. 1998).

Results and Discussion

Various preventive methods to reduce membrane fouling were tested, such as filtration (different pore sizes) and sedimentation. When no pretreatment was applied, high membrane fouling was found. By filtrating with disc filters, the results indicated that fouling can be controlled longer but after 1.5h of operation, the flux suffered a severe decline, leading to the conclusion that a more intensive pretreatment was required. To reduce membrane fouling, sedimentation and mesh filtration of 0.1 mm were selected for longer operation (Fig 2., left). Osmotic backwashing (OB) and flushing was included in the filtration regime to extend the operation time (Fig 2., right). The plant showed stable permeability when operating using an osmotic pressure difference of 10 bar and using osmotic backwashing and flushing every 20 min of filtration. The results showed that OB and flushing must be applied to avoid foulant deposition but once fouling has occurred, fouling could not be removed by a physical pretreatment and chemical cleaning would be required.

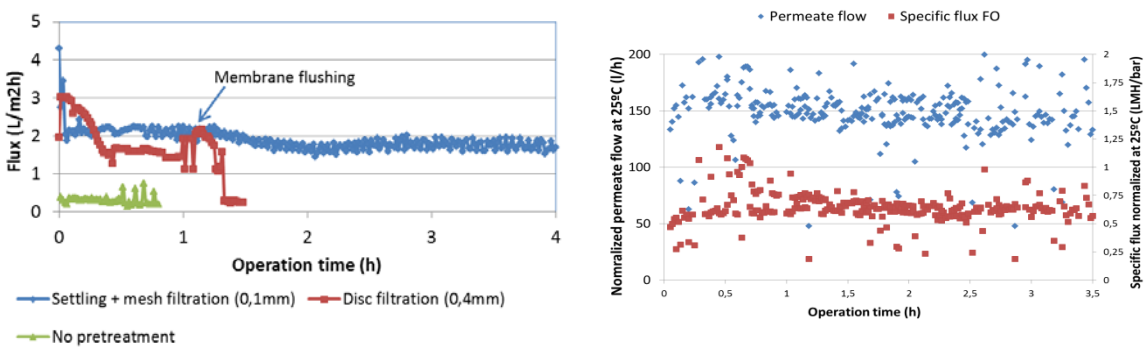


***Fig.2**. Operation of the FO-NF plant with direct filtration of wastewater using different pretreatments (left) and results of the FO-NF operation applying automatic cleaning strategies (right)*

NF permeate showed a high quality for reuse (fig 3, left): TDS, phosphorus and sulfate were not detected (under the detection limit) while a removal from the influent greater than 90% for most of the nutrients and micropollutants evaluated in this study (fig 3, right). On the other hand, the conductivity remained constant along the

experimentation and below 1 mS/cm. Regarding to N-compounds removal, the rejection of ammonium is up to 70%. On the other hand, even low strength wastewater, as the influent of this study (124 ± 39 mg.L^{-1}), could be pre-concentrated by FO to the range suitable for biogas production via anaerobic treatment. However, other ions such as sulfate are also concentrated (fig 3, left) and this, under anaerobic conditions, is reduced to sulfide and competes with the microorganisms responsible for the generation of methane (Chen et al., 2008). In the range of this study, it would be required to incorporate the organic matter removed by feed pretreatment (average inlet concentration of 382 ± 77 mg L^{-1}) and to control the sulfate concentration in order to increase the efficiency of methane production.

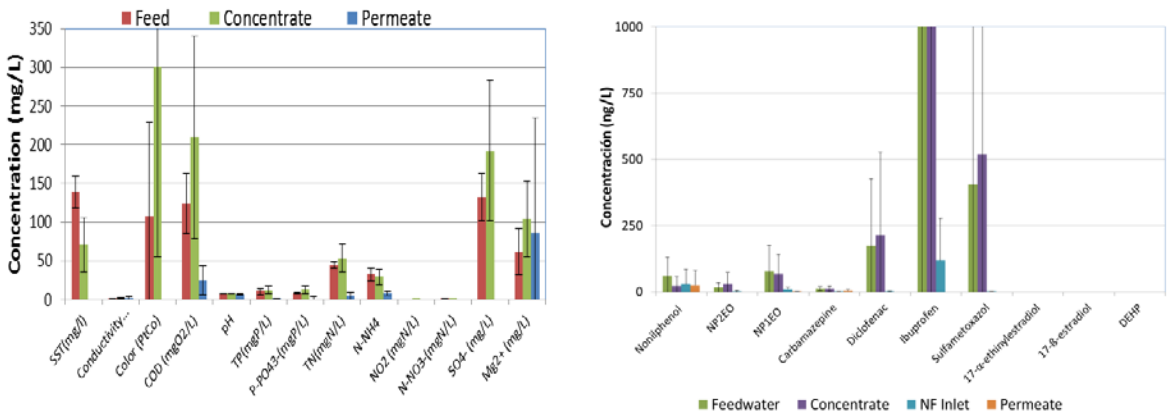


Fig. 3. Results of FO feed, FO concentrate and NF permeate nutrient characterization (left) and emerging pollutant characterization (right).

Conclusions

It has been demonstrated that FO is a low-fouling technology that can achieve a stable, high-quality permeate for wastewater treatment and reuse. The experimentation of different pretreatment technologies concluded with the selection of settling and mesh filtration of 0,1mm as the optimal pretreatment for controlling membrane FO fouling. Successful permeability recovery was found when using osmotic cleaning, which was comparable to chemical cleaning and could be included in the filtration regime to assure sustainable operation. Furthermore, FO-NF process achieved a removal from the influent greater than 90% for most of the nutrients evaluated in this study, achieving a permeate with high quality for reuse. Additionally, FO is a suitable method to increase the COD in wastewater and potentially the

biogas production in an anaerobic treatment. However, a compromise with recovery must be found, as other parameters will as well be concentrated like sulfate and conductivity, which may be detrimental for the anaerobic treatment and for the final water reuse.

References

Ansari. A.J., Hai, F.I., Price, W.E., Drewes, J.E., Nghiem, L.D. (2017) Forward osmosis as a platform for resource recovery from municipal wastewater - A critical assessment of the literature, Journal of Membrane Science, 529, 195-206.

Ansari. A.J., Hai, F.I., He, T., Price, W.E., Nghiem, L.D. (2018) Physical cleaning techniques to control fouling during the pre-concentration of high suspended-solid content solutions for resource recovery by forward osmosis, Desalination, 529, 195-206.

Chen Y., Cheng, J. J., Creamer, K., S. (2008) Inhibition of anaerobic digestion process: A review. Bioresource Technology 99, 4044-4064.

Clesceri, L. S., Greenberg, A. E. & Eaton, A. D. (1998) Standard Methods For The Examination of Water and Wastewater. American Public Health Association American Water Works Association / Water Environment Federation Washington, DC, USA.

Corzo. B., De la Torre, T., Sans, C., Escorihuela, R., Navea, S., Malfeito J.J. (2018). Long-term evaluation of a forward osmosis-nanofiltration demonstration plant for wastewater reuse in agriculture. Chemical Engineering Journal, 338, 383–391.

Schneider, C., Rajmohan, R. S., Zarebska, A., Tsapekos, P., Hélix-Nielsen, C. (2019). Treating anaerobic effluents using forward osmosis for combined water purification and biogas production.Science of the Total Envir. 647, 1021–1030.

Disruptive water reuse scheme based on Direct Ultrafiltration (DUF) of municipal wastewater

I. Saudrais, C. Daines*, Y. Poussade**, F. Boisquillon*, H. Faujour***, H. Humbert***

** Veolia Recherche & Innovation, Maisons-Laffitte, France*

*** Veolia Technical & Performance Department, Aubervilliers, France*

**** Veolia Middle East, Dubai, United Arab Emirates*

Introduction

Wastewater treatment plays an increasing role in providing safe and reusable water in order to limit water scarcity in many areas in the world. Today, conventional treatment solutions for reuse purposes are mainly applied in centralized WWTP and are based on preliminary physico-chemical and biological treatment steps before filtration and disinfection.

A new scheme for centralized or decentralized applications able to treat raw municipal wastewaters directly with membranes without a biological treatment step was investigated at pilot scale. Main expected benefits are (i) significant footprint reduction (ii) lower sludge production and iii) easier start-up and operation with less odor nuisances than conventional schemes including biology processes. Secondly, high water quality can be reclaimed anywhere along the existing sewer mains and not only at an existing WWTP. This avoids the necessity of dedicated distribution pipes for the transport of the reclaimed water which is often an economic obstacle to the feasibility of reuse projects. Finally, thanks to membrane rejection, reduced volumes of retentates rich in fresh organic carbon (on DUF) and nutrients (on RO) could favor energy and nutrients recovery.

Material and Methods

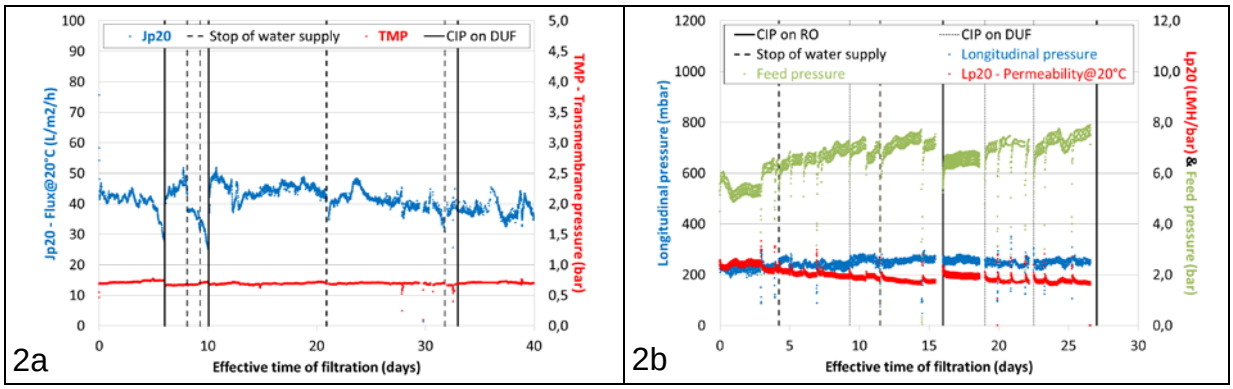
Pilot trials were conducted under continuous operation using real sewage wastewaters (COD=600mg/L; TSS=200mg/L; TN=70mg/L; TP=10mg/L). Capacities of the DUF and RO pilot units are 100-300L/h. Crossflow membranes tested are commercially available. UF membranes are tubular with 30nm nominal pore size. RO membranes are spiral-wound for brackish water with 99.6% salt rejection. Tested recovery rates were 85% for DUF and up to 70% for RO.

Results and Conclusions

Different DUF pretreatments were investigated, such as settling, chemical enhanced settling (CES) and fine screening. Best hydraulic performances of DUF were achieved using fine screening corresponding to the lowest TSS removal efficiencies. Remarkably, it was demonstrated that a minimum value of TSS in the UF

recirculation loop was necessary to prevent membrane fouling. With settling or CES as pretreatment, removal of TSS was too important leading to insufficient TSS concentrations is the UF recirculation loop leading to more rapid drops of UF flux and more frequent cleanings. For the selected pretreatment, different operating parameters on DUF and RO were studied notably flux or TMP, inlet pH, crossflow velocities, frequencies and methods of chemicals cleanings.

Operating conditions were optimized to achieve high and stable fluxes and to limit membrane cleaning frequencies. Figures 1 present an example of DUF and RO hydraulic performances. In the conditions of our trials it was possible to maintain 40LMH@20°C at a constant TMP of 1bar on the DUF unit for several weeks of filtration. RO pilot unit was operated with a constant flux of 12LMH@20°C at 70% conversion rate by keeping feed and differential pressures stable over the period. Chemical cleanings (CIP) were conducted every 8-15 days for both units.



Figures 1. Performances of DUF (2a) and RO (2b) pilot units

In parallel, permeate and retentate qualities were monitored. RO permeate quality was as good as permeate produced by traditional reuse schemes based on secondary and advanced tertiary (UF + RO) treatment (Table 1). Removal rates of most of the parameters especially COD, TSS, TN and TP exceeds 97%.

Table 1. Inlet wastewater characteristics and comparison of outlet wastewater characteristics for different process schemes

Parameter	Inlet wastewater	Outlet wastewater		
		Conventional WWTP (EU standard)	Conventional WWTP followed by UF + RO	New reuse scheme based on DUF + RO
COD (mg/L)	600	< 125	< 5	< 5
TSS (mg/L)	200	< 30	0	0
TN (mg/L)	70	< 10 to 15	< 1	< 1
TP (mg/L)	10	< 1 to 2	< 0,03	< 0,03
Removal of micropollutants		No / low	Yes / high	Yes / high
Reduction of total salinity		No / low	Yes / high	Yes / high

Pilot trials are still running in order to further reduce chemicals consumption and increase the productivity. Perspectives for 2019 are to construct and start-up a first commercial reference in Middle-East.

A novel self-cleaning electrospun BiOBr/Ag photocatalyst membrane with UV exposure applied for membrane distillation treatment of textile wastewater.

Jiaxin Guo, School of Energy and Environment City University of Hong Kong, Hong Kong SAR, China; Dickson Y.S. Yan, The Technological and Higher Education Institute of Hong Kong, 20A, Tsing Yi Road, New Territories, Hong Kong SAR China; Frank L.-Y. Lam, The Hong Kong University of Science and Technology, Chemical and Biological Engineering, Clear Water Bay, Kowloon, Hong Kon SAR China; Bhaskar Jyoti Deka, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China; Alicia K.J. An, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China

Introduction

Membrane Distillation (MD) is an effective approach to solve the current crises of resource depletion and environmental deterioration[1]. This research adopted the electrospinning technique to fabricate a hydrophobic porous membrane for MD treatment of textile wastewater that addresses the membrane fouling issue. An innovative electrospun photocatalyst BiOBr/Ag membrane was introduced for MD treatment of dyeing wastewater coupled with post-MD UV exposure for fouled membrane regeneration. The BiOBr/Ag membrane was fabricated by successfully coating an electrospun PVDF-co-HFP (E-PH) membrane with BiOBr/Ag catalyst particles using electrospray technology, with the goal to achieve higher hydrophobicity with the self-cleaning property under UV light. The coating of BiOBr/Ag particles on the BiOBr/Ag membrane's surface accelerated dye foulant degradation through the strong oxidization capacity of electron-holes when exposed to UV. Thus, compared to the two commercial membranes, the BiOBr/Ag photocatalyst membrane obtained significant improvement in recovery efficiency of water contact angle (95.6%) and water flux (92.2%) under UV illumination, pointing to its potential for fouled membrane regeneration.

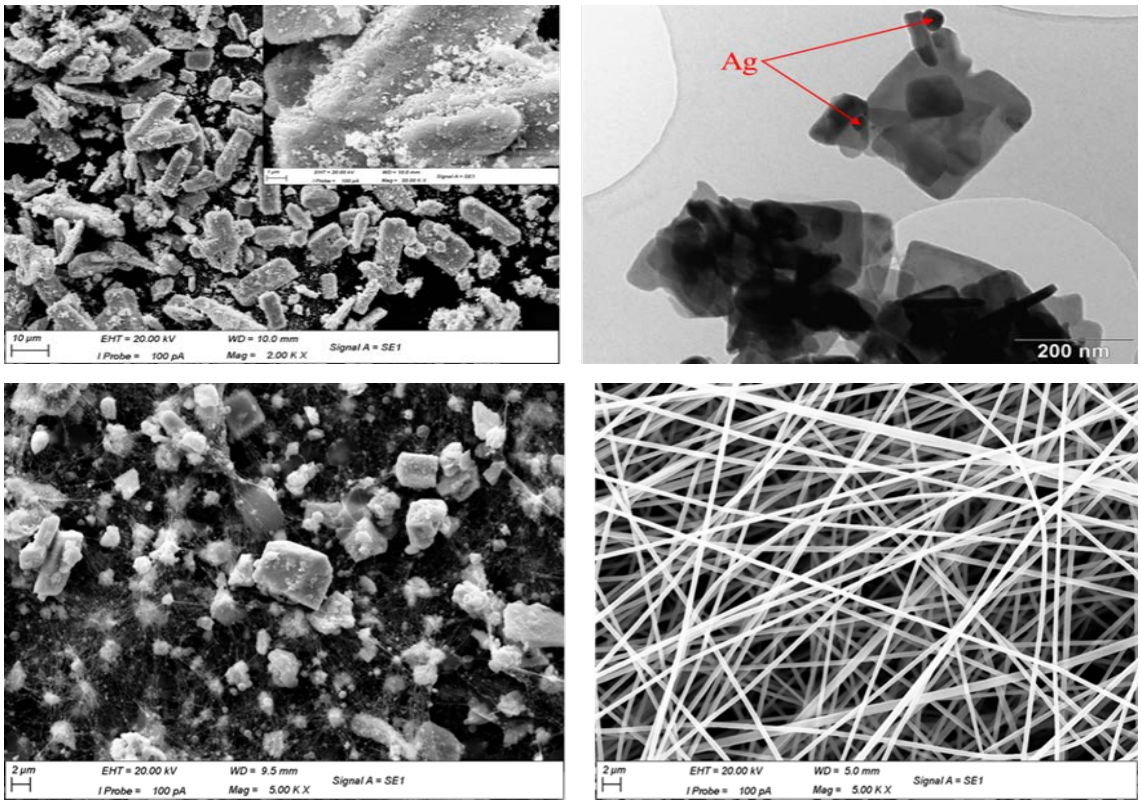
Materials and Methods

The dope solution for fabricating the bottom layer of the electrospun (E-PH) membrane was created by adding PVDF-HFP in a combined solvent of DMF and

acetone with a small fraction of LiCl2 (PVDF-HFP:DMF:acetone = 15:59.5:25.5, wt %) and stirred at 70 °C for 12 h until all three compounds were homogenously and completely dissolved. The polymer solvent was degassed throughout the course of stirring under ambient temperature before electrospinning. The dope solution for the electrospraying process was prepared by dissolving 0.84 g of BiOBr/Ag and 0.42 g of the PVDF-HFP polymer in a 5.58-mL DMF solution and stirred at 60ºC for 6 h. The BiOBr/Ag nanoparticles were coated on the dried E-PH membrane by electrospraying technology. During electrospraying process, a high voltage of 22kV was employed on a 0.8-mm diameter nozzle with a 1 mLh-1 dope solution injection rate, and the coating layer was collected on a rotating collector 11-cm apart. The process for fabricating the resultant BiOBr/Ag nanoparticle-coated E-PH membrane (hereafter E-BiOBr membrane).

Results and Discussion

Applying electrospray technology, the BiOBr/Ag particles were coated on the E-PH membrane to create the E-BiOBr/Ag membrane. The SEM image present the surface morphology of the E-BiOBr/Ag membrane and show cuboid shape particles which correspond to BiOBr/Ag. The SEM image showing the morphology of supporting layer, which is the nanofiber E-PH membrane fabricated by electrospinning technology, is entirely different from that of the coating layer. The XRD patterns of the virgin E-PH membrane and the BiOBr/Ag-coated E-PH (E-BiOBr/AG) membrane were obtained. In the case of the E-PH membrane, only one peak showed at 2θ value of 20.8°, which correspond to β-phase crystallization. Compared with the virgin E-PH membrane, many new peaks appeared in the XRD pattern of the E-BiOBr/Ag membrane, indicating the BiOBr/Ag particles coated on the membrane surface. A stability test was conducted on the BiOBr/Ag coating, and the coating layer demonstrated a stable DI water/dye solution contact angle value when immersed under solutions with pH levels ranging from 2 to 12.



Conclusion

In this study, after coating silver nanoparticles on the BiOBr photocatalyst, the electric conductivity was enhanced that effectively prevented the recombination of electrons and oxidized hole. Furthermore, the innovative electrospun photocatalyst BiOBr/Ag membrane was tested for MD treatment of dyeing wastewater coupled with post-MD UV exposure for fouled membrane regeneration. The fouling processes on all three membranes were monitored in real-time using OCT. The coating of BiOBr/Ag particles on the BiOBr/Ag membrane's surface accelerated dye foulant degradation through the strong oxidization capacity of electron-holes when exposed to UV. Thus, the BiOBr/Ag photocatalyst membrane achieved the higher hydrophobicity with the self-cleaning property under UV light.

References

[1] A.K. An, J. Guo, E.-J. Lee, S. Jeong, Y. Zhao, Z. Wang, T. Leiknes, PDMS/PVDF hybrid electrospun membrane with superhydrophobic property and drop impact dynamics for dyeing wastewater treatment using membrane distillation, J. Memb. Sci. 525 (2016) 57–67.

Water reclamation with hybrid powdered activated carbon / ceramic microfiltration: pilot studies for the removal of EfOM and contaminants of emerging concern

Rui M.C. Viegas, Elsa Mesquita*, Margarida Campinas*, Cristina M.M. Almeida**, Maria João Rosa**

** Water Quality and Treatment Laboratory, Urban Water Division, Hydraulics and Environment Department, LNEC – National Civil Engineering Laboratory, Lisbon, Portugal; rviegas@lnec.pt*

*** Department of Toxicological and Bromatological Sciences, Faculty of Pharmacy, University of Lisbon, Lisbon, Portugal*

Abstract

This paper addresses the enhanced removal of effluent organic matter (EfOM) and pharmaceutical compounds (PhCs) in wastewater treatment by powdered activated carbon/coagulation/ceramic microfiltration. Four chemically diverse PhCs are targeted: ibuprofen, carbamazepine (CBZ), sulfamethoxazole (SMX) and atenolol (ATN). Pilot assays (100 lmh, 10 mgFe/L) run with PhC-spiked sand-filtered secondary effluent and 15 mg/L PAC dosed in-line or to a 15-min contactor showed no PAC-driven membrane fouling and better performance with PAC contactor, reaching significant removals of CBZ and ATN (56%), SMX (47%), colour (48%), UV254 (35%) and DOC (28%). A detailed cost analysis points to total production costs of 0.22 €/m^3 for 50 000 m^3/day, mainly associated to equipment/membranes replacement, capital and reagents.

Keywords: Ceramic membranes; cost analysis; hybrid membrane processes; microfiltration; pharmaceutical compounds; water reclamation

Introduction

Sustainable water management must nowadays consider alternative water sources, and reclaimed water is a good candidate. Low pressure ceramic membrane filtration is an emerging option for safe water reclamation for unrestricted uses given its high effectiveness for suspended solids and bacteria, and mechanical and chemical robustness with operational and subsequent cost efficiency advantages over polymeric membranes (Loi-Bruegger et al., 2006; Panglisch et al., 2010). In previous

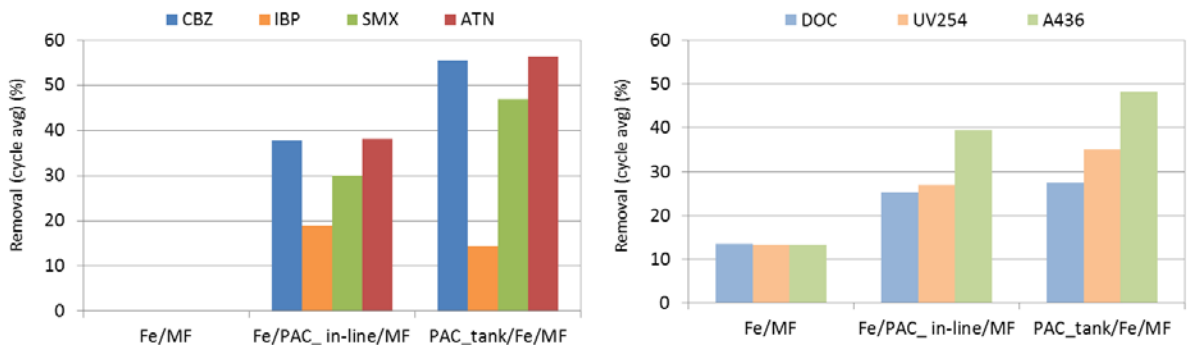
studies (Viegas et al., 2015), one-year 24/7 pilot demonstration of coagulation - ceramic filtration was developed in Portugal in two wastewater treatment plants (WWTPs) in Lisbon metropolitan area. The results obtained demonstrated the technology's effectiveness, reliability and efficiency towards water quality, with the process consistently producing highly clarified (monthly median < 0.1 NTU) and bacteria-free water, regardless the severe variations in its intake. Further studies were then developed aiming at enhancing the removal of organics by powdered activated carbon (PAC) dosing. Four contaminants of emerging concern, namely four chemically different and widely used pharmaceutical compounds (PhCs) were targeted, as well as effluent organic matter (EfOM) to minimize the by-products formation potential when a post-chlorination is required for water reuse. This paper presents operational and quality results obtained and a cost analysis of the process as a function of the plant flow rate.

Materials and Methods

The reclamation scheme comprised sand filtration of the WWTP secondary effluent followed by coagulation and hybrid powdered activated carbon / ceramic microfiltration (PAC/MF). The pilot (fully automated, remote controlled and with in-line monitoring of pressure, flow rate, temperature, pH and turbidity) and the MF membrane (0.1 µm pore size, Metawater, Japan) are described in Viegas et al. (2015). The tests were performed in dead-end mode, at a constant flux (100 L/(m^2.h), in short lmh), with 60-min filtration time followed by backwash, with two chemically enhanced backwash (acid + chlorine) per day, and $FeCl_3$ (10 mg Fe/L) and PAC (15 mg/L, Norit SAE Super, Cabot) dosing. Two PAC dosing modes were tested: in-line and to a contact tank providing 15 min contact time. Four pharmaceuticals compounds with different physical-chemical properties were selected for the studies: ibuprofen/IBP (anionic and relatively hydrophobic), carbamazepine/CBZ (neutral hydrophobic), sulfamethoxazole/SMX (anionic hydrophilic) and atenolol/ATN (cationic hydrophilic). Three campaigns were performed with PhC spiking, 2 µg/L each. The PhCs were quantified by SPE-LC-MS/MS (Gaffney et al., 2014). EfOM was analysed for dissolved organic carbon (DOC), UVA254 and colour (A436) onto samples filtered (0.45 µm polypropylene filters).

Results and Discussion

The results showed no PAC-driven membrane fouling, as similar transmembrane pressure and fouling rate were observed for Fe/MF and for PAC/Fe/MF, namely 0.37 bar and 231 Pa/min, respectively, for Fe/MF vs 0.40 bar and 194 Pa/min for PAC_tank/Fe/MF. Regarding PhC and EfOM removals, a major increase was observed when dosing PAC (Figure 1). With Fe/MF no CEC removals were observed while EfOM removals were ~12%. When PAC was dosed to a 15 min contact tank, ~50% higher removals of CECs were obtained than with in-line dosing, with the highest removals (56% for PAC_tank vs 38% for PAC_in-line) being obtained for CBZ and ATN. While the higher removals for CBZ can be attributed to hydrophobic interactions with the PAC, for ATN it should be due to PAC–EfOM–ATN interactions (Viegas et al. 2018). Under these conditions, the EfOM removals observed, namely 40% for colour, 35% UV254 and 28% DOC, are particularly beneficial if a post-chlorination is required for water reuse, since they lessen the chlorine demand and the disinfection by-products formation potential. The post-chlorination is usual for unrestricted irrigation, to provide a disinfectant residual in the reclaimed water distribution network.



a b

Figure 1 CECs (a) and EfOM (b) cycle-averaged removals by Fe/MF, Fe/PAC_in-line/MF and PAC_tank/Fe/MF (initial concentrations: CBZ, IBP, SMX, ATN 2 μg/L each; 5 mg/L DOC; 0.15 cm^{-1} UV254; 1.3 m^{-1} A436).

Based on these and on previous results (Campinas et al., 2016) cost functions for CAPEX and OPEX were developed. The technical and financial assumptions are described in Campinas et al. (2016), adapted to the data obtained from the pilot demonstration of Fe/MF and Fe/PAC/MF, namely 0.40 bar TMP, inlet pressure, plant downtime for backwash and CEBs, PAC (2.95 €/kg) and coagulant cost (1.4 €/kg Fe).

The costs of the components were adapted from the literature or provided from suppliers and are expressed as power type functions of the form:

$$Cost = a \cdot variable^{b}$$

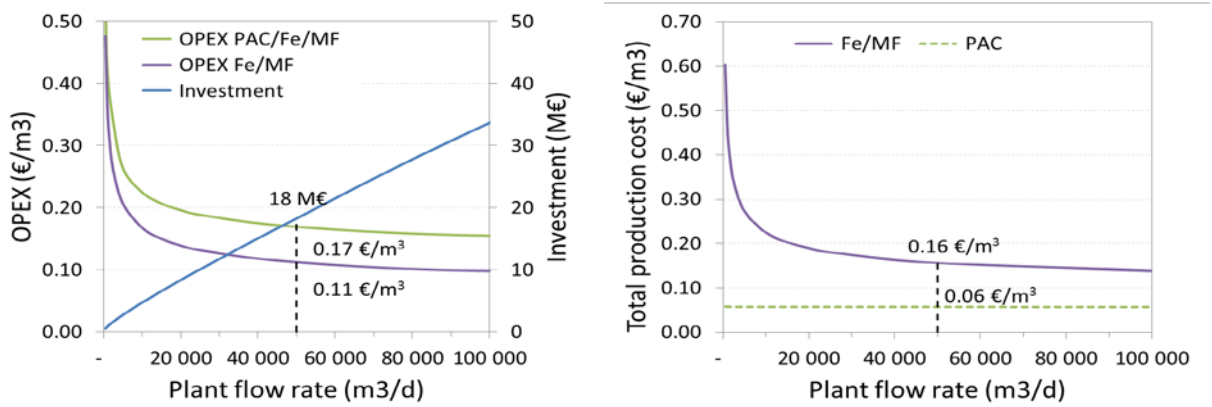
Table 1 lists the variables and the parameters a and b per type of cost.

Figures 2 and 3 depict the costs for treating the WWTP sand filtered secondary effluent studied. The OPEX and investment costs (Figure 2a) and the total production costs (€/m^3) (Figure 2b) are plotted as functions of the plant flow rate, for the Fe/MF and PAC/Fe/MF processes, while the cost structure, breakdown in capital, replacement of components, reagents, energy, maintenance and personnel (Figure 3), is plotted for the median flow rate of the case study WWTP (50 000 m^3/d). A PAC dosing of 15 mg/L was assumed and its dosing cost includes the reagent, the required pump(s) and the mixing and pumping energy costs.

Table 1 Cost functions of the components (Campinas et al., 2016).

Input cost	Variables; parameters
Membranes cost (€)[1]	membrane area (m^2); a = 756, b = 0.97
Pipes and valves cost (€)[2]	membrane area (m^2); a = 5313, b = 0.42
Instruments and controls (€)[2]	membrane area (m^2); a = 1296, b = 0.66
Tanks and frames (€)[2]	membrane area (m^2); a = 2732, b = 0.53
Miscellaneous (€)[2]	membrane area (m^2); a = 7052, b = 0.57
Pumps (€)[3]	power (kW) x safety factor (2): a = 26011, b = 0.354

Cost function [1] obtained from costs provided by the supplier on September 2016; [2] adapted from Guerra and Pellegrino (2012); [3] obtained from costs presented in Ramos et al. (2015)



a b

Figure 2 (a) Investment cost and OPEX for Fe/MF and for PAC/Fe/MF and (b) total production cost for Fe/MF and for PAC with filtered WWTP secondary effluent, highlighting the values for 50 000 m^3/d, the median flow rate of the case study WWTP.

As can be observed in Figure 2 the OPEX and the total production costs (€/m^3) are substantially different for very small and big plants, e.g. total production costs of 0.22 €/m^3 for a 50 000 m^3/day plant (the median flow rate of the case study WWTP) and 0.52 €/m^3 for a plant treating 1000 m^3/day. Furthermore, the plant scale is particularly impacting the costs below 20 000 m^3/day, whereas these are fairly constant above 60 000 m^3/day.

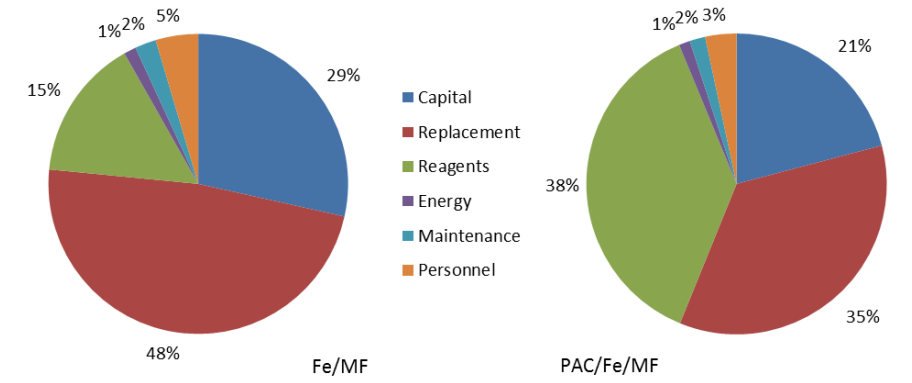


Figure 3 Cost structure of the Fe/MF and PAC/Fe/MF for a plant flow rate of 50 000 m^3/d.

The cost structure (Figure 3) reveals that when using Fe/ceramic MF, the main costs are associated with replacement of equipment and membranes (48%), capital (29%) and reagents (15%). When PAC is added, i.e. for PAC/Fe/ceramic MF, the cost structure changes are mostly related with the relative contribution of reagents to the total costs, with an increase to 38% of this fraction and a reduction in equipment/membrane replacement (35%) and capital (21%).

Conclusions

The pilot PAC/Fe/ceramic MF tests run with sand-filtered secondary effluent spiked with four chemically different pharmaceutical compounds showed that 15 mg/L PAC did not promote membrane fouling and that PAC dosing to a 15-min contactor performed better than its in-line dosing. In these conditions, PAC promoted significant removals (47%-56%) of three target PhCs, with the highest removals being obtained for carbamazepine and atenolol (56%). Considerable EfOM removal was also achieved, which is beneficial if a further post-chlorination is required for water reuse.

A detailed cost analysis of the process, as a function of the plant flow rate, was performed pointing to total production costs of 0.22 €/m^3 for a 50000 m^3/day plant, with a higher share of OPEX (0.17 €/m^3), mainly associated to equipment/membranes replacement and reagents costs than of CAPEX (0.05 €/m^3).

Acknowledgments

The authors acknowledge Juliane Braecker, Stefan Panglisch, André Tatzel and Tobias Abbink from IWW (Germany) and Águas do Tejo Atlântico teams of R&D, Laboratory, Maintenance and Operation for their helpful collaboration. The European Commission is acknowledged for funding TRUST in the 7th Framework Programme under grant agreement n.° 265122.

References

Campinas M., Viegas R.M.C., Silva C., Rosa M.J. (2016). Technical Guidelines of PAC/MF – Powdered Activated Carbon/Ceramic Microfiltration for Drinking Water Production, Deliverable of LIFE Hymemb, ed. 1, ISBN: 978-972-49-2299-7, LNEC, Lisbon, Portugal.

Gaffney V.J., Cardoso V.V., Rodrigues A., Ferreira E., Benoliel M.J., Almeida C.M.M. (2014). Análise de fármacos em águas por SPE-UPLC-ESI-MS/MS. Química Nova 37(1), 138-149.

Guerra K., Pellegrino J. (2012). Investigation of Low-Pressure Membrane Performance, Cleaning, and Economics Using a Techno-Economic Modelling Approach, Science and Technology Program Report No. 174. U.S. Department of the Interior, Bureau of Reclamation (USA).

Loi-Bruegger A., Panglisch S., Buchta P., Hattori K., Yonekawa H.,Tomita Y., Gimbel R. (2006). Ceramic membranes for direct river water treatment applying coagulation and microfiltration. Water Sci. Technol. Water Suppl. 6 (4), 89-98.

Panglisch S., Kraus G., Tatzel A., Lickes J.-P. (2010). Membrane performance in combined processes including ozonation or advanced oxidation, powdered activated carbon and coagulation – investigations in pilot scale. Desalination 250 (2), 819-823.

Ramos A., Matos C., Costa C., Moura C., Lacerda F., Costa F., Alves I., Jorge I., Teixeira J., Cunha R. (2015). Smart water grids: gestão das redes em tempo real na bacia de Aldoar. Proceedings of Encontro Nacional de Entidades Gestoras de Água e Saneamento (ENEG 2015), Porto, Portugal.

Viegas R.M.C., Mesquita E., Campinas M., Almeida, C.M.M., Rosa M.J. (2018). Designing a PAC/NF advanced process for controlling pharmaceutical compounds in reclaimed water. *In* Sanitation Approaches & Solutions and the Sustainable

Development Goals. Eds. J.S. Matos, M.J. Rosa. ERSAR, EWA, APESB, CERIS. Lisbon, pp. 69-82.

Viegas R.M.C., Mesquita E., Campinas M., Inocêncio P., Teixeira A.P., Martins J., Rosa M.J. (2015). Water reclamation with hybrid coagulation–ceramic microfiltration: first part of a long-term pilot study in Portugal. Journal of Water Reuse and Desalination 5 (4), 550-556. DOI: 10.2166/wrd.2015.122.

Eco-efficiency of on-site water reclamation at a large brewery

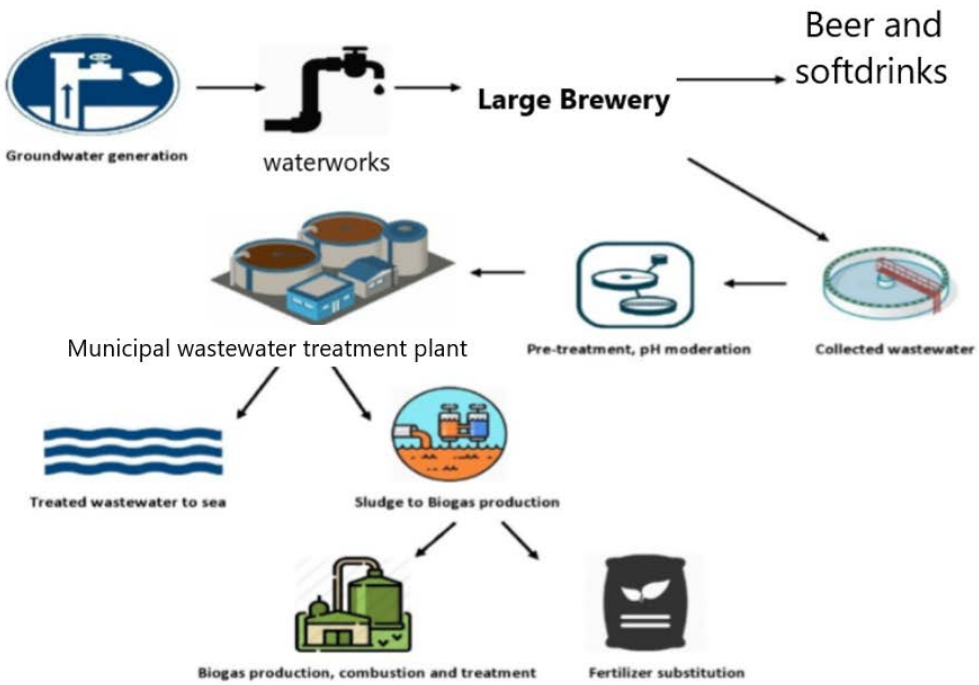
B. Godskesen[1]; D. D. Sundaram; H. J. Albrechtsen[1]; M. Rygaard[1]; Technical University of Denmark (DTU), DK-2800 Lyngby, Denmark;

Breweries are large water consumers and recognizes a need for improved water efficiency. Meanwhile the food industry is facing a major challenge in reducing environmental impacts and improve profitability, i.e. a need for eco-efficient production. The goal of our study was to assess the environmental and economic performance of a possible radical change to the water management for a large Danish brewery that will reclaim up to 80% of the on-site process water production. Our Eco-efficiency method combines assessment of economy with life-cycle assessment (LCA) to evaluate if the process would generate more value through technology and process changes whilst reducing resource use and environmental impact. The case study is based on a proposed on-site 'Energy and Water reclamation plant' that will take advantage of the large volume of process released by the brewery. Besides water reclamation, it is proposed to recover heat energy from the process water while treating the effluent water to a higher quality than by conventional process water treatment. The resource recovery solution includes a membrane bioreactor (MBR) in combination with RO treatment, heat pumps for thermal heat recovery, and sludge digestion for biogas production. Our assessment considers the entire water chain from extraction of groundwater, until the treatment of sludge from process water. The functional unit is daily treatment of 1,990 L of process water equivalent to a production of 1,710 L of beer and soft drinks.

For comparison, we assessed a baseline scenario (Fig. 1) where the brewery daily imports 3,765 m^3 drinking water from and discharges 1,990 m^3 process water to a public water utility. Two alternative scenarios of the 'Energy and Water reclamation plant' were assessed: A) On-site Energy and Water reclamation plant with effluent discharge to the Sea and B) a similar system but with re-use of water at the production facility. The proposed alternatives were described in detail and an inventory of mass and energy flows established.

In the economic evaluation both proposed scenarios of the 'Energy and Water reclamation plant' lead to markedly savings for the brewery with largest savings

related to the solution with reclamation and reuse at the brewery. Alternative A has no change to the impacts on freshwater resources, as the water is lost to the Sea as in the baseline. In alternative B it was projected that the on-site reclamation would reduce freshwater withdrawal impacts by 45% compared to the baseline. In terms of environmental impacts the two alternatives are largely similar to the baseline scenario. However, the 'Energy and Water reclamation plant' performs worse on two toxicity impact categories (10-30%) compared to the baseline scenario.



Figur 1. Baseline scenario where the brewery buys drinking water from the municipal water supply and sends process water to the municipal wastewater treatment plant.

The evaluations in our study lead to the conclusion that the proposed treatment solutions are more eco-efficient compared to the baseline scenario at the brewery when considering the economy, impact categories from the LCA (besides human toxicity cancer and ecotoxicity freshwater) and freshwater withdrawal impacts.

Our results show how Eco-efficiency assessment can assist decision-making in water reuse management at a large-scale food or beverage production facility and help companies on the way towards more sustainable production.

Water efficiency in food industry – ways to improvements

H.-J. Albrechtsen[1]; H. Bengaard[2]; J. Rasmussen[3]*

[1]Technical University of Denmark (DTU), Kgs. Lyngby, Denmark; [2]Danish Agriculture & Food Council, Copenhagen, Denmark; [3] Water Advice, Helsinge, Denmark

**hana@env.dtu.dk*

Background

Water use is essential in food industry, since it is one of the largest water-consuming industries in Denmark and globally. Furthermore, water quality is crucial to ensure high safety of the food products. This project DRIP – 'Danish partnership for Resource and water efficient Industrial food Production' – is a public/private partnership focused on water efficiency in the food industry. The project aims at a paradigm shift in industrial water efficiency through demonstration and implementation of a 'water-fit-for-purpose' concept. The concept moves from a food safety regulatory demand of using drinking water quality for all purposes to use of upgraded water sources based on closed loop solutions, which fit the requirements for the specific use. The goal is a reduction in water consumption in the industry of 15 – 30 %.

Water is the overarching focus of the partnership, but the business rationale for the food industries and their technology and knowledge providers is justified based on not only water savings and water reuse, but also the associated energy savings as well as possible recovery of resources in process and wastewater.

This is reflected in the overall success criteria of the project: 'Water-fit-for-purpose' concepts and closed loop solutions will be applied successfully in the food sector in Denmark within the present or a modified regulatory framework that has been put in place through close collaboration with and support to the relevant authorities.

Cases

A number of feasibility studies are conducted in the project to develop, implement and evaluate new treatment technologies and implementation methods. Below are given a few examples.

Rinse water

At the HKScan poultry abattoir in Vinderup, Denmark, It was demonstrated that the rinse water could be directed against the current in the section of the production where chicken feets are cleaned and cooled before packing and export to the East. This has the potential to save about 100 m^3 of water a day, corresponding to 50 % of the water consumption in this process step, or 6-7 % of the factory's total water consumption.

Water treatment for production of soft drinks

To achieve the specific taste of a Coca Cola the water used for the production has to be treated very carefully. This is usually leading to an annual waste of 130 millioner liter good water at Carlsberg at Fredericia, Denmark. However, in this project we have implemented a new water treatment which is improving the quality of the soft drinks nearly without any waste of water, since this water is re-used in other processes in the factory. This is an investment of approx. 1.3 mio €, but it is paid back in 3-4 years.

DRIP
Water efficient industrial food production

http://drippartnership.com/

The Partnership

The partnership consists of 13 food companies (e.g. Carlsberg, Arla, Danish Crown) and technology providers (e.g. UltraAqua, Grundfos, Siemens, Alfa Laval, DSS), three universities (DTU, CBS, Univ. Copenhagen) and a research and technology organization (Teknologisk Institut). The authorities Danish Veterinary and Food Administration, Environmental Protection Agency and Nature Agency are associated partners. The partnership was launched in 2015 and will run until 2020 with an investment of 6.6 mio € from Innovation Fund Denmark and 6.4 mio € from the partners.

Water reuse in food industry– Practical examples from dairy and potato processing industry

Klaus Dickhoff, EnviroChemie GmbH, Rossdorf, Germany

The food industry typically is an intensive water user with strict quality requirements for process water. Water recycling and reuse can reduce the amount of fresh water consumed and wastewater generated. Beside economic and environmental benefits the companies gain greater independence on external water sources and discharge conditions. The concept for water recycling is usually part of an overall concept for optimized water and wastewater treatment. Beside an increase of resource and energy efficiency the aim is to optimize operating costs.

Companies producing dry and evaporated products, for example in the dairy industry, have to handle the generated vapor condensates. The volume of vapor condensates can reach several hundred cubic meters per day, depending on the produced amount of dry products. The aqueous condensates contain organic impurities. During storage the condensates tend to production of odour. The recycled water can be reused as process water for different production purposes.

During the presentation **practical examples** from dairy and potato processing industry located in Germany will be presented. In this context the overall concept for optimized water and wastewater treatment as well as the technical and economic potentials are addressed.

- At a diary up to 40 m^3/h of vapor condensates are generated during production. The vapor condensates are characterized by a low salt content and contain organic impurities. The aim of the vapor condensate treatment is to obtain hygienically safe water which can be reused as process water for different production purposes. For this a combination of biological and membrane treatment technology with UV disinfection was chosen. Special emphasis was placed on the possibility to sanitize the plant. This includes hot water sanitization with the resulting material requirements. The realization and start-up of the plant was started in summer / autumn 2018.
- At a potato processing plant only a certain volume of treated process water is allowed to be discharged into a receiving water body. An expansion of the production is scheduled for 2018. The increase of treated process water would

exceed the permissible discharge volumes. Water recycling and reuse was the solution for the problem. In the future about 37% of the treated process water is going to be recycled and can be reused for production purposes. The process water is treated up to direct discharge quality mainly via biological treatment steps. For water recycling the process water is further treated via membrane technology and disinfection with chlorine dioxide. The resulting desalinated and sterilized water is going to be reused for washing, peeling and cutting of the potatoes during production. The recycling of process water is part of an overall concept for optimized water and wastewater treatment at the production site. In 2014, the aerobic wastewater treatment was modernized and extended by an anaerobic treatment stage which significantly reduced the operating costs. The specific amount of sludge to be disposed was reduced by approx. 50%, the specific power consumption by approx. 60%. Beside this about 435,000 Nm^3 of biogas are produced annually and used for steam generation instead of fossil fuels. Due to production expansion the whole wastewater treatment plant is expanded in 2018.

Industrial Water Reclamation and Reuse in India

J. Lahnsteiner, VA TECH WABAG, Vienna, Austria, presenting author; P. Andrade, VA TECH WABAG, Chennai, India; R. Mittal, VA TECH WABAG, Chennai, India

Introduction

Apart from environmental protection, large quantities of freshwater can be saved by industrial water reuse and recycling. This boosts the industrial water supply reliability which can be endangered due to increased freshwater demands for agricultural and potable purposes (caused mainly by population growth and climate change). In India, VA TECH WABAG Ltd. has built more than twenty water reclamation plants for various industrial water recycling and reuse applications. In this paper, four of these cases are presented: the Jindal WRP (source water: coal gasification effluent; reuse of the reclaimed water as cooling make-up), the Dahej WRP (source water: petrochemical effluent; reuse of the reclaimed water as boiler make-up), the Paradip WRP (source water: refinery effluent; reuse of the reclaimed water as boiler make-up) and the Koyambedu WRP (source water: municipal secondary effluent; reuse mainly in the automotive supplying industry).

Methodology

In all cases, advanced multi-barrier systems including ultrafiltration (UF) and reverse osmosis (RO) have been utilised in order to meet the strict quality requirements for recycling as boiler make-up and/or cooling make-up. VA TECH WABAG Ltd. India was commissioned with their construction, operation and surveillance.

Water reclamation cases

Angul Jindal Steel and Power Coal Gasification Plant

At the Angul Jindal Steel and Power Coal Gasification Plant, used water from coal gasification (secondary effluent from biological treatment) and cooling tower blow down is reclaimed and recycled as cooling tower make-up (TDS < 50 mg/L). The water reclamation plant (Q = 8,400 m^3/day; start-up 2016), mainly consists of high rate solid contact clarification, dual media filtration, ultrafiltration (Figure 1) and reverse osmosis (three stages).

Figure 1 Angul/Jindal Water Reclamation Plant - Ultrafiltration Unit

A special feature is that the RO brine is reused for dust suppression in ash handling (Figure 2) accomplishing zero liquid discharge in this facility.

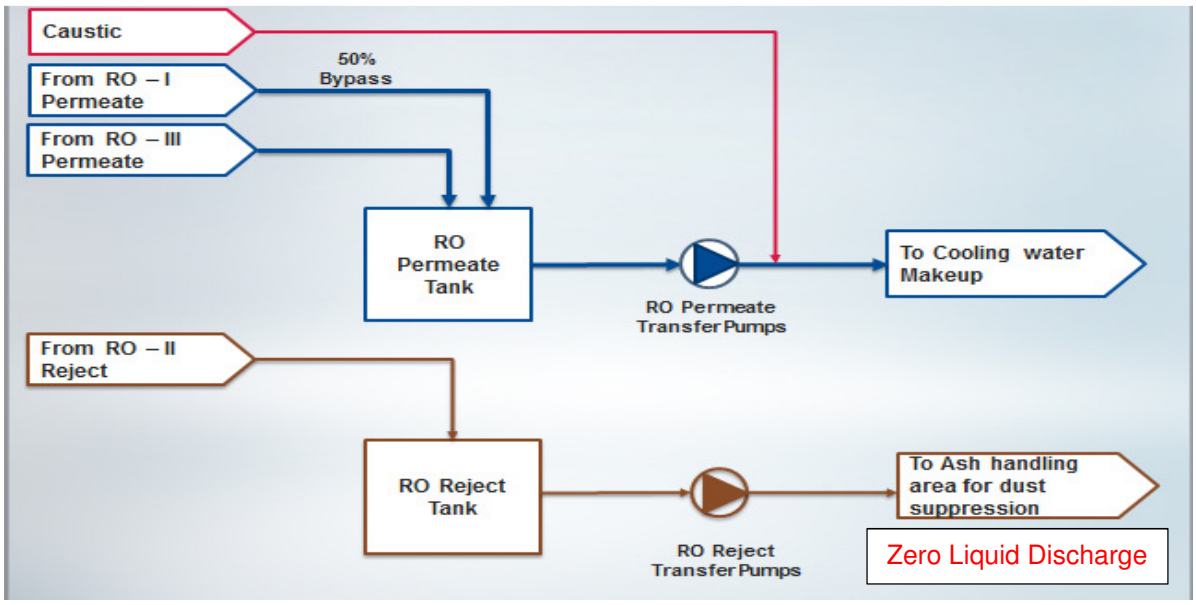


Figure 2 Angul/Jindal Water Reclamation Plant- Reuse of the RO Permeate and Brine (ZLD)

Reliance Dahej Refinery and Petro-chemical Complex

At Dahej, a complex (advanced multiple barrier) effluent treatment and water reclamation system with anaerobic treatment (UASB), MBR (Figure 3) and reverse osmosis as core technologies has been in operation since the end of 2015. The reclaimed water (RO permeate) production capacity is 43,200 m^3/day (future capacity: 57,600 m^3/day) and therefore the system represents the largest industrial water reclamation and recycling facility in India. The RO concentrate is discharged into the sea. A challenging COD limit of 150 mg/L has been set, which requires the extensive removal of this parameter in the upstream biological treatment units (UASB, MBR).

Figure 3 Reliance Dahej Water Reclamation Plant -Membrane Bioreactor

Indian Oil Corporation Ltd. Paradip Refinery

At Paradip, a complex effluent treatment and water reclamation system with a robust two-stage biological aerobic system, ultra-filtration and reverse osmosis as core process steps has been in operation since mid-2016. The current reclaimed water capacity (RO permeate) is 28,000 m^3/day (future capacity: 45,000 m^3/day). Special features are comprised by wet air oxidation (Figure 4) for the detoxification of sulphidic and naphtenic spent caustic and the removal of recalcitrant COD from RO brine by

powdered activated carbon in order to meet the discharge standard of 125 mg/L for sea disposal.

Figure 4 Paradip Refinery – Wet Air Oxidation

Chennai CMWSSB Koyambedu Water Reclamation Plant

In March 2016, a contract was awarded for a 45,000 m^3/d water reclamation plant (source water: municipal secondary effluent) at Koyambedu, which will provide high-grade water (UF and RO are the core process steps) to various industries (automotive supply industry, etc.) south-west of Chennai (at Irungattukottai, Sriperumbudur and Oragadam) via a 72 km-long pipeline. This contract also includes 15 years of operation and maintenance by a water technology specialist, which guarantees a safe and reliable supply of high quality water (start-up in second half of 2019). In this connection, it can be stated that the water reclaimed from secondary effluent represents a drought-proof supply at relatively low cost. Seawater desalination is more expensive. In Chennai, the specific cost of desalinated water (produced by a 100,000 m^3/d SWRO) is approx. 0.7 EURO/m^3 (OPEX + CAPEX). The cost of a comparable water reclamation plant producing the same quantity (100,000 m^3/d) and quality (300 mg/L TDS.) is estimated to be roughly less than half (approx. 0.3 EURO/m^3) of the

aforementioned value for sea-water desalination. Figure 5 shows an aerial view of the Koyambedu water reclamation plant under construction (photo taken in January 2019).

Figure 5 Chennai Koyambedu Water Reclamation Plant

The Dow Terneuzen 2025 water reuse concept – Incorporating over 20 years of industrial water reuse experience

Marc Slagt, Dow Benelux BV, Terneuzen, Netherlands, presenting author; Jochen Henkel, Dow Deutschland AgmbH, Rheinmuenster, Germany, presenting author; Niels Groot, Dow Benelux BV, Terneuzen, Netherlands, presenting author

The water reuse concept of the Dow Terneuzen site is worldwide recognized as a milestone project for industrial water applications. The original concept was implemented in the late 90s to expand the facility's production capacity and driven by the limited freshwater availability in the region. It was time to review the concept and to incorporate the valuable lessons learned over the past two decades of operation. The goal of the new concept foresees to maximize the reuse of the wastewater sources (municipal + industrial), to minimize/eliminate the current Biesbosch freshwater source and at the same time to enable future capacity increase by 20%.

The presentation will discuss the main challenges and limitations of the current concept. We will introduce a new concept that overcomes these limitations but at the same time maintains the level of redundancy, cost efficiency and increases the level of robustness.

However, the goal of the presentation will be to overcome the preconception that complex water layouts are difficult to operate and expensive. We will demonstrate that the true value of an enhanced and state of the art concept is only discovered with a different engineering mindset and if the boundary of the system is not limited to the water treatment but extended to the manufacturing/production site. Consequently, the success of such projects depends significantly on the willingness to cooperate and interchange knowledge beyond the typical and often limited scope of a water treatment plant

Advanced RO for water reuse and brine concentration in Copper Smelter effluents

Ignacio Martín García[1], Carlos Echevarria[1], Jesús Salinero[1], Marina Arnaldos[1],
Xavier Bernat [1], *Alberto Mejía Pérez[2], Irene Ruiz Oria[2], Guillermo Ríos Ransanz[2]*
1 Cetaqua, Centro Tecnológico del Agua. Crta. de Esplugues, 75, 08940 Cornellà de Llobregat, Spain
2 Atlantic Copper S.L.U. Avda. Francisco Montenegro s/n, 21001 Huelva, Spain

Abstract

The aim of the present study is to evaluate the influence of implementing flow reversal concept in reverse osmosis (RO) systems for water reuse and as pre-concentration stage for ZLD implementation in Copper smelters. Results from the present study have shown that appropriate optimization of flow reversal time enables to reduce precipitation and therefore to increase recovery rates in comparison to conventional RO systems. The higher concertation factor brought by flow reversal concept, presents the potential to significantly reduce costs associated to brine crystallization when ZLD treatment is pursued

Introduction

Zero liquid discharge (ZLD) is an ambitious wastewater management strategy that eliminates any liquid waste leaving the plant or facility boundary, with most of water being recovered for reuse. Reverse Osmosis, has been incorporated into ZLD systems in order to reduce the amount of contaminated effluent volume to be processed in the evapo-crystallization stage, improving the overall process cost–efficiency. Although RO represents an energy- efficient liquid concentration option in comparison to thermal evaporation, it can concentrate effluents only up to a certain level of salinity due to limits in the pressure applied to produce treated water, and to the precipitation of salts on the membrane surface which negatively affects membrane life and performance (Fritzmann et al, 2007).

Recent developments in desalination technologies applied for brine concertation include flow-reversal RO (Gilron et al, 2006). Flow Reversal is an innovative process

for operation of RO systems, in which the flow direction of the saline stream in the RO pressure vessel arrays is periodically switched. By periodically switching the flow direction, scale does not have time to form on membrane surfaces before being swept away by undersaturated feed solution conditions. This approach results in higher recoveries of water to be reused as well as lower volumes of brine to be processed in the downstream energy-intensive evaporator crystallizer. This approach could bring about lower energy consumptions that make ZLD a viable option in the mining industry and elsewhere, and thus demonstration of the feasibility of the process in real operational environments is of relevance.

The aim of the present study is to evaluate the influence of implementing flow reversal concept in RO systems for water reuse as pre-concentration stage for ZLD implementation in copper smelters. Two alternative flowsheets for the treatment of medium and high salinity streams were tested at bench and pilot scale to evaluate the best option in terms of volume reduction for the integration of the different streams in a ZLD treatment plant.

Materials and methods

The first evaluated option consisted of a blend of 90 % by volume of actual treatment plant effluent (PTEL) and the remaining 10 % of the Nickel Carbonate plant sourced from an Atlantic Copper smelter (Huelva, Spain). Before blending the PTEL, effluent was softened with sodium carbonate at pH of 12 (with NaOH) and after blending, both streams were treated with UF membranes to remove solids for the RO flow reversal trials. Water quality of the resulting blend and pre-treatment of these streams is shown in Table 1.

A 600 L/h permeate capacity bench scale flow reversal pilot was employed for the evaluation of the flow reversal concept using the blend of copper smelter effluent streams. In all the experiments, both feedwater and permeate were recycled back to the feed tank, conversion rate was initially set at 75 % with constant feed pressure set of 16 bar and antiscalants dosing of 2 ppm of PC-191 (for $CaCO_3$ and $Ca(PO4)_2$ scaling) was applied. During the trials, phosphate and carbonate concentrations were monitored to detect the beginning of scaling.

Table 1. Feedwater composition employed for the evaluation of PTEL and nickel carbonate effluents combined and only the PTEL effluent (Eff treatment with flow reversal RO

Parameter	Blended effluents	PTEL Effluent		
		Period 1 0-40 h	Period 2 40-100 h	Perido 3 100-205 h
Temp. (º C)	-	18 [13-24]	16 [11-25]	23 [12-30]
pH	9.11	9.4 [8.3- 11.7]	6 [3.52-9.3]	10.1 [2.4-12.3]
Cond (mS/cm)	12.5	4.7 [3.3-5.6]	5.0 [4.85-5.96]	6.2 [5.0-8.5]
Turb (NTU)		0.35 [0.1-0.9]	0.27 [0.1-0.4]	0.27 [0.08-0.8]
TDS (mg/L)	8800	3743 [3065-5600]	2938 [2445-3695]	3637 [1680-5075]
TotalAlkalinity (mgCaCO3/L)	108/212[1]	50.7 [31.2-78.6]	13 [0-42]	151 [0-390]
NO3 (mg-N/L)	11.1	7.0 [2.2-10.7]	2.9 [1.2-9.0]	2.0 [1.5-2.8]
Ca (mg/L)	50-64	234.8 [<20-534]	41.0 [22.5-54.8]	323 [90.2-976]
Cl (mg/L)	947-934	749.4 [403-1166]	878.6 [684.0-1214.0]	1190.6 [807-1688]
F (mg/L)	-	5.1 [3-7]	6.4 [4.2-8.6]	10.9 [7.1-15]
K (mg/L)	32	34.7 [26-43]	19.6 [10.3-28.3]	26.9 [13.3-39.3]
Na (mg/L)	3676	1129.2 [914-1296]	1128 [934-1342]	1074 [410-1905]
NH4 + (mg-N/L)	10.5	2.7 [1-4]	1.8 [0.9-3.9]	1.7 [1.0-3.4]
PO4-3 (mg-P/L)	4.3	4.7 [0-10]	3.8 [3.7-3.8]	1.9 [0.2-38.2]
SO4-2 (mg/L)	5720	1555.4[1348-2013]	1140 [967-1269]	1127 [878.0-1774]
Silica (mg Si/L)		2.7 [2.1-3.3]	-	-

1. Carbonate/bicarbonate in mg/L
2.

The scheme consisting of the blend these two streams was compared against a second alternative consisting of the pre-concertation of the medium salinity stream with flow reversal, sourced from the treatment plant effluent (PTEL), partially softened with ion exchange resin and pre-treated with ultrafiltration membranes. The pre-treatment produced RO feedwater with turbidity ranging between 0.2-0.4 NTUs and SDI values below 3 % /min. According to the composition of the pre-treated PTEL effluent three different operational periods were identified (Table 1). Based on the water quality analyses shown in Table 1, precipitation of calcium species (CaCO3, CaSO4, CaPO4 and CaSO4) is expected to occur at recovery rates exceeding 75-80 %, with the highest scaling potential showed for periods 1 and 3, that were characterized by high pH (9.4 and 10.1) , Calcium (235-323 mg Ca/L) and total alkalinity (50.7-151 mg/L) values. In contrast, period 2 showed lower scaling potential, with a lower average pH of 6 as well as lower Calcium and alkalinity values that averaged 41 mgCa/L and 13 mgCaCO3/L respectively.

For the evaluation of the pre-concentration of the PTEL effluent, a 6000 L/h flow reversal RO pilot plant that was operated continuously during a maximum of 6 to 8 hours per day. The RO pilot plant comprised a total of 40 brackish water 4 inch RO elements, with a total membrane area of 315 m^2, divided in 10 pressure vessels. Each two pressure vessels were grouped in a block, with 3 blocks working as the first stage, the fourth as the second stage and a fifth block as the third stage (Figure 1), with booster pumps for the second and third stages flux control. Two different flow reversal sequences were independently applied:

1st and 3rd stage periodically switched from one block to another. In this case, flow reversal involves that the tail element of the 3rd stage becomes the first element of the first stage, when a block is switched form the 3rd to the first stage.

The 2nd stage is not exchanged between blocks, but flow reversal is applied though the change of the feed line.

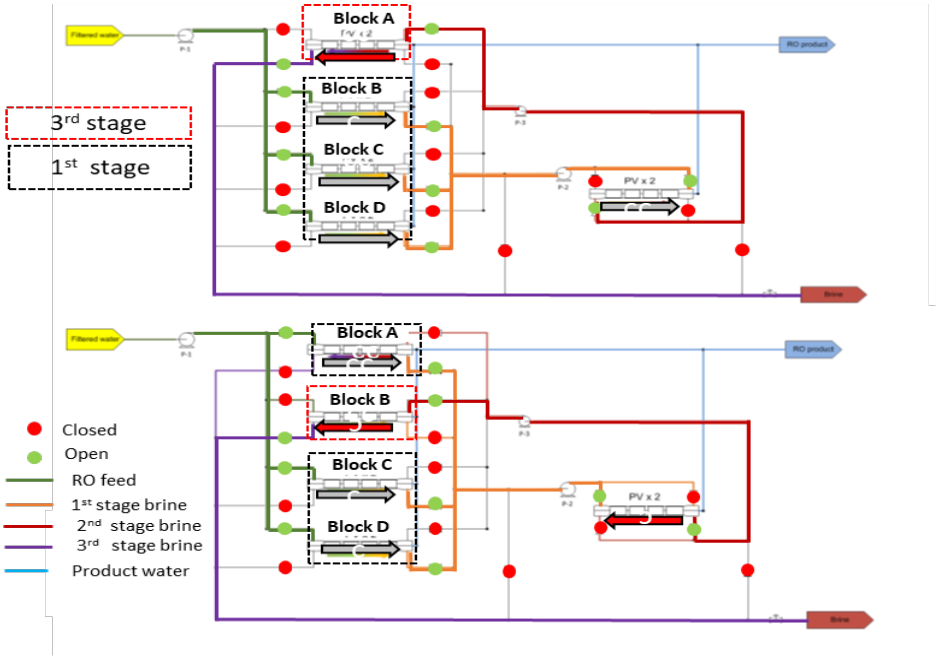


Figure 1 Schematic representation of Flow reversal pilot plant

During pilot plant operation recovery rates between 85 and 92 % were adapted according to the system performance observed during the periods of different water quality. System fluxes between 16 and 18 LMH were applied, switching between the first and third stages applied every 50 minutes and flow reversal on the second stage every 2 hours

Results and Discussion

The feasibility of the flow reversal RO for the pre-concentration of the of the blend of the PTEL and nickel carbonate streams was evaluated in one baseline trial conducted without flow reversal and with two additional tests in which flow reversal times of 45 and 30 minutes were applied. The application of flow reversal every 45 minutes, showed a slower drop of permeate flow in comparison to the baseline trial. However, in both cases scaling was evidenced by a reduction in phosphate concentration from 4.4 to 3 ppm in the baseline and from 5.4 ppm to 0.9 ppm with 45 minutes flow reversal. In the third trial, with flow reversal applied very 30minutes permeate flow rate remained stable and phosphate levels in the concentrate increased from 2.5 to almost 5 ppm probably indicating dissolution of deposited precipitates from previous tests. Once flow reversal was stopped, during the following 78 hours, a significant permeate flow reduction was observed together with a reduction in phosphate levels from 5 to 3 ppm.

The performance of the flow reversal RO treating only the PTEL effluent with the water has been evaluated through the evolution of the normalized permeate flow (DOW normalization) for each of the stages to identify stable operational conditions across changes in feedwater TDS, temperature and set recovery rate percentage (Figure 2).

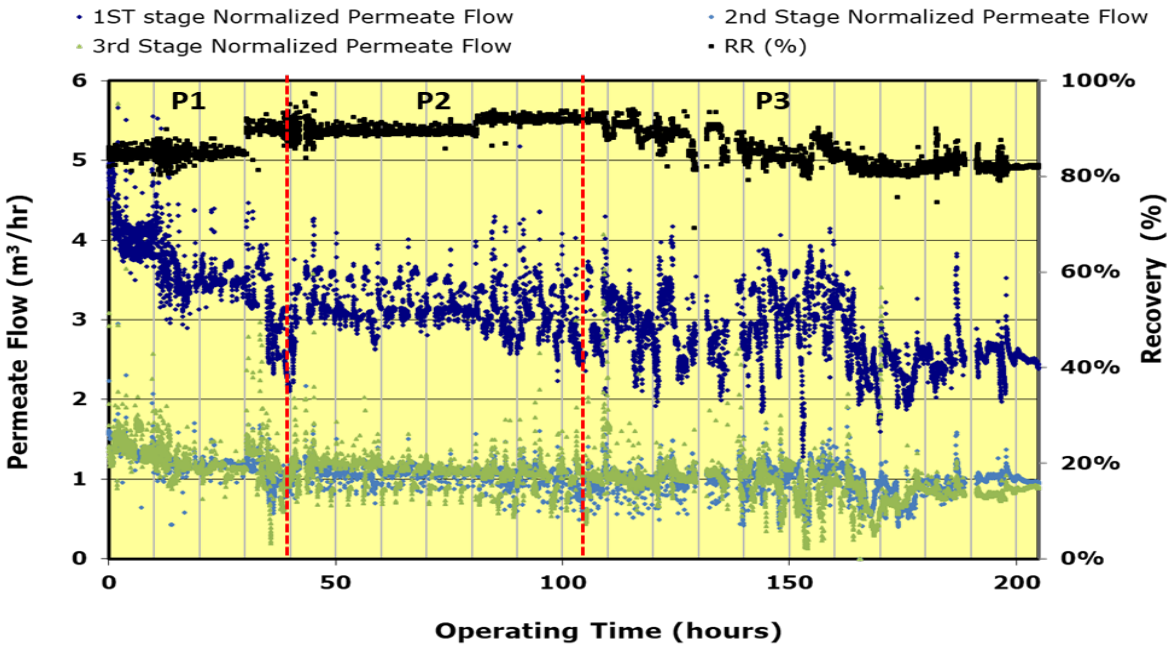


Figure 2 Normalized permeate Flow and recovery of flow reversal pilot plant treating PTEL effluent during period 1 (P1), period 2 (P2) and period 3 (P3)

The first period in which a recovery rate of 85 % was applied (0 to 40 hours) was characterized by an initial loss of membrane performance followed by stable operation in all three stages. A similar trend was observed after increasing recovery rate up to 90 % in period 2 (40-80 h), with an initial drop in normalized permeate flow followed by stable operation for 40 hours. The increase in recovery rate to 92 % in period 2 (80-105 h) resulted in a 15-20 % decrease in normalized permeate flow in the first stage within less than 8 h. Due to the unstable performance recovery was gradually decreased from 92 % to 80-82 % with fast decline in permeate production observed through this period which was caused by the higher levels of calcium and alkalinity in feedwater.

Conclusions

Results from the present study have shown that appropriate optimization of flow reversal time enables to reduce precipitation and therefore to increase recovery rates in comparison to conventional RO systems. The higher concertation factor brought by flow reversal concept, presents the potential to significantly reduce costs associated to brine crystallization when ZLD treatment is pursued. Feasibility tests conducted for the pre concentration of Copper smelter effluents with flow reversal RO

indicate that brine volume is reduced at least 25 % when both streams are concentrated separately in comparison to the pre concertation of the blend of both streams.

Acknowledgements

This work is part of the RED SCOPE project, funded by the European Institute of Innovation and Technology (EIT) under the Project Agreement 16222. This body of the European Union receives support from the European Union's Horizon 2020 Research and Innovation Programme.

References

Fritzmann, C., Löwenberg, J., Wintgens, T., Melin, T. (2007). State-of-the-art of reverse osmosis desalination. Desalination, 216 (1-3):1-76

Gilron, J., Waisman, M., Daltrophe, N., Pomerantz, N., Milman, M., Ladizhansky, I., Korin, E. (2006). Prevention of precipitation fouling in NF/RO by reverse flow operation,
Desalination 199 29–30.

Water Reseach Foundation's Agricultural Water Reuse Research Efforts

Kristan C. VandenHeuvel, The Water Research Foundation, Alexandria, Virginia, USA

The potential for use of recycled water for agricultural irrigation is especially promising in the air and semi-arid regions of the world where groundwater depletion is an issue. This potential remains underutilized due to various challenges to agricultural reuse. To address this need, The Water Research Foundation (WRF) is currently funding a series of agricultural water reuse research projects and developing an agricultural water reuse research agenda to address timely research needs.

WRF is a nonprofit research cooperative officially formed in January 2018 as the result of the integration of the Water Environment & Reuse Foundation and the Water Research Foundation, with the mission of providing exceptional water research to advance science and technology. The new Foundation serves all areas of drinking water, wastewater, stormwater, and reuse through innovative, actionable research. The Foundation also plays an important role in the translation and dissemination of applied research, technology demonstration, and education through creation of research-based educational tools and technology exchange opportunities.

The WRF agricultural water reuse research portfolio includes fifteen projects covering topics in economics and policy, sustainable practices, and management approaches. Several research efforts are currently underway. The ongoing projects provide information on the status of irrigated agricultural water reuse in the United States and abroad (Reuse-15-08), economic benefits of reuse for agriculture (Reuse-16-06), and the impacts of the FDA Food Safety Modernizations Act Produce Safety Rule on reuse (Reuse-16-07). A summary of findings from ongoing WRF agricultural water reuse research projects will be presented.

Sustainability requirements of wastewater management concepts for new industrial park developments in water-stressed regions

S. Bauer[1], A. Dell[1], J. Behnisch[2], H.J. Linke[1], M. Wagner[2]

[1] *Technische Universität Darmstadt, Department of Landmanagement, Darmstadt,* Germany; [2]*Technische Universität Darmstadt, Department of Wastewater Technology, Darmstadt, Germany*

Abstract

Requirements for wastewater management and water-reuse concepts with respect to sustainability are gaining especially in times of climate change greater importance. Hence, area savings as well as concepts which provide diverse water-reuse applications have to be implemented for enabling new developments. The IW²MC→R provides a solution strategy via an optimized wastewater treatment and by providing reuse water "fit for purpose" for several infrastructural applications. The concept increases thus the water-reuse opportunities and minimizes land consumption.

Keywords: Concepts for water-stressed regions; sustainable wastewater management and water-reuse concept, water-reuse "fit for purpose",

Introduction

The development of Industrial Parks (IP) is generally related to the availability of water. Due to water shortage, e.g. in western/northern regions of China, developments are often hindered as e.g. Production Plants (PP) have high water requirements depending on their individual processes. But water is also needed for infrastructural purposes, such as the irrigation of greens or street cleaning. Thus, to enable new IP locations in water scarce regions, a sustainable water supply has to be ensured. The worsening climate change demands also new sustainable water-reuse concepts. Another important aspect is that IP developments drive urban developments (Zhao et al. 2017), which usually take place in densely areas. Thus, in IPs, surface for treatment plants is often limited due to the restricted availability of land as it is mostly provided for PP. Hence, the reduction of land consumption and a high water-reuse potential is important by implementing such water-reuse concepts.

Material and Methods

To enable sustainable IP developments, an innovative Industrial WasteWater Management Concept with the focus on Reuse (brand name: IW²MC→R) is developed. The concept includes the treatment of industrial wastewater in a Central

Wastewater Treatment Plant (CWWTP) and an additional Water-Reuse Plant (WRP) which provides reuse water “fit for purpose”. To achieve sustainability the IW²MC→R is aimed to reduce the land consumption via an area-saving construction type of the CWWTP and the WRP. Thus, the wastewater treatment processes have to be optimized. Furthermore, the concept enables an optimization of the water-reuse opportunities by reaching a high Industrial Park Reuse Factor (IPRF). The IPRF describes the relation between the wastewater inflow to the CWWTP and all required reuse water flows. The IPRF includes the Infrastructure Reuse Factor (IRF), which relates to the infrastructural reuse applications, e.g. irrigation, street cleaning and toilet flushing. Additionally, the IPRF includes the Production Plant Reuse Factor (PPRF), whereby it is possible to calculate the reuse water requirements for the PP, such as process water (Bauer et al. 2018a).

To calculate and to evaluate area requirements for the CWWTP and WRP and to calculate the IPRF, the creation of a Model Industrial Park (MIP) is essential. Therefore, the case study of China was chosen due to several investigations. For a first calculation of the IRF six exemplary PP were taken into account. Accordingly, the IRF results in ~25 % by including three infrastructural reuse applications: irrigation of green spaces, street cleaning and toilet flushing (Bauer et al. 2018a). To get more viable and close to reality results, an extended calculation by considering 19 PP (instead of six PP) was conducted. In addition, further reuse applications (cooling water and firefighting water) were considered. With regard to the land consumption of the wastewater treatment plant, the needed treatment technology for the MIP is identified as well as average sizes of CWWTPs and WRPs are analyzed.

Results and Discussion

Characteristics of the MIP with 19 production plants

For the enlarged MIP several types of industries, such as chemical, paper, food and beverage production facilities, are taken into account, as various production types with diverse water requirements are often localized in IPs. Additionally, the wastewater of a canteen and the generally sanitary wastewater are considered.

Table 1: Production Plants in the MIP with the characteristics of the different wastewater flows

No.	Wastewater origin (production process/other)	annual output	Wastewater Characteristics							Reference
			Flow	COD	N	P	TSS	TDS	TS	
		[t/a]	[m³/d]	[kg/d]	[kg/d]	[kg/d]	[kg/d]	[kg/d]	[kg/d]	
CATEGORY A: wastewater with carbon as a main component										

1	H_2O_2	230,000	945	1,207	0	0	58	nda	nda	BVT Large Volume Organic Chemical Industry (2017)
2	Polystyrene	300,000	904	33	0	0	8	nda	nda	BVT Production of Polymers (2007)
3	Chlorine	215,000	365	26	0	0	nda	212	nda	BVT Chlor-Alkali Manufacturing Industry (2014)
4	Fruit juice	40,000	147	250	3	1	nda	nda	nda	DWA-M766 & Rosenwinkel et al. (2015)
5	Maize starch	1,100,000	1,658	3,315	10	0	nda	nda	nda	DWA-M 776
6	Wheat starch	182,500	700	19,250	700	140	nda	nda	nda	DWA-M 776
7	Yeast	55,000	1,243	26,541	230	34	nda	7,087	nda	DWA M 778 & Rosenwinkel et al. (2015)
8	Sugar (beets)	1,000,000	2,740	23,973	370	0	nda	nda	nda	DWA-M 713 & Rosenwinkel et al. (2015) & Südzucker Werk-Offenau
9	Silicone	50,000	3,288	1,973	0	0	nda	29,451	nda	BVT Production of Speciality Inorganic Chemicals (2007)
10	Ethanol	800,000	25,001	2,387,624	118,756	8,876	nda	nda	2,250,117	Rosenwinkel et al. (2015)
11	Paper	300,000	10,274	8,527	0	0	nda	nda	nda	DWA-M 731
12	Canteen	-	375	709	4	2	nda	nda	nda	DWA M 775
CATEGORY B: wastewater with carbon and nitrogen as main component										
13	Butchery (cattle)	100,000	260	1,822	137	14	nda	nda	nda	DWA-M 767 & Rosenwinkel et al. (2015)
14	Potato	175,200	1,920	6,985	568	48	nda	nda	nda	DWA M 753
15	Animal by-products	15,000	41	339	53	0	52	nda	nda	DWA-M 710
16	Filament Glass fibre	500,000	8,904	601	89	0	nda	11,037	nda	BVT Manufacture of Glass (2013)
CATEGORY C: wastewater with carbon, nitrogen and phosphorous as main component										
17	Superphosphate	850,000	2,911	1,397	3,959	1,374	nda	nda	nda	BVT Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilizer Industries (2007)
18	Soft drinks	600,000	2,564	1,749	34	18	nda	nda	nda	Rosenwinkel et al. (2015) & DWA M 766 & Nachhaltigkeits-bericht 2015 Coca Cola Deutschland
19	Potato starch	10,000	45	633	57	7	nda	nda	nda	DWA-M 776 & Rosenwinkel et al. (2015)
20	Sanitary wastewater	-	1,769	1,056	18	14	nda	nda	nda	
CATEGORY D: other										
21	Sodium carbonate	1,200,000	28,603	1,216	1,106	205	nda	4,138,852	nda	BVT Large Volume Inorganic Chemicals - Solids and Others industry (2007)
	Sum		**94,658**							

nda: no data available, COD: chemical oxygen demand, N: total nitrogen, P: total phosphorus, TSS: total suspended solids, TDS: total dissolved solids, TS: total solids

Based on the characteristics of the wastewater flows, they were divided into categories (A to C) according to their carbon, nitrogen and phosphorus content (see table 1). It was assumed that the wastewater would be of a constant quality throughout the entire year. Criterion of the characterization was the minimum nutrient supply for aerobic biological wastewater treatment with COD:N:P of 100:5:1 (Sahm et al. 2013), as it is the central purification process of each CWWTP (Bauer et al. 2018a). Wastewater flows with special characteristics such as sodium carbonate (see no. 21, table 1), which have a very high salt content, have to be considered separately and should not be mixed with others. Incineration could be one solution for those flows. Based on this consideration of the basic parameters for the characterisation of wastewater, a treatment track was defined, which has to ensure a cleaning performance in order to comply with all required limit values. Those limit values are based on the Chinese water reuse standards GB/T 18920-2002 and GB/T 19923-2005. Due to the many food industries in the MIP, which produce highly

loaded organic wastewater (Ranade und Bhandari 2014), in categories A to C the amount of COD (2,488,010 kg/d) is relatively high compared to the amounts of nitrogen (124,987 kg) or phosphorus (10,528 kg). It is therefore appropriate that the CWWTP provides at least two treatment tracks for wastewater treatment: anaerobic treatment to reduce carbon pollution and aerobic treatment to eliminate nutrients and further reduce COD (see figure 1).

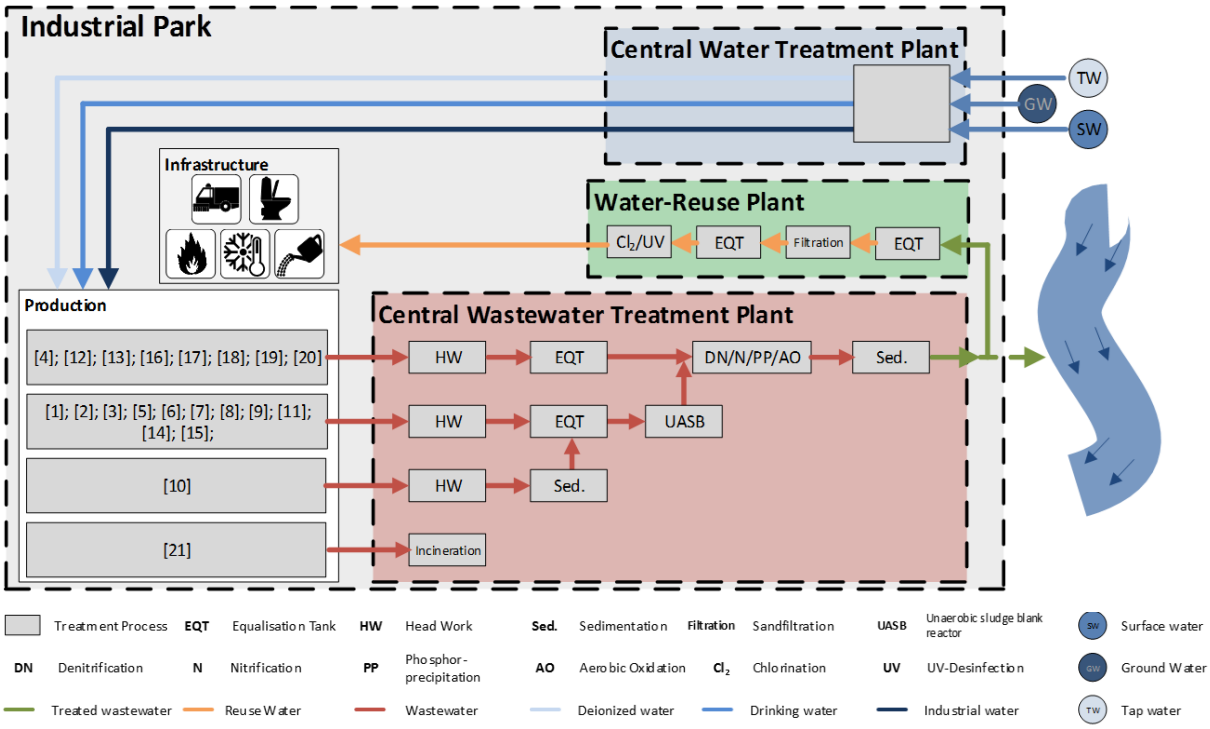


Figure 1: The IW²MC→ R with respect to 19 PP (own figure)

The anaerobic treatment makes it possible to obtain biogas and thus achieve the most energy-efficient treatment of wastewater. A detailed consideration of the wastewater flows shows that ethanol (see no. 10, table 1) must be pre-treated to reduce the high solids concentrations. In this case, a simple sedimentation stage would be the best solution. The anaerobically pre-treated wastewater has to be discharged further into the aerobic process line to achieve further elimination of COD and nutrients. After the aerobic biological treatment, the treated wastewater is largely purified of COD and nutrients. In order to meet the requirements for the reuse standards, the treated wastewater is discharged to the WRP, filtered, disinfected by means of UV and mixed with chlorine. It can then be reused for different applications. As the Chinese quality requirements of reuse water for irrigation, toilet flushing, firefighting, street cleaning and cooling are very similar, the effluent of the CWWTP/WRP is expected to keep all the limits. Thus, to reach the required water quality, only one treatment technology of the WRP is necessary.

With regard to the dimension of the MIP with 19 PP different average values of 12 existing Chinese IPs and governmental design regulations served as a basis. The total MIP thus has a size of 823 ha, the green spaces take up 165 ha (20 %) and the area of roads amounts 74 ha (9 %). Due to the restricted availability of land, as it is mostly provided for PP, the size of the CWWTP and WRP have to be minimized via optimized treatment processes. Analyses of 10 Chinese CWWTPs in different IPs show, that the average size in relation to their treatment capacity is about 2.0 m^2/m^3. Calculated with the sum of the wastewater flow of the MIP (94,658 m^3/d, see table 1) the CWWTP would have a size of approx.19 ha (~2 % of the total IP area). Due to low inflow loads from the CWWTP to the WRP, and thus due to an appropriate treatment process to provide reuse water "fit for purpose", the area of the latter is expected to be substantially smaller than the area of the CWWTP. For a first appraisal, aerial photographs of three existing Water-Reuse projects in different parts of the world using as well additional filters and disinfection after the conventional treatment processes to provide reuse water with a similar quantity e.g. for irrigation or toilet flushing, are analyzed. The average size in relation to their capacity is about 0.5 m^2/m^3. With a reuse water flow of 13,539 m^3/d (see table 2) the WRP would have a size of less than 5 % of the calculated CWWTP size.

Table 2: Calculation of the reuse water flows in the MIP with 19 PPs

	Specific water demand	**Data referring to the MIP**	**Calculated reuse water demand (m^3/d)**
Toilet flushing	40 L/employee×day	35,389 employees	1,416
Street cleaning	2.5 L/m²×day	74 ha (=0.09×823 ha)	1,850
Irrigation of green spaces	2.0 L/m²×day	165 ha (=0.2×823 ha)	3,300
Fire fighting			60
Cooling tower make-up water (2%) for:			
H_2O_2 production	9 $m^3/t_{Product}$	230,000 t/a	113
Polystyrene production	50 $m^3/t_{Product}$	300,000 t/a	822
Sodium carbonate	75 $m^3/t_{Product}$	1,200,000 t/a	4,932
Filament glass fibre	1.5 $m^3/t_{Product}$	500,000 t/a	41
Cooling tower make-up water average for other PPs	67 m³/production plant×day*	15 production plants	1,005
		Sum reuse water demand	**13,539**

* Source: Average cooling tower make-up water demand of two Industrial parks assuming an evaporation of 2 %

Calculation of the (enlarged) Infrastructure Reuse Factor (IRF)

For this enlarged calculation further applications such as cooling and firefighting water are taken into account. For the implementation of the IW²MC→R it is premised that with respect to the water shortage in several regions the IP only enables recirculating cooling instead of once-through cooling systems. The latter needs high water flows which cannot be provided in water-stressed regions. Therefore, the calculation of the IRF only includes the make-up water for cooling towers. Due to VGB R455 and R135 it is estimated with 2 % of the total cooling water demand. For

four of the 19 PPs a specific cooling water demand is given. For a first approximation of the others it is calculated with the average cooling water demand of two existing IPs. As in water stressed regions as well the provision of firefighting water could be a challenge, (underground) fire water storage tanks are considered. In order to maintain the water quality, a partial water exchange in these tanks is expected, what results in a permanent water demand of 60 m^3/d (InfraServ Gendorf) (see table 2) even if there is no fire. For toilet flushing, street cleaning and irrigation of green spaces the calculation of the water demand is based on Bauer et al. 2018a (see table 2). For the MIP with 19 PP in China the result is an IRF of ~14,3 % (wastewater flows: 94,685 m^3/d; reuse water demand: 13,539 m^3/day), which is less than the IRF of six PP. An essential reason for this lower factor is the considerably higher wastewater effluents of the chosen PPs. While the MIP with six PP had an average wastewater volume of only 1,325 m^3, the MIP with 19 PP has an average wastewater effluent of 4,870 m^3/d and thus amounts to 3.6 times. A closer look to the wastewater flows reveals that the sodium carbonate PP (see no. 21, table 1) has with 28,603 m^3/d an extremely high effluent, whereas the production of superphosphate was with 2,914 m^3/d the highest wastewater producer regarding the MIP with six PP.

Conclusions

Regarding the required surface of the CWWTP and WRP, an optimized treatment process reduces the required area inside the IP. A technical upgrade of a CWWTP with a WRP could thus be conceivable due to its low land consumption. The results, regarding the IPRF, show that depending on the PPs, the IPRF can be lower despite further reuse applications, which is due to the different wastewater flows of the respective PP. But a previous study showed that the reuse opportunities can increase by additional reuse applications in the adjacent urban areas which, is required for enabling such developments in water scarce regions (Bauer et al. 2019). Additionally, the IPRF can be increased by an optimized IP management by controlling new PP settlements with respect to their wastewater effluents. An optimized IP management can thus compensate the PPs higher or lower wastewater effluents (Bauer et al. 2018b). Providing a solution to enable new developments in water-stressed regions, the $IW^2MC \rightarrow R$ has to fulfill diverse sustainability requirements. Hence, via an optimized treatment technology providing reuse water “fit for purpose” the concept tackles these challenges.

References

Bauer, S.; Dell A; Behnisch, J; Chen, H;, Bi, X.; Nguyen, V.A.; Linke H.J., Wagner, M. 2018 *Water-reuse concepts for industrial parks in water-stressed regions in South-East-Asia*, Conference Paper for IWA Regional Conference on Opportunity for Water Reuse in Southeast Asia, Phuket, Thailand.

Bauer, S.; Dell A; Behnisch, J.; Linke, H.J.; Wagner, M. 2018 *Optimizing water-reuse opportunities for Industrial Parks,* Paper submitted for WEFTEC 2019, Chicago, Illinois, USA.

Bauer, S.; Linke H.J.; Wagner, M. 2019 *Sustainable urban development by an integrated industrial-urban water-reuse concept for South-East Asian Regions*, Paper submitted for the IWA Journal Water Reuse & Desalination (in review process), accepted for IWA Efficient 2019 Conference in Manila (Jan 13-16, 2019), Philippines.

InfraServ Gendorf 2018 Umwelterklärung 2018. https://www.emas.de/fileadmin/user_upload/umwelterklaerungen/reg/DE-155-00047_155-00052_Industriepark-InfraServ-Gendorf.pdf (accessed 14 Septmber 2018)

Ministry of Housing and Urban-Rural Development of the P. R. China (MoHURD) (formerly Ministry of Construction of the P. R. China), China.

- GB/T 18920-2002: The reuse of urban recycling water - Water quality standard for urban miscellaneous water consumption 2003
- GB/T 19923-2005: The reuse of urban recycling water - Water quality standard for industrial water consumption 2006

Ranade, Vivek V.; Bhandari, Vivay M. 2014 *Industrial Wastewater Treatment, Recycling, and Reuse*. Elsevier, Philadelphia, USA.

Rosenwinkel, K.-H.; Kroiss, H.; Dichtl, N.; Seyfried, C.-F.; Weiland, P. 2015 *Anaerobtechnik. Abwasser-, Schlamm- und Reststoffbehandlung, Biogasgewinnung (Anaerobic technique. Waste water, sludge and residual material treatment, biogas production),* 3. Auflage Springer, Berlin, Germany.

Sahm, H.; Stahmann, K.-P.; Antranikian, G.; Takors, R. 2013 *Industrielle Mikrobiologie (Industrial Microbiology).* Springer Spektrum, Berlin, Germany.

Zhao, Sidong; Bi, Xiaojia; Zhong, Yuan; Li, Lin 2017 Chinese industrial park planning strategies informed by American edge cities' development path - case study of China (Chongzuo)-Thailand Industrial Park. In: *Procedia Engineering* 180, China, pp. 832–840.

Dealing with uncertainty in the conceptual design of industrial water reuse networks

Dagmar Pohl, Maike Beier, Stephan Köster; Institute of Sanitary Engineering and Waste Management, Leibniz University Hannover, Germany

Abstract:

A hierarchical design approach for industrial water reuse networks is presented that considers uncertainties in the design phase to identify key parameters, prioritise additional data acquisition and obtain robust and sustainable solutions. The approach can accommodate different technical design methods and can be flexibly applied to a variety of planning contexts, leveraging the designer's creativity and experience.

Keywords: industrial water reuse, uncertainty, conceptual design, model-based planning

Designing industrial water reuse networks - a challenging task

In the face of increasing water scarcity, minimizing freshwater intake can become a crucial factor to establish or expand industrial sites. Beyond the usual in-process recycling, cross-process and cross-factory water networks pave the way for new opportunities to increase water efficiency. But such an approach, which can be particularly attractive for industrial parks, increases the complexity of planning. In the early design phase, mostly only very limited and uncertain information is available. Only a proper consideration of the uncertainty in this design process leads to sustainable solutions and, additionally, increases the transparency of decision making. A new methodology is described for the development of an overall water management concept and the selection of specific technical treatment methods in a three-level hierarchy, taking into account given uncertainties.

Uncertainty analysis and planning methods

For the design of industrial water management concepts, data is required on wastewater flow rates and contaminant loads, water demands and acceptable water qualities, the performance of treatment processes as well as additional information for the assessment of alternatives, such as prices and stakeholder preferences. The data may be uncertain due to incomplete or imprecise knowledge (reducible/epistemic uncertainty) or because of true variability e.g. due to varying influent characteristics or unpredictable future developments (irreducible/aleatoric uncertainty). Depending on the source of un-

certainty, epistemic uncertainty can be reduced through collection of additional data, e.g. by experiments, or through technical measures. Apart from uncertain model inputs, the choice of the model itself may contribute significantly to the uncertainty of the calculated performance indicators (Refsgaard et al., 2006; Most, 2011). Many different methods exist to develop overall water management concepts and/or treatment trains, ranging from graphical methods to heuristic rules to mathematical optimisation approaches (see e.g. Faria and Bagajewicz, 2009; Jezowski, 2010; Ullmer et al., 2005). The level of detail and scope of the methods varies greatly, e.g. the number of considered contaminants, the complexity of process models or the system boundaries. For graphical methods, uncertainty can be considered by plotting the expected ranges instead of the nominal values. For mathematically formalised approaches, various uncertainty and sensitivity analysis methods can be applied to examine output variability and identify influential input parameters (see Borgonovo, 2017; Saltelli, 2008, for a general overview). The obtained information can then be used to prioritise further data acquisition and identify optimisation potentials. However, the large number of uncertain parameters lead to an intractable design and sensitivity analysis task when the design and operation of treatment processes is estimated simultaneously on the overall system level (e.g. entire industrial park). This can be overcome by decomposing the problem into manageable subproblems, ensuring that significant interactions are not overlooked. As promising water management concepts are developed in more detail and additional data becomes available, prior assumptions need to be checked and, if significant deviations are noticed, previous decisions should be re-evaluated. This requires the systematic documentation of the development process, which is also advantageous for communicating with stakeholders and for re-using gained insights in later projects. One possibility to effectively document and visualise the design process are for instance cascaded option trees (Bednarz et al., 2014).

Three-level approach to design under uncertainty

Fig. 1 illustrates the proposed hierarchical approach for the design of industrial water reuse networks considering uncertainty, which is presented in the following.

Step 1: Finding promising overall concepts (industrial park level) The goal of this step is to identify promising overall concepts, ensuring a reliable water supply and discharge. A

list of available water sources and sinks is compiled (the water demand and wastewater production of the water users can be considered as sink and source, respectively).

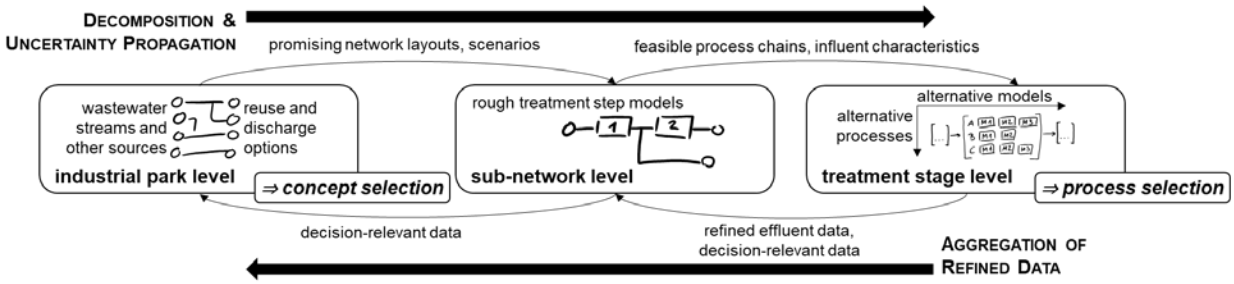


Figure 1 Overview of the proposed hierarchical approach

Some have to be included in the water management concept - e.g. those related to water users or stormwater - while others are optional, such as use of the municipal water supply or direct discharge. Quantitative information about the expected ranges and long-term temporal variance (e.g. due to production and maintenance schedules or seasonality) of the flow rate and relevant quality parameters is needed. Treatment processes do not need to be considered in detail at this stage; rough estimations of the associated treatment effort are sufficient to design reasonable concepts. Based on the gathered information, scenarios are defined that represent likely load cases for which the water management concepts will be designed, special load cases for which the concepts need to work (e.g. maintenance intervals) and further scenarios of interest, such as possible future developments. The first two types of scenarios are crucial, i.e. water supply and discharge have to be ensured, while the latter type is used for further assessment. How scenarios are defined depends on the specifics of the project and on the encountered uncertainty. By way of example, consider a greenfield project in which the concentration of COD of a certain wastewater is yet unknown. Data collected from several comparable plants is plotted in Fig. 2. Clearly, the concentration levels are not the same for different plants, whereas the variation of the concentrations is similar. Accordingly, it can be assumed that the true concentrations of the future plant's wastewater will be somewhere in the overall range of encountered concentrations (epistemic uncertainty), with comparatively small variations (aleatoric uncertainty). Instead of considering the whole range of uncertainty at once, defining two scenarios (high/low concentration level) is more realistic in this case.

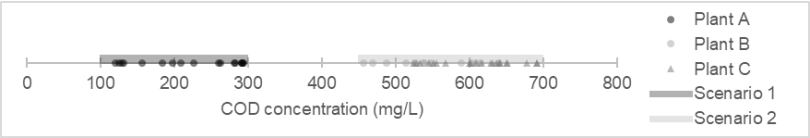


Figure 2 Wastewater COD concentration (grab samples) of three similar plants and derived scenarios (exemplary data)

The acceptability of the developed candidate concepts is first checked for all crucial scenarios. Alternatives that do not have a sufficiently high probability of ensuring water supply and discharge with reasonable effort are revised or discarded. The remaining concepts are also examined for the additional scenarios. Promising overall networks are decomposed into independent sub-networks for the next step.

Step 2: Designing feasible process chains (sub-network/treatment train level) In this step, feasible combinations of treatment steps for a sub-network are designed and minimum required treatment efficiencies for the respective treatment steps are identified. The design is based on the range of applicability and expected treatment efficiency for main treatment or technology types. These represent a group of processes which target the same major components for removal and have a similar range of applicability. For influent characterisation and effluent requirements, the previously defined scenarios are used. The probability of meeting the specified quality requirements for the designed process chains is estimated by uncertainty analysis, varying influent characteristics and process performance simultaneously, e.g. by Monte Carlo simulation. Following the approach of the previous step, the alternatives are evaluated for all defined scenarios, discarding unacceptable process chains. If only some combinations of parameters lead to acceptable results, Monte Carlo filtering and sensitivity analysis can be used to narrow down the range of parameters that lead to acceptable results and to identify the most influential parameters. This information can provide valuable guidance for more detailed design. For instance, if the results show that a process chain is only acceptable when the salt removal efficiency is greater than 95%, an appropriate process can be selected. Or if peak concentrations in the influent lead to a violation of the effluent quality requirements, this might be overcome by providing an equalisation tank. Using the refined information obtained in this step, prior estimations should be checked and, if necessary, adjusted.

Step 3: Choosing the best processes (treatment stage level) The next step is to choose the best performing processes for each single treatment step. Here, not just the applicability but especially the evaluation of the processes in terms of the chosen assessment criteria is considered. Consequently, the process models used in this step have to provide a basis to calculate the corresponding decision-relevant factors as accurately as possible. In addition to parameters related to the treatment performance, uncertainty of dimensioning parameters, specific energy and auxiliary demands etc. needs to be accounted for. Again, the scenarios defined in the first step are used to characterise sinks and sources. Processes are dimensioned based on the corresponding design scenario and their operation is evaluated for all scenarios. Most dimensioning approaches already account for variable influents e.g. by using 85th percentile values. If the influent variability defined in the scenarios matches the expected true variability (aleatoric uncertainty), it can be used directly for dimensioning and for estimating operation-related performance indicators. To account for model uncertainty, several models for the same process should be used to ensure that the model choice does not influence the design decisions. A possible result of such an approach is illustrated in Fig. 3: The estimated total costs for processes A and B are overlapping. However, despite the also ambiguous results for process C, no further refinement is needed at this point, as process C is clearly the economically most attractive option. This example also illustrates that the required data accuracy depends on the given context.

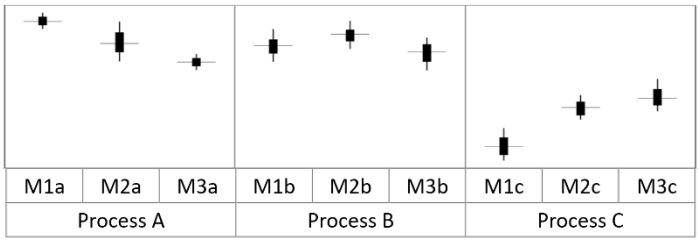


Figure 3 Total cost for process alternatives, estimated using multiple models (M) per process (exemplary data)

Uncertainty is propagated from the influent (based on the scenarios) through the series of treatment steps, using the refined estimated effluent quality of one step as influent estimate for the subsequent treatment step. Finally, prior assumptions on feasibility and performance are checked using the refined results and adjusted if necessary.

Step 4: Aggregation and selection of overall concept(s) Performance indicators estimated in step 3 are aggregated for the whole process chain and further for overall management concepts. For concepts that include identical sub-networks, this significantly saves computational effort compared to analysing entire networks on a system-wide level without decomposition. If the data basis is not accurate enough to select a favoured concept in the light of the aggregated uncertainty, an efficient strategy for further data acquisition or refinement can be mapped out using the results of the previously conducted uncertainty and sensitivity analysis of the process models (variance cutting).

Conclusions

Considering uncertainty in the design phase increases the reliability, robustness and acceptance of water reuse solutions. Optimisation potentials and critical knowledge gaps which influence design decisions are revealed and further data acquisition prioritised. Using a structured, well-documented design approach facilitates communication with stakeholders and helps to increase transparency and trust. The presented hierarchical approach makes this challenging task tractable.

Acknowledgements

This research has been funded by the German Federal Ministry of Education and Research (BMBF) in the project “WaReIp – Water-Reuse in Industrial Parks”.

References

Bednarz, Andreas, Bettina Rüngeler, and Andreas Pfennig. 2014. “Use of Cascaded Option Trees in Chemical-Engineering Process Development.” *Chemie Ingenieur Technik* 86 (5): 611–20.

Borgonovo, Emanuele. 2017. *Sensitivity Analysis: An Introduction for the Management Scientist*. Vol. 251. International Series in Operations Research & Management Science. Cham, Switzerland: Springer International Publishing.

Faria, Débora Campos de, and Miguel J. Bagajewicz. 2009. “On the Appropriate Modeling of Process Plant Water Systems.” *AIChE Journal* 4 (7).

Jezowski, Jacek. 2010. “Review of Water Network Design Methods with Literature Annotations.” *Industrial & Engineering Chemistry Research* 49 (10): 4475–4516.

Most, Thomas. 2011. “Assessment of Structural Simulation Models by Estimating Uncertainties Due to Model Selection and Model Simplification.” *Computers & Structures* 89 (17-18): 1664–72.

Refsgaard, Jens Christian, van der Sluijs, Jeroen P., James Brown, and Peter van der Keur. 2006. “A Framework for Dealing with Uncertainty Due to Model Structure Error.” *Advances in Water Resources* 29 (11): 1586–97.

Saltelli, Andrea. 2008. *Global Sensitivity Analysis: The Primer*. Chichester: Wiley.

Ullmer, C., N. Kunde, A. Lassahn, G. Gruhn, and K. Schulz. 2005. “WADO: Water Design Optimization—methodology and Software for the Synthesis of Process Water Systems.” *Journal of Cleaner Production* 13 (5): 485–94.

Development of a decision support tool to foster water reuse

Matthieu Jacob, Total, France; Bruno Delahaye, Total, France ; Jean-Baptiste Bayart, Quantis, Switzerland

Introduction and objectives

As one of the energy companies, Total uses water for many purposes and its activities are generally dependent on this resource. As a consequence, water reuse projects are more and more investigated by operations. Even if water reuse may often contribute to reduce environmental impacts and to mitigate water risks, the investment decision is mostly driven by the direct “return on investment”. To extract a more integrated value, Total and its partner Quantis developed an in-house Water Reuse Assessment Tool (Wat-R-Use): a multi-criteria tool to support decision making in a systematic approach taking into account local regulation and environment.

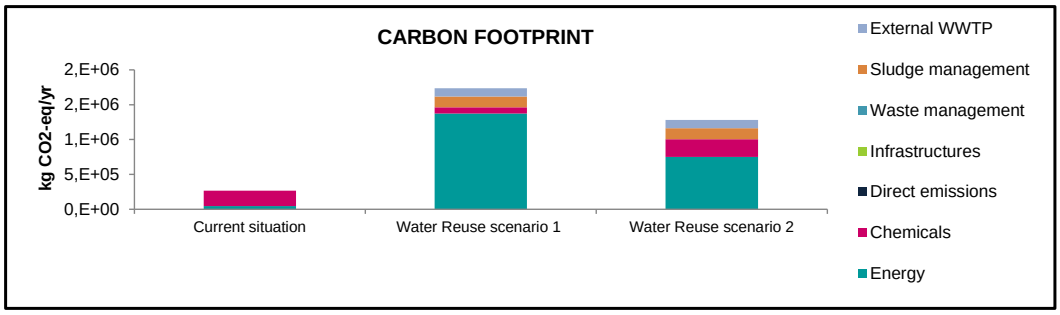
Methodology approach and results

Wat-R-Use addresses the following questions: (i) Is the water reuse solution profitable? (ii) Are there any physical, regulatory or reputational water-related risks on this site, and does the water reuse project allow to mitigate them? (iii) Does water reuse reduce or increase the environmental footprint (including energy use and carbon)? (iv) Does water reuse reduce or increase social impacts? (v) What are the performances of alternative water reuse solutions, compared to the current solution?

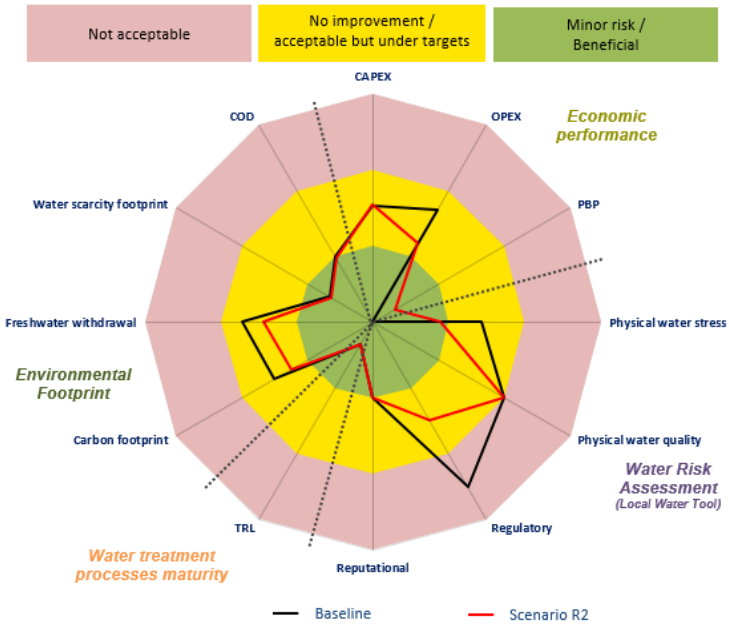
The most relevant indicators, considering Total’s context, have been selected and implemented within the Wat-R-Use tool: (i) Economic performances (Capex, Opex, payback period, IRR, levelized cost of water,...), (ii) Water risk issues (physical, regulatory, technical risks…), (iii) Environmental performances (carbon footprint, water footprint), (iv) Social impacts (employment, impacts on local population)

Wat-R-Use was used on several industrial case study in Total to assess the benefits and drawbacks of several water management options. This study focuses on two different case studies.

The first case study takes place on a petrochemical site. It requires the use of sophisticated water treatments. Except withdrawal of water (reduced by 40%), all the other indicators show a degradation of performance (increase of carbon footprint (X5, see figure below) and water consumption (3%)). It is mainly due to the extra energy and chemicals that are required to run the water reuse scenario.



The second case study takes place on a solar panel manufacture. The strategy was first to reduce water consumption directly at the heart of the process and then to re-use the existing released water through existing treatment facilities, tentatively optimizing the corresponding investments. This approach was positive both in term of environment and also in term of economics (see figure below). Water withdrawal decreased by 42% with 13% potential operating cost saving.



Conclusions and recommendations

Developing such life cycle-based assessment method for prioritizing investment decisions allows Total to evaluate the integrated benefit of water reuse, recycling & reduce, considering at the same time all the sustainability dimensions, economical parameters and water resources optimization. Regarding the environmental, water risk, and social aspects, it allows moving from empirical and perception-based decisions to semi-quantified-based decisions the using database for default values within the Wat-R-Use tool.

Zero Liquid Discharge by Reuse of Wastewater in an Office Complex in India

Martin Kureck, Koch Membrane Systems, Aachen / Germany;
Dr. Christoph Thiemig, Koch Membrane Systems, Aachen / Germany
Amey Pradhan, Koch Membrane Systems, Mumbai / India

Abstract:

Due to water scarcity and problems in supply of clean water, the Indian Government recently introduced requirements for Zero Liquid Discharge (ZLD) for all water-intensive industries. This forces industries to employ measures to reduce and reuse wastewater generated in factories & large commercial complexes. At the new Ford campus in Chennai, an office complex for 12.000 people, a wastewater treatment and reuse system is installed, using a combined process of MBR (membrane bioreactor) and RO (reverse osmosis).

All wastewater is treated by an MBR. The treated water is partially used for irrigation and partially fed to an RO system, which produces a high quality water supply for the HVAC system of the complex.

Keywords: Reuse; ZLD; MBR

Background

India is facing growing issues with water scarcity. Growing population and economic growth have increased demand in fresh water supply. In many areas, ground water levels are deteriorating due to increased water consumption and unreliable monsoons.

To a large extent, the mismanagement of water resources has exacerbated the problems of water scarcity and variability, leading to critical situations in many parts of the country. Leakage and inefficiencies in the water supply system account for nearly 50 percent of municipal water use. Over 70 per cent of surface and groundwater resources are contaminated (1). Low awareness about water scarcity and its social economic values as well a lack of a harmonized perspective in

planning, management and the use of water resources underlie this mismanagement of coordinated regulations, institutions and incentives to balance various needs for water (2).

Facing those issues, the Indian Government has made it mandatory for industries to go in for Zero Liquid Discharge (ZLD). Industries are obliged to employ reduce, recycle & reuse models for wastewater generated in the factories & large commercial complexes. No new industry or office complex is given a consent to establish if it doesn't agree to implement an ZLD scheme. In addition, the existing industries are also being sent notices to implement ZLD or face closure.

The wastewater recycling system at the new Ford Motor's Global Business Unit office complex in Chennai is an exemplary measure to face those demands.

Challenge

The campus will host up to 12,000 people and include operations of Ford Global Business Services in areas of IT, Product Engineering, Finance and Accounting, Data Analytics and Manufacturing among others. The complex is located on the outskirts of Chennai in southern India. Chennai is one of the worst water-starved cities in India in regard of plummeting ground water table and rainfall deficit. Water is not only scarce but also facing quality issues on account of sea water intrusion as well as poor upkeep of various water bodies.

Apart from legal requirements, the complex would depend on trucked water, brought to the site in tankers sourced from multiple wells, which makes the demand for water reuse even more urgent. The office complex is the first in the region to implement a complete water recycling solution.

KMS' concept of a combined MBR / RO system was chosen due to the compact, low footprint layout and the ability to provide two water qualities for different reuse purposes.

a) Treated wastewater post-MBR for irrigation / flushing

b) Highly purified, de-ionized water post-MBR + RO for HVAC system

Providing the different water qualities in the required amounts helps reducing overall operational costs.

Detailed system description

The flow schematic of the complete water collection and treatment system is shown in Figure 1.

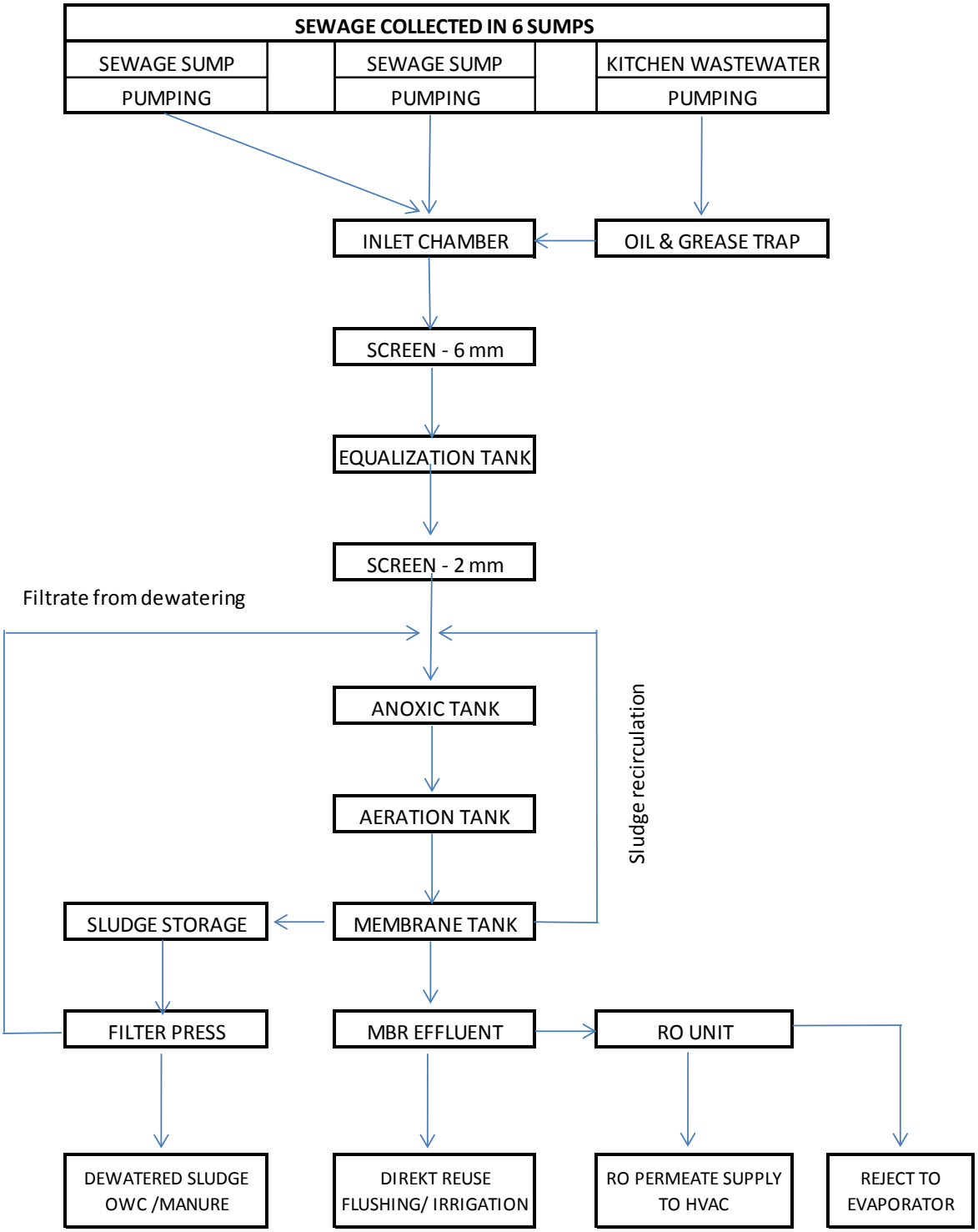


Figure 1: Flow schematic

Wastewater from all over the complex is collected in several pumping stations and transferred to the centralized treatment plant. Pretreatment of the raw wastewater consists of a 2-stage static screen (10 and 6mm) followed by an oil and grease trap before it enters in an aerated underground buffer tank (500 m^3) to buffer peak load flows of up to 143m^3/h. The equalized flow (24 m^3/h) is then pumped via a fine screen (rotary drum screen, 2 mm punched hole mesh) towards the MBR system. The following table summarizes the feed conditions and the operational parameters of the MBR.

Table 1: Feed- and operational parameters of the MBR

Wastewater Characteristics	Units	Value
Average daily flow	m^3/d	576
Peak flow	m^3/h	143
Water Temperature	°C	20 – 25
COD	mg/l	300 – 400
BOD	mg/l	250 – 300
TKN	mg-N/l	40 – 50
NH3-N	mg-N/l	35 – 40
TSS	mg/l	300 - 400
MBR output		
COD	mg/L	< 30
TSS	mg/L	< 0,1
Coliform bacteria count	CFU/100	< 100

Pretreated wastewater enters the anoxic zone where it is mixed with the activated sludge. The subsequent aerated tanks (two trains +one for future upgrade) are gravity fed from the anoxic tank. From the aerated tanks, the activated sludge overflows into a common feed channel from where submerged centrifugal pumps transfer the sludge to two MBR filtration trains. Each train contains one hollow fibre MBR module type PULSION® LE16-16, each with a membrane area of about 700m^2. The filtration tanks have an overflow weir directing the activated sludge back into the anoxic zone where the sludge loop closes.

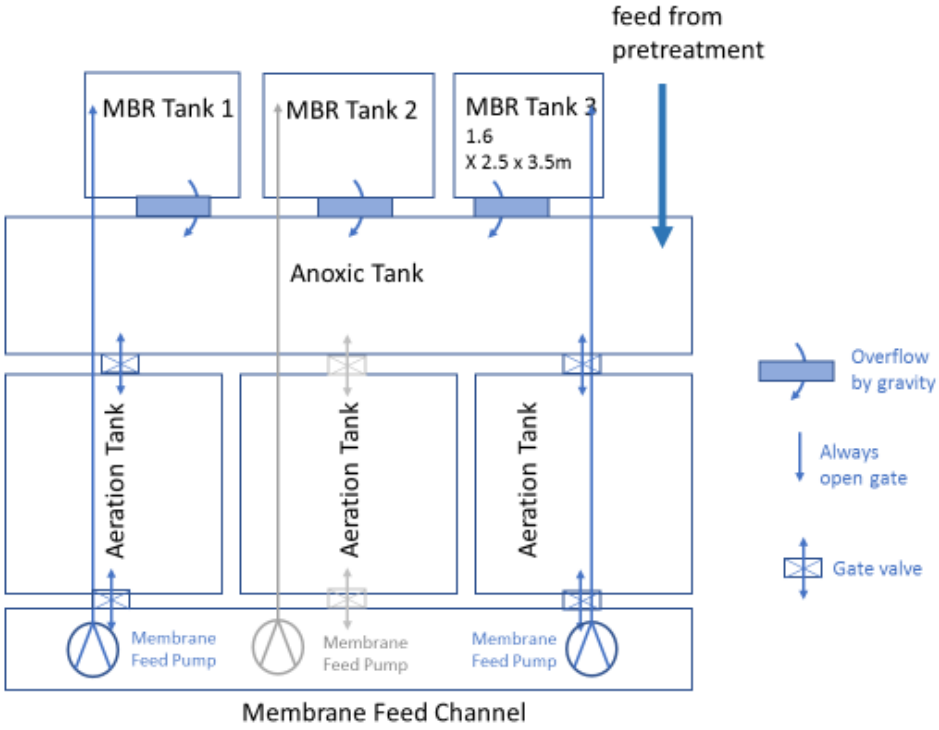


Figure 2: Schematic of the MBR

The biologically treated and solid-free filtrate extracted from the MBR modules is stored in two large buffer tanks.

Tank 1 (500 m³) stores the water for reuse. Without any further treatment the water is fed for irrigation of greens and trees within the office complex.

Tank 2 (100 m³) provides feed water for the RO system.

From the RO feed water tank, MBR filtrate is transferred to the RO Skid (2x100% unit, 288 m² membrane area per skid). The system is designed to produce 156 m³/d of deionized water for the HVAC system.

In order to increase overall efficiency and as quality constraints for the HVAC system are less strict than the expected permeate produced by the RO, a blend bypass can be used to mix post-MBR filtrate with the post-RO permeate.

Table 2: Parameters of the Reverse Osmosis system

2 x 100% units. 6:3, 4M array with TFC® HR4040 membranes

Parameter	Units	Value	
Average daily flow	m^3/d	156	
Membrane area (skid)	m^2	288	
Recovery rate	%	67	
Feed TDS	mg/l	2000	
Feed Hardness (CaCO3)	mg/l	970	
Feed Chloride	mg/l	1000	**Required***
Permeate TDS	mg/l	30	< 500
Permeate Hardness	mg/l	1,5	< 250
Permeate Chloride	mg/l	15	< 100

*Limits for Reuse in HVAC system for blend of MBR& RO permeate

Results

As of April 2019, due to delays in the civil engineering execution, the water treatment system is not yet operational. The system will be commissioned in the second half of May. First operational experiences will be available and presented at IWA water reuse 2019 in June.

References

1. Kumar, S.V., and Bharat, S.K. 2014. Perspectives on a Water Resource Policy for India. Discussion Paper October 2014. The Energy and Resources Institute TERI.

2. Government of India, Ministry of Water Resources. 2012. National Water Policy (2012). http://wrmin.nic.in/writereaddata/NationalWaterPolicy/NWP2012Eng6495132651.pdf Accessed: 1 February 2016.

Motivations for Increased Use of Recycled Water for Agricultural Irrigation

B. Sheikh, Water Reuse Consulting, San Francisco, CA, USA; presenting author;
K. Nelson, University of California, Berkeley, CA, USA;
A. Thebo, Pacific Institute, Oakland/USA;
B. Haddad, University of California, Santa Cruz, CA, USA;
T. Gardner, ARRIS Water, Highgate, South Australia, Australia;
J. Kelly, ARRIS Water, Highgate, South Australia, Australia;
A. Adin, Hebrew University of Jerusalem, Jerusalem, Israel;
R. Tsuchihashi, Jacobs, San Francisco, CA, USA;
N. Funamizu, Hokkaido University, Sapporo, Japan;
S. Spurlock, Denver Urban Gardens, Denver, CO, USA;
K. VandenHeuvel, The Water Research Foundation, Alexandria, VA, USA

Abstract

Increasing the use of recycled water for irrigation of agricultural lands is a global inevitability. The primary aim of the work was to determine the existing impediments and to find solution to those challenges. The main impediments and incentives are: water supply availability (impediment) and scarcity (driver); water quality impact (impediment) and avoided discharge (incentive); regulatory constraints (impediment) and flexibility, or mandate (incentive); economics, finances (impediment) and government assistance (incentive); institutional barriers (impediment) and collaboration (driver); and public perception, stigma (impediment) and familiarity (driver). The major conclusion is that with incentives and drivers, at least 4 Mm^3 per day of additional recycled water can be used for irrigation of agricultural lands in the United States.

Keywords: Recycled Water, Reclaimed Water, Impediments, Agricultural Reuse

This document is abstracted from the Executive Summary of a project report by the same authors and published by the Water Research Foundation in March 2019 (WRF, 2019).

Introduction

The potential to increase the use of recycled water for agricultural irrigation is substantial, as it consumes the highest percentage of water taken from developed water resources in the arid, and semi-arid regions of the world. However, this potential remains under-realized because of impediments. Contrasting percentages of recycled water use in different arid zone regions suggests that impediments to its use and ways of overcoming the challenges are region-specific. Understanding how the incentives and impediments to agricultural reuse vary with local context is essential for understanding the tradeoffs and technology requirements for the different end uses of recycled water.

Materials and Methods

This project employed multiple methods to evaluate the range of impediments and incentives impacting the use of recycled water in agriculture and how their relevance differed among various stakeholder groups. Analyses were conducted at the project, regional, national, and global scales, and included the perspectives of various stakeholder groups including water and wastewater utilities, growers, and regulators. The activities undertaken in the project consisted of the following:

- **Literature review**: A review of peer-reviewed publications, as well as government and industry reports related to the uses of recycled water for agriculture.
- **International case studies**: Developed by project team members, case studies were based on a review of documents and surveys. The case studies identified highlight countries where team members were able to access reliable data relevant to agricultural water reuse: Israel, Japan, Australia, Jordan, and a few other countries in the Middle East/North Africa region.
- **Stakeholder workshop**: A one-day workshop was held in Sacramento, California. Forty attendees participated, including regulators, utilities, consultants, farmers, and academic researchers.
- **Review of utility documentation**: Documents included utility websites, state permits, NPDES permits, recycled water permits, consulting reports/presentations, and Urban Water Management Plans.

- **Interviews**: Interviews, exploring drivers and impediments, were conducted with utility managers, regulators and growers, purposefully selected to capture a range of agricultural reuse types.
- **National geospatial assessment**: All Publicly Owned Treatment Works (POTWs) were georeferenced and assessed for their potential (volumes, quality, distances) to supply recycled water to nearby agricultural lands.

Results and Discussion

Impediments to the use of recycled water in agriculture vary substantially from one location to another. At least 64 distinct factors were recognized, acting as impediments in some cases and as divers in others. These factors were revealed in interviews, breakout groups, review of water/wastewater agencies' documentation, and the relevant literature. Some of the identified impediments in one region acted as drivers under certain conditions in other regions. The relevancy of these factors varied among stakeholder groups. Impediments to and drivers for use of recycled water in agriculture can be generally grouped into the following classes:

- Water supply availability (impediment) and scarcity (driver).
- Water quality impact (impediment) and avoided discharge (driver/incentive).
- Regulatory constraints (impediment) and flexibility, or mandate to reuse (driver/incentive).
- Economics, financial issues (impediment) and government assistance (driver/incentive).
- Institutional barriers (impediment) and collaboration (driver).
- Perception, acceptance, stigma (impediment) and long-term familiarity (driver).

Water quantity (i.e., scarcity, drought, climate-change, and overdraft) was one of the most frequently cited impediments and/or drivers across all stakeholder groups. Where water supplies are abundant at low cost, recycled water cannot compete unless other drivers are present. On the other extreme, water scarcity is by far the most important driver for use of recycled water in agriculture.

Water quality issues are both impediments and incentives to agricultural reuse. The potential long-term effects of elevated salinity in some recycled water is of concern to growers. For some utilities, limits on nutrient discharges to surface waters serve as

an incentive to practice agricultural reuse, thereby reducing their discharges to surface waters.

Regulatory constraints vary greatly from one area to another because there are no international or national (U.S.) standards for water reuse. State regulations range from inhibitive to permissive, and in rare instances, encouraging. Twenty-six states allow the irrigation of food and non-food crops, while 19 states only allow the irrigation of non-food crops. Seven states currently prohibit the use of recycled water for agricultural irrigation. Few countries have nation-wide standards for irrigation. Notable examples are Israel (enforceable criteria) and Australia (suggested guidelines)

Economic or financial impediments are frequently cited by wastewater utilities. Capital investments needed to upgrade treatment facilities and/or construct recycled water distribution networks to agricultural customers are some of the most commonly cited impediments for utilities. This impediment is closely linked to the distance between the source of recycled water and the location of the farm fields requiring water for irrigation, as well as potential to utilize existing irrigation distribution pipes.

Institutional barriers are common where wastewater agencies, water supply utilities, and grower organizations are unable or unwilling to collaborate, share costs, recognize benefits, and agree to commit to long-term development of a water reuse project.

Public perception of recycled water use in growing irrigated crops was a major challenge in early projects, but it is no longer cited as a major impediment to new agricultural reuse projects. Precedent-setting projects with successful long-term use of recycled water for irrigation of market crops

The extent of existing water reuse for agricultural irrigation in the United States was evaluated using data from the U.S. EPA Clean Watersheds Needs Survey (CWNS, 2012). Recycled water for some form of irrigation is practiced in 41 states. Beneficial irrigation with recycled water and spray irrigation (sometimes only for effluent disposal) together account for approximately 3% of existing wastewater flows. Treated wastewater effluent that could be reallocated for agricultural reuse without causing any downstream impacts includes volumes disposed via evaporation (from open ponds or aerosolization from high-pressure nozzles), estimated at 0.63 Mm^3/d and ocean discharge at 12 Mm^3/d.

The CWNS data was also analyzed in conjunction with irrigated cropland data to evaluate the potential for increased agricultural reuse. It is estimated that approximately 10 million hectares of croplands (equivalent to 44% of all irrigated croplands) are located within 8 Km of publicly owned treatment works (POTWs) across the United States. In aggregate, POTWs in the eastern United States could meet approximately 75% of the irrigation demand of that region. In the western United States, POTWs produce enough effluent to meet approximately 17% of existing irrigation demands. Wastewater plants with high potential for agricultural reuse can provide a total of 4 Mm^3/d of recycled water for irrigation of 80,000 Ha of farmland throughout the United States.

Conclusions

The challenges to use of recycled water in agriculture can be overcome. The factors helping to surmount these impediments range from government incentives (i.e., supportive policies, subsidies, grants, and loans), user-friendly regulations, collaboration among the diverse water management silos, comprehensive education and outreach, and innovations in wastewater treatment and reuse technologies. Drivers of agricultural reuse continue to evolve as more geographically diverse communities see value in this practice as a cost-effective water management strategy. Examples of long-term, safe operation of similar projects at peer utilities is a critical factor in both motivating project initiation, as well as alleviating concerns about water quality and health risk among growers.

In the long-term, water scarcity, caused by a combination of urban population growth, climate change, and competing demands for water, will make recycled water use in agriculture a critical component of local water management and food supply strategies. This study identified a diverse range of approaches to help overcome impediments to agricultural reuse, including:

- Subsidies at the national and regional levels to local projects to reflect the overall societal benefits of water reuse, especially for agriculture (e.g., sustained food production).
- Cost-sharing, technical assistance, sharing of experiences, and collaboration among utilities and farmers to close the institutional gaps that can limit projects from moving beyond the planning phase.

- Regulatory reform in states where well-intentioned prohibitions against use of recycled water are still active.
- Legislative mandates for certain uses of recycled water have proven most effective at removing established barriers to uses of recycled water.
- Environmental restrictions on discharges of wastewater effluents to the environment have an indirect beneficial impact on the financial feasibility of water recycling, especially for agriculture.
- Groundwater protection rules against nitrogen contamination can indirectly benefit agricultural use of recycled water when farmers adjust their nitrogen fertilizer application to account for the nitrogen content of recycled water.
- Public outreach and education based on sound science to help nullify the opponents' arguments even before they arise.
- Investments in research and in the development of new technologies targeting water quality, and plant and soil protection may reduce or eliminate impediments relating to water quality.
- Cost effective methods to reduce salinity and meet disinfection requirements.

As enumerated, many solutions are available to help overcome the impediments to use of recycled water in agriculture. These remedies and incentives can be examined by the utilities and growers interested in using recycled water for beneficial purposes. From the extensive list of available solutions, those most appropriate solutions for the local conditions can then be selected and adapted. A dedicated champion is essential to pursue these remedies persistently, with the clear vision that: (a) the recycled water resource is too valuable to go to waste, (b) irrigated agriculture is particularly important to society for its supply of food and fiber, and (c) recycled water can be readily produced as a safe, appropriate source of irrigation water.

References

CWNS, 2012, https://www.epa.gov/sites/production/files/2015-12/documents/cwns_2012_report_to_congress-508-opt.pdf

WRF, 2019 "Agricultural Use of Recycled Water: Impediments and Incentives" accessed on May 1, 2019 at: https://www.werf.org/a/ka/Search/ResearchProfile.aspx?ReportId=Reuse-15-08

Risks of pollution and its assessment in wastewater irrigated agricultural systems (ROUSSEAU)

Miquel Salgot[1], Monserrat Folch[1] M. Silvia. Díaz-Cruz[2], Damià Barceló[2], Amadeo R. Fernández-Alba[3], M. Jesús Bueno[3], Giovanny García[2], Ana C. Soler[2], K. Paola Sepúlveda[1]

[1] Faculty of Pharmacy. University of Barcelona, 08028 - Barcelona, Spain; [2]Institute of Environmental Assessment and Water Research, Spanish Council for Scientific Research (IDAEA- CSIC). J. Girona 18-26, 08034-Barcelona, Spain; [3] University of Almería, Ctra. Sacramento s/n, 04120 – Almería, Spain.

Abstract

A collaborative project (ROUSSEAU) financed by the Spanish Ministry of Science, Innovation and Universities was launched in 2018, with the objective to clear knowledge gaps in the reuse of reclaimed water in irrigation and to contribute to a future EU regulation for reclaimed water use for agriculture. Three types of crops, water reclamation techniques, and irrigation systems in three study sites define the project. Three teams are collaborating in the project, with different roles: reuse environment definition, reclaimed water-related pollutants determination and environmental impacts.

Introduction

Water availability is a key factor when managing agriculture in the Mediterranean climatic areas. Climate Change (CC) forecast describes a changing pattern of precipitation, more concentrated in time, thus demanding more irrigation water for supply and quality safety. New resources must be used to solve the unbalance between offer and demand, seasonal or structural. Reclaimed water can fulfill this void as a new resource, but needs further work to determine its quality, applicability and its relationships with the environmental matrices.

Since agriculture is usually the most water demanding human activity; has always played a main role in global societies. Water helps supplying food as well as a wide range of raw materials for industries, provides public services, and keeps the countryside alive by providing jobs. The excessive use of water resources and the

more frequent droughts due to CC leaded the use of reclaimed water as a complementary, temporal or permanent additional water source. Reclaimed water uses will depend mainly on its quality. The extent of wastewater reclamation treatment will determine the quality of water to be used, then causing a variation of treatment costs which should be added to the analytical and management ones. This economic variable is paramount since EU rules establish that all costs incurred should be incorporated to the prices. Nevertheless, this approach presents some difficulties when reusing reclaimed water for agriculture.

Ensuring food security goes beyond securing a sufficient supply of water (FAO, 2013). For this reason, in order to reuse reclaimed water in appropriate conditions, it is necessary to fulfill a number of requirements. Among them, adequate quality, year round availability; economic, social and environmental feasibility studies; guidelines defining the quality for every use allowed; management and operation of the facilities; formation of the end users and, finally, wastewater prices policy, contemplating how and who covers the expenses.

Reclaimed water uses will depend on its quality (Pal, 2014). The extent of wastewater treatment will determine the quality of reclaimed water, its cost being variable depending on the type of treatment and the desired quality.

In assessing the anticipated impacts of climate change on agricultural water management, water availability is a critical factor. Climate change will affect agriculture; water resource availability will be altered by changed rainfall patterns and increased rates of evaporation (EU, 2007).

ROUSSEAU (Materials and Methods)

The propagation of waterborne biological and chemical emerging contaminants to soil, plants and humans is being investigated under Rousseau: three types of crops, water reclamation techniques, and irrigation systems in three study sites define the project. The works underwent on water (as indicated later), soils (with different levels of clay) and plants (carrot, lettuce and tomato). The pollutants' levels detected in the produced vegetables will also be studied later on, to estimate the food security derived from their consumption.

Considering the EU circular economy initiative, the reclamation systems and application strategies will be evaluated using environmental (Hazard Analysis and

Critical Control Points WHO 2006, Sanitation Security Planning – WHO 2015) and economic (cost-benefit) tools.

Reclaimed water used

The irrigation water used for this project is generated as follows:

1. The classical wastewater treatment train (activated sludge), generating reclaimed water, using Coagulation/Flocculation-Filtration-Disinfection. Usually is not pure reclaimed water but a mix of water from different origins.
2. Advanced treatment of secondary treated wastewater using natural components in reactive layers.
3. Wastewater treated with MBR and mixed with groundwater (GW).

Two different types of irrigation are also used (drip and sprinkler).

Microbiological and chemical analysis

The analysis of the common components of soils and water (nutrients, organic matter) and main microbiological analysis (*E. coli*, bacteriophages are being performed. Special microbiological components are determined in some samples (nematode eggs, cysts/oocysts of *Giardia* and *Cryptosporidium*). BOD, nutrients, turbidity, and suspended solids as well as other basic parameters such as ionic majority compounds, TOC and heavy metals are also being determined.

Advanced analytical methods based on LC-MS/MS, LC-HRMS, GC-MS/MS and GC-HRMS will be applied to wastewater, soil and plant tissues samples for chemicals quantification and transformation products (TPs) identification. QuEChERS method (Parrilla et al. 2018) is used for extraction. The method was optimized for the determination of 55 PPCPs including UV filters, parabens, antibiotics, anti-inflammatories, anti-epileptics and anti-depressants, among other contaminants of emerging concern (CEC) including pesticides.

For the analysis of soils, the classical soil science analytical methods have been used MAPA (2007)

Risk assessment

Human and ecological risk of both types of pollutants will be evaluated later on in the project when having a sufficient number of analytical results considering different end-points: soil, water and human by using different modelling tools. Pollutants' plant

intake evaluation will be relevant to estimate daily intake rates (EDI) and the associated risk to humans.

Socio-economic prospective

Apart from the calculation of costs and prices to be paid for the reclaimed water, other characteristics need to be considered. From intangible benefits to the increase of living standards, several circumstances and new characteristics accounted for. The cost-benefit calculation will be the tool mainly applied in this project. The constraints related to formation and information activities will also be dealt with.

Experimental plots

a) *Palamós WWTP (near Barcelona, Northeast Spain)*(Figure 1)

Soil type: Soil and mixture soil + 15% clay (15%). The original soil is sandy.

Irrigation system: sprinkler and drip.

Water used: 1 and 2*.

b) *Murcia region, southeast Spain*

Soil type: Clayey soil

Irrigation system: sprinkler and drip

Water used: 3

c) *Viladecans (in an Agricultural Park near Barcelona)*

Soil type: Sandy

Irrigation system: absorption by the plants' roots from a shallow aquifer. Sprinkling in the first phases of the culture.

Water used: 3

d) *Apart from it, a pilot study to evaluate the propagation and distribution of organic pollutants' residues from regenerated water to a red cabbage crop by irrigation is being carried out in a greenhouse in Almería.*

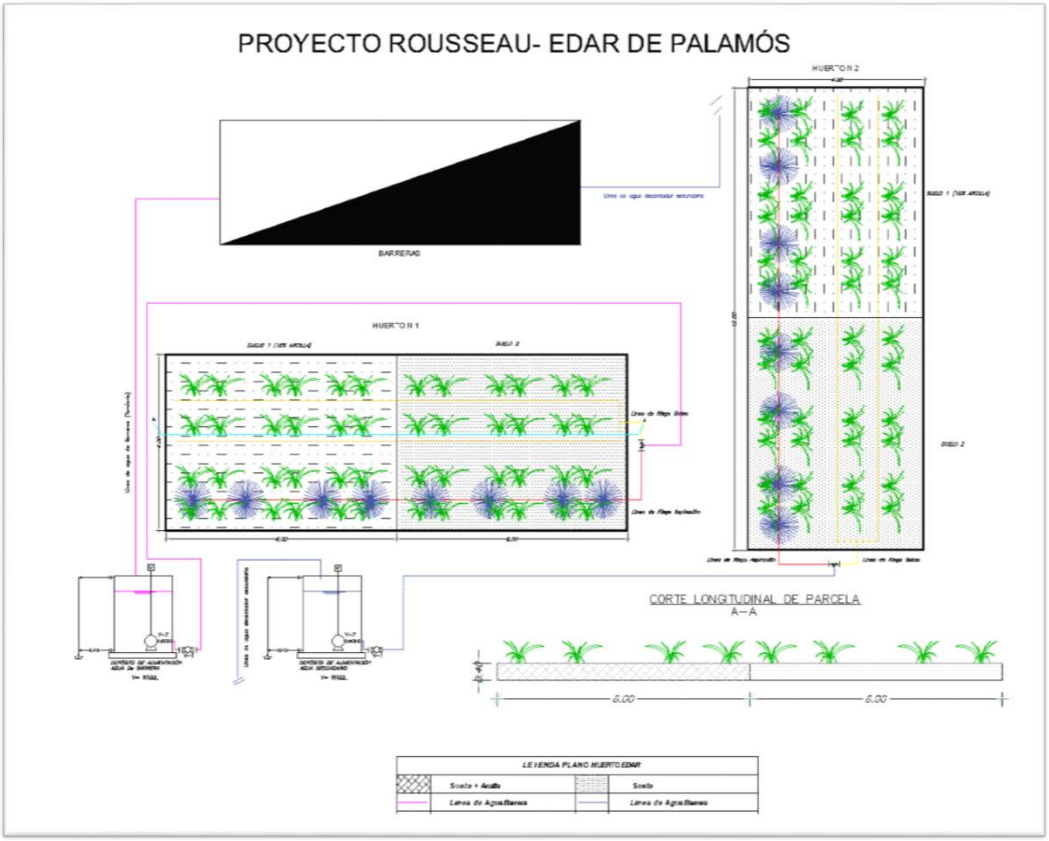


Figure 1: Experimental plots Palamós WWTP

Discussion

The results evaluated up to now show that the methods used are adequate for the determination of a big number of contaminants of emerging concern (CEC).

Irrigation water, plants and soils have been analysed and the initial levels of pollutants in the different matrices have been determined.

The team members visited the experimental plots and they experienced the difficulties to validate the diagrams of distribution of irrigation water and establish the water mix used to irrigate in every case. This mix is changing over time, which will create uncertainty on the final conclusions. The Palamós's site is experimental, and is used exclusively for research purposes, while the other two sites – Viladecans and Murcia – are agricultural fields, which confers an added value to the project.

Conclusions

The analytical methodologies used for the project are adequate and have been validated for the pollutants searched.

As an example of results, in the lettuce crops grown in Palamós' site and irrigated with secondary treated wastewater, the pesticides diphenoconazol, dimetyate,

fenhexamide, fluxapiroxad and trifloxistrobin have been detected at concentration levels between 0,4 and 8 µg/L while in the plots irrigated with reclaimed wastewater the concentrations were between 0,3 and 5 µg/L.

It is important that the team members visit the experimental fields and interact with the farmers to exactly determine the real cropping conditions.

Acknowledgements

All the works are financed by the ROUSSEAU (CTM2017-89767-C3-1-R) project Spanish Ministry of Science, Innovation and Universities and the EU HORIZON 2020 project ACWAPUR (PCIN-2015-245).

References

EU, (2007) Addressing the challenge of water scarcity and droughts in the European Union. European Union, Brussels (COM/2007/0414).

FAO, 2013. Statistical yearbook. World Food & Agriculture, Rome 978-92-5-107396-4

Pal, A., Jekel, M., Reinhard, M., Gin, K.Y., (2014) Environ. Int. 71, 46–62.

MAPA (Ministerio de Agricultura, Pesca y Alimentación) (2007) La alimentación en España. Dirección General de Industria Agroalimentaria y Alimentación. Ministerio de Agricultura, Pesca y Alimentación, Madrid, España.

Parrilla P., Lozano A., Ferrer C., Martínez, M.J., Fernández-Alba, A. (2018) Improvements in identification and quantitation of pesticide residues in food by LC-QTOF using sequential mass window acquisition (SWATH®)

ROUSSEAU project (2017): CTM2017-89767-C3-2-R. Spanish Ministry of Science, Innovation and Universities

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater. Volume 2: Wastewater use in agriculture. World Health Organization, Geneva, Switzerland

WHO (2015). Sanitation safety planning. Manual for safe use and disposal of wastewater, greywater and excreta. World Health Organization, Geneva, Switzerland.

Sustainable wastewater reuse for agricultural application

presenting author: Aleksandra Lazic, Xylem Inc., Stockholm, Sweden;
Christian Baresel, IVL Swedish Environmental Research Institute, Stockholm, Sweden

Highlights

Reuse of municipal wastewater is the responsible solution to manage water scarcity, but configuring the most sustainable treatment system is challenging. This study offers an approach based on sustainability tools (e.g. environmental and economic evaluations, effluent performance and plant size) in the configuration of the agriculture reuse treatment systems.

Introduction and objectives

Water reuse for agriculture can be achieved with additional tertiary and disinfection steps, however it is important to analyze these steps from both environmental and economic outcomes.

The goal of this project is to optimize wastewater treatment processes for sustainable agriculture reuse of treated wastewater. The starting point is to assess the environmental and economic profile of two treatment trains that combine the secondary treatment (sequencing batch reactor, SBR) with two different tertiary treatment technologies. The environmental impact assessment of the treatment trains is done using life cycle assessment (LCA). The economic evaluation was performed using life cycle cost (LCC).

Methodology approach

Two (2) different treatment trains for water reclamation for agriculture and urban use were evaluated for three different full-scale sizes 20,000, 100,000 and 500,000 PE.

The environmental assessment is carried out with LCA methodology according to ISO 14044 (2006). The goal is to compare the environmental profiles of treatment lines, which deliver reclaimed water for the same purpose.

The upstream boundary of the assessed system is the wastewater at the point of intake to the SBR. The downstream boundary considers all the effluents including

reclaimed water and sludge treatment (aerobic sludge stabilization step, thickening and dewatering).

Analysis and results

Results of the study allowed designing a sustainability tool integrating the environmental, economic and treatment performances of the two selected treatment lines and three studied plant sizes. The outcome of the tool provides a comprehensive understanding of the degree of sustainability of the treatment train for a specific application and raises visibility of the factors that have the greatest effect on the environmental impacts, the investment and operational costs.

Generally, tertiary treatment steps with disinfection have only a small impact on the overall environmental impact even though those steps upgrade the water quality to non-potable water reuse standards. Within the tertiary treatment and disinfection step, energy consumption used for operation contributes the most.

Evaluation of the LCC revealed that for each of the selected treatment trains, the operating cost (OPEX) is larger than the investment cost (CAPEX) over the 20 years of lifetime of the plant. In addition, the energy consumption accounts for more than 50% of the total OPEX based on European energy and labor prices.

Conclusions and recommendation

This study shows that various wastewater treatment trains can achieve the same reuse effluent quality while having different environmental and economic impacts. Sustainability tools (effluent quality, LCA, LCC, energy consumption, footprint, water efficiency) should be used to provide a more complete understanding of the environmental, economic and social impacts when selecting the most sustainable reuse treatment train of a certain size.

In addition, conventional treatments can be used to reach Reuse Quality Standard and make reuse a safe solution for agriculture application. These conventional treatments are very cost effective making water reuse for agriculture an affordable solution to better manage freshwater resources.

Cultivation of *Capsicum chinense* seedlings with different irrigation water sources

Marcos H.G. Ribeiro; Nathalia F. Bomfim; Savia Gavazza; Lourdinha Florencio; Wanderli R.M. Leite; Mario T. Kato.

Federal University of Pernambuco, Department of Civil and Environmental Engineering, Laboratory of Environmental Sanitation, Recife, Brazil

Introduction

The water reuse technique conserves water resources while reducing pollution (USEPA, 2004). According to Telles and Costa (2007), the treated effluent is fundamental in the planning and management of water resources as an alternative water source for agricultural purposes. However, the use of sewage in agricultural soils should consider aspects related to soil characteristics (Kacprzak et al., 2017). The use of treated sewage is, therefore, an alternative solution to supply partially or totally the water and nutritional demands in agriculture. Peppers are very present in Brazilian agribusiness, especially in family agriculture, a very present modality in the semi-arid region of Brazil. Besides the ornamental potential, fruits can be used for other purposes, such as sauces and jellies. It presents desirable characteristics to organic fertilization, great radicular mass, in addition to the high capacity of absorption of nutrients. The species is indicated for high temperatures regions, which favor seeds germination and the development of the plant and the fruiting. Cultivation time between sowing and fruit harvest is between 90 and 120 days and the recommended cultivation can be either in open air or in a greenhouse (Reifscheiner, 2000; Ribeiro et al., 2015). The aim of the present study was to evaluate the cultivation of pepper plants using three water souces: (i) treated effluent, (ii) tap water and (iii) distilled water.

Material and methods

Experiment I

The cultivation was carried out with pepper species, *Capsicum chinense,* variety *Boyra Habanero*, in 200-mL pots. Twelve pots were used per treatment and each contained three seeds that were sown at a depth of 3 cm. The pots were daily irrigated to 50% of the soil saturation capacity during the first 15 days, and to 85%

until the end of the first part of the experiment (FAO,2003). This first experiment consisted of three different irrigation treatments: (i) treated effluent, (ii) tap water and (iii) distilled water. Plant development was evaluated by the height, number of leaves per plant and survival rate (proportion of survived plants by total planted). Data were analyzed using Shapiro-Wilk for normality. The average values obtained in the treatments were compared with ANOVA and Tukey´s range test for normal distribution or Kruskal-Wallis otherwise.

Experiment II

The plants irrigated with treated effluent and tap water in the Experiment I were transplanted to 10-L pots and cultivated in a greenhouse. Mineral fertilizers with NPK were supplied to achieve the nutritional demand. The soil saturation level in the pots was maintained to 100% until harvesting. Plant development was evaluated by the height, number of leaves, content of selected nutrients (N and P) and total chlorophyll. Fruits were evaluated according to length, diameter and weight. Data were analyzed using Shapiro-Wilk for normality. The average values obtained in the treatments were compared with Student´s *t*-test and for normal distribution or Mann-Whitney U test ($P \leq 0.05$) otherwise.

Water and soil characteristics

Physical-chemical analyses for soil were performed according to Andreoli (1999); Kuo (1996) and Silva (2009); in the case of tap and distilled water and effluent, they were determined according to APHA (2012); Concentrations of metals present in the irrigation waters (Na, K and Ca) were detected by flame photometry.

Table 1 shows the irrigation water characteristics and Table 2 shows concentration of nitrogen (TKN, NO_3^-, NH_4^+), phosphorous, carbon and pH in soil used.

Table 1. Irrigation waters characteristics.

Variable	Treated effluent	Tap water	Distilled water
TKN ($mg.L^{-1}$)	23,00	1,40	ND[1]
NO_3^- ($mg.L^{-1}$)	0,22	ND	ND
NH_4^+ ($mg.L^{-1}$)	16,00	1,23	ND

COD ($mg.L^{-1}$)	95,52	ND	ND
P ($mg.L^{-1}$)	2,82	0,34	ND
pH	7,29	6,80	7,24
CE ($\mu S.cm^{-1}$)	776	316,14	229
Na ($mg.L^{-1}$)	82,70	32,80	ND
K ($mg.L^{-1}$)	13,85	5,20	ND
Ca ($mg.L^{-1}$)	15,90	4,50	ND

[1.] Below Detection Limits

Table 2.Concentration of selected nutrients, C and pH in soil used in the experiments I and II.

Variable	Soil
TKN ($mg.kg^{-1}$)	324,90
$N\text{-}NO_3^-$ ($mg.kg^{-1}$)	46,04
$N\text{-}NH_4^+$ ($mg.kg^{-1}$)	19,29
P ($mg.dm^{3-1}$)	277
C ($mg.kg^{-1}$)	2,44
pH	7,30

Results

Table 3 presents the seedling characteristics at the end of the Experiment I. The seedlings irrigated with treated effluent presented the highest average of height, number of leaves and survival rate, while the lowest values were obtained with distilled water, as expected. However significant differences were not identified.

Table 3. The effect of different irrigation waters on height, number of leaves and survival rates at the end of Experiment I.

Irrigation	Height (cm)	Number of leaves ($unit.plant^{-1}$)	Survival rate (%)
Treated effluent	5.90±2.14a	6.70±1.06a	27.78
Tap water	5.56±3.29a	6.25±2.25a	22.22
Distilled water	4.10±3.20a	5.80±2.20a	27.78

The highest amounts of nitrogen, phosphorus and metals (Na, K, Ca) are likely related to the best results achieved with the treated effluent used for irrigation. On the contrary, their deficiency in distilled water corroborates with the lowest results of height, leaves number and survival rate. The soil characteristics containing enough nutrients and compounds may have contributed with the comparable results of the first treatment.

Figure 1 shows the average height and number of leaves per plant, according to the treatment used during cultivation (30, 90 and 120 days after planting) along the Experiment II. Both results are in accordance with those of correspondent treatments in Experiment I (Table 3). Irrigation with treated effluent resulted in slightly higher values for height and number of leaves during the development stages of the plant, but differences were not statistically significant.

Figure 1. Average height of plants according to treatment at 30, 90 and 120 days after planting (Experiment II).

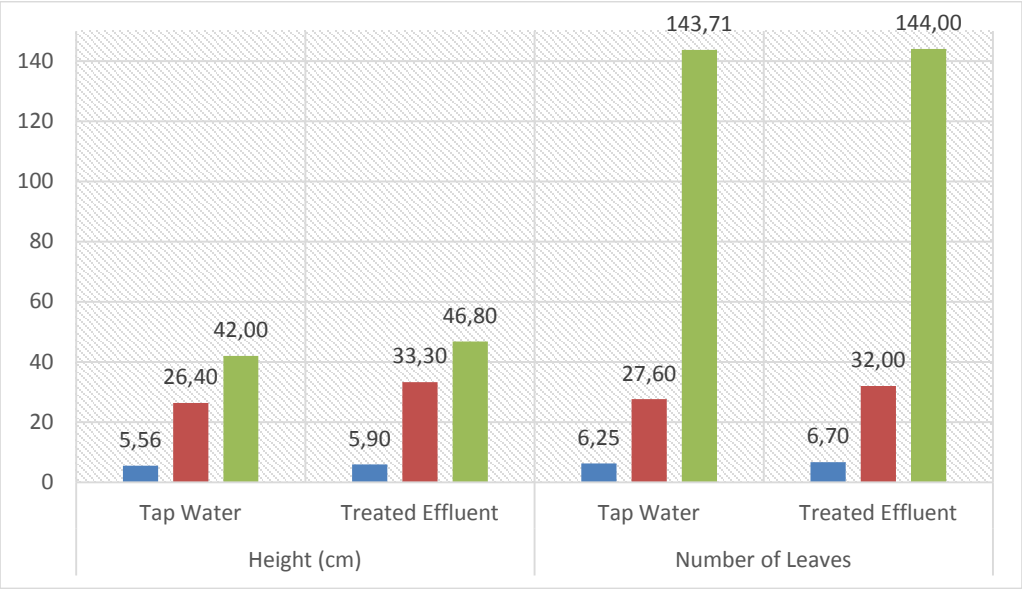


Table 4 presents plants and fruit characteristics obtained in the Experiment II. The results for fresh and dry matter corroborate with those presented in Tables 1 and 2, since plants irrigated with treated effluent presented higher values compared to those irrigated with tap water. Results for total chlorophyll (a + b) were higher for plants irrigated with tap water. Such result is a likely indicator of either hydric or saline stress. Plants under water stress usually reduce the chlorophyll content since water

deficiency or salinity benefits the synthesis of reactive oxygen species by inducing the oxidation of photosynthetic pigments. It is a typical indicator of oxidative stress, as a consequence of pigments photo-oxidation associated with chlorophyll molecules self-degradation (CARLIN, 2012). Low chlorophyll levels may be also addressed to an adaptive response to stressors (MENDES, 2011).

Table 4. Characteristics of plants and fruits after 120 days of irrigation (Experiment II).

Parameter	Treated effluent	Tap water
Characteristics of the plants		
Fresh matter ($g.plant^{-1}$)	155.29±40.30a	146.46±42.53a
Dry matter ($g.plant^{-1}$)	36.74±14.22a	34.19±10.50a
Total Nitrogen ($g.kg^{-1}$)	42.88±5.07a	44.42±4.68a
Total Phosphorous ($g.kg^{-1}$)	3.77±0.43a	4.48±0.48a
Total Chlorophyll ($mg.g^{-1}$)	3.35±0.26a	4.12±0.28b
Characteristics of the fruits		
Length (cm)	32.13±1.23a	34.07±3.01b
Diameter (cm)	28.43±1.40a	29.66±1.64b
Weight (g)	6.47±0.61a	6.48±0.87a

There were no significant differences between the two treatments concerning the weight of the pepper fruits. These results corroborate with those of Almuktar (2015), who associated the high amount of nutrients supplied by the combination of compost and treated effluent that cause damage to fruits. However, Almuktar (2017), obtained higher length and weight outcomes for *Capsicum annuum* fruits irrigated with an enriched nutrient wetlands effluent.

Conclusion

Although the treated effluent resulted in higher values for dry and fresh matter, height and number of leaves, no significant differences were identified compared to others treatments in both Experiments; Chlorophyll outcomes indicate a possible saline stress for plants irrigated with treated effluent; High nutrient concentrations supplied by the treated effluent resulted in low values for height, diameter and fruit weight in the Experiment II.

References

ALMUKTAR, S. A. A. A. N., et al. "Recycling of domestic wastewater treated by vertical-flow wetlands for irrigating chillies and sweet peppers." *Agricultural Water Management*149 (2015): 1-22.

ALMUKTAR, S. A. A. A. N., SUHAIL N. A., SCHOLZ M. "Recycling of domestic wastewater treated by vertical-flow wetlands for irrigation of two consecutive Capsicum annuum generations." *Ecological Engineering* 107 (2017): 82-98.

ANDREOLI, C. V. (1999). *Uso e manejo do lodo de esgoto na agricultura e sua influência em características ambientais no agrossistema*. Universidade Federal do Paraná.

CARLIN, S. D.; RHEIN, A. F. de L; SANTOS, D. M. M. dos. Efeito simultâneo da deficiência hídrica e do alumínio tóxico no solo na cultivar IAC91-5155 de cana-de-açúcar. Semina: Ciências Agrárias, v. 33, n. 2, p. 553-564, 2012.

FAO – FOOD AND AGRICULTURE ORGANIZATION. **Users manual for irrigation with treated wastewater**. Technical Report. Cairo, Egypt. p.72, 2003.

KACPRZAK, M. et al. Sewage sludge disposal strategies for sustainable development. Environmental Research, 156, 39-46, 2017.

MENDES, B. S. da S.; WILLADINO, L.; CUNHA, P. C. da; OLIVEIRA FILHO, R. A. de; CAMARA, T. R. Mecanismos fisiológicos e bioquímicos do abacaxi ornamental sob estresse salino. Revista Caatinga, v. 24, n. 3, p. 71-77, 2011.

PESCOD, M. B. Wastewater treatment and use in agriculture-FAO irrigation and drainage paper 47: Food and Agriculture Organization of the United Nations. **Natural Resources Management and Environment Department. http://www.fao. org/docrep/T0551E/t0551e06. htm**, v. 4, 1992.

REIFSCHNEIDER, F .J .B. (Org.) Capsicum: pimentas e pimentões no Brasil. Brasília: Embrapa. 113p. 2000.

RIBEIRO, C. S. et al. 2015. BRS Juruti: the first Brazilian habanero-type hot pepper cultivar. Horticultura Brasileira, 33(4), 527-529.

SILVA, F. C. D. S. (Ed.). (2009). *Manual de análises químicas de solos, plantas e fertilizantes*. Brasília: Embrapa Informação Tecnológica; Rio de Janeiro: Embrapa Solos.

TELLES, Dirceu D.; COSTA, R. H. P. G. Reúso da água: Conceitos, teorias e práticas. **São Paulo: Editora Blucher**, v. 2, 2007.

USEPA, USAID. Guidelines for water reuse. **EPA/625/R-04/108, 25-167-250**, 2004.

Matching agricultural freshwater supply and demand: using recycled water for subirrigation purposes

Ruud P. Bartholomeus, KWR Watercycle Research Institute, Nieuwegein, the Netherlands and Wageningen University, Soil Physics and Land Management Group, Wageningen, the Netherlands; M.H.J. van Huijgevoort, KWR Watercycle Research Institute, Nieuwegein, the Netherlands; A. van Loon, KWR Watercycle Research Institute, Nieuwegein, the Netherlands; G.A.P.H. van den Eertwegh, KnowH2O, Berg en Dal, the Netherlands; K.J. Raat, KWR Watercycle Research Institute, Nieuwegein, the Netherlands; ruud.bartholomeus@kwrwater.nl

Abstract:

We are increasingly confronted with drought damage in agriculture and nature, as well as an increasing pressure on the availability of water for high-grade applications, such as the production of drinking water. Strategies are being developed to control these risks and to secure long-term supplies of freshwater. These include increasing regional self-sufficiency to meet the demand for freshwater and improving the utilization of available water sources. We provide results of a pilot study in which industrial treated wastewater (TWW) is used for subirrigation in an agricultural field. Results show that the water availability for crops can be optimized by subirrigation with TWW as water source, and the need for groundwater or surface water extraction decreases.

Keywords: Drought; Industry; Subirrigation; Treated waste water; Water reuse

Introduction

Agricultural crop yields depend largely on soil moisture conditions in the root zone. Climate change leads to more prolonged drought periods that alternate with more intensive rainfall events. With unaltered water management practices, reduction in crop yield due to drought stress will increase. Therefore, both farmers and water management authorities search for opportunities to manage risks of decreasing crop yields. Available groundwater sources for irrigation purposes are increasingly under pressure due to regional coexistence of land use functions that depend on groundwater levels or compete for available water. At the same time, treated wastewater from industries and domestic wastewater treatment plants is quickly

discharged via surface water towards sea. Exploitation of these freshwater sources may be an effective strategy to balance regional water supply and agricultural water demand.

In order to reduce the risk of waterlogging, farmers have drained their land to get rid of excessive soil moisture quickly. In order to limit excessive drainage, controlled drainage systems have been developed, which allow to retain groundwater within agricultural parcels. Such controlled drainage allows to actively control groundwater levels and soil moisture conditions at an agricultural field (Ayars et al. 2006). Moreover, water can be actively added to the system, which turns a controlled drainage system into an infiltration system, which is called subirrigation. The goal of subirrigation is to raise the groundwater level and improve the soil moisture conditions for plant growth through capillary rise. Subirrigation is a subsurface irrigation method that can be more efficient than classical, aboveground irrigation methods using sprinkler installations, as only water that is used for plant transpiration leaves the groundwater system. Unused water is kept within the groundwater system. Subirrigation is very much valued in growing crops as direct evaporation loss is reduced and the energy consumption is low (Bigah et al. 2019).

In this study, we use TWW as external freshwater source for subirrigation purposes. Such direct use of TWW for irrigation provides better control over soil moisture, hence better growing conditions for crops, and a reduced need for groundwater or surface water extraction. Additionally, subsurface irrigation has the advantage over surface irrigation that direct contact of the TWW with the plant is minimized.

A pilot study to examine the effects of the use of TWW in a subirrigation system has taken place at the Bavaria Beer Brewery in the south of the Netherlands (Figure 1, Bartholomeus et al. (2018)). The Bavaria Beer Brewery extracts a large amount of groundwater and discharges TWW to the surface water. At the same time, neighbouring farmers invest in sprinkler irrigation using groundwater to maintain their crop production during drought periods. This leads to increasing pressure on the regional groundwater availability. To reduce the water footprint of the brewery and the abstractions of farmers, excess TWW is delivered to a nearby field by subirrigation.

Within the pilot study, a subirrigation system has been installed and tested. We combine both process-based modeling of the soil-plant-atmosphere system and field

experiments to i) investigate the amount of water that needs to be and that can be subirrigated, and ii) quantify the effect on soil moisture availability and herewith reduced needs for aboveground irrigation.

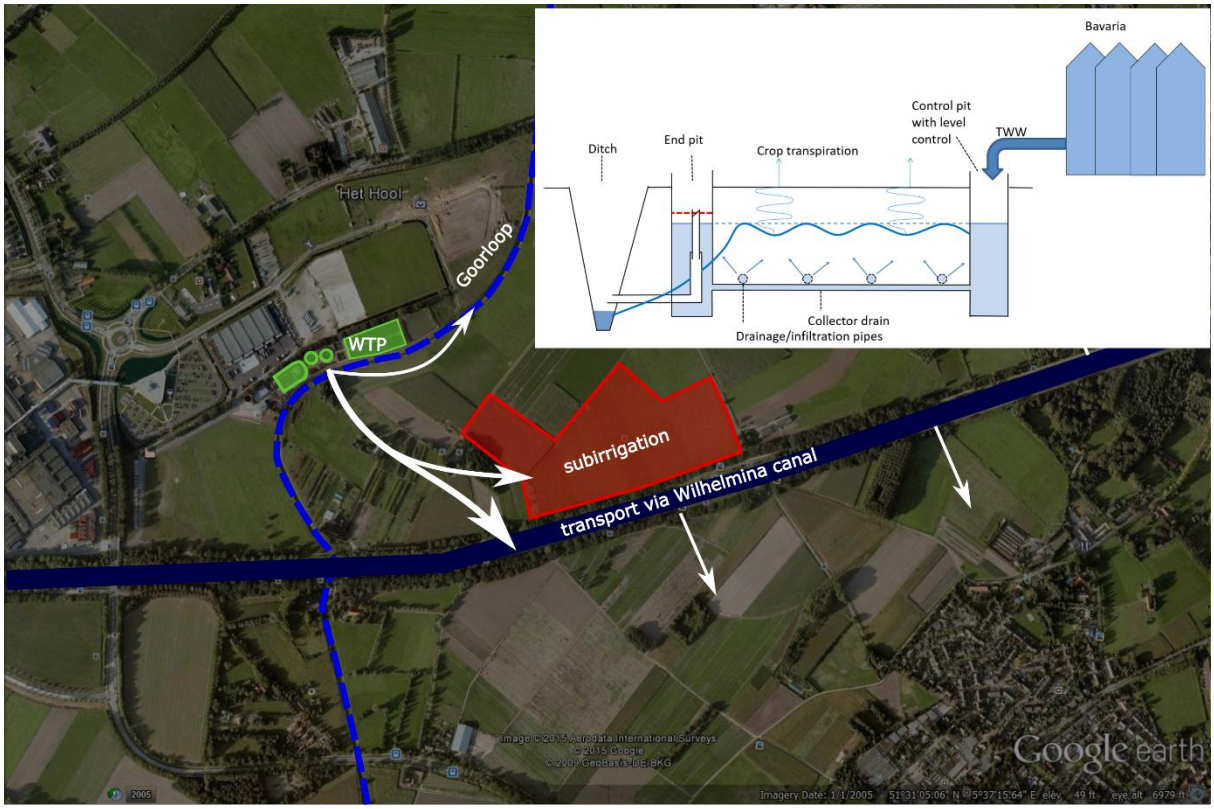


Figure 1 TWW from the Bavaria wastewater treatment plant ('WTP', green) is discharged via three routes: directly to the plot of agricultural land ('subirrigation', red) and to the Wilhelmina canal (dark blue). The canal transports TWW to fields at a greater distance from the WTP. The (conventional) discharge to the Goorloop (light blue) is minimized. Inset: schematic view of the subirrigation-system with TWW as water source for the Bavaria-case.

Material and Methods

A subirrigation system has been installed by using subsurface drains, which are interconnected through a collector drain, and connected to an inlet control pit for the TWW to enter the subirrigation system (Figure 1). A network of sensors has been installed to measure both the effect of subirrigation on i) groundwater levels and soil moisture contents in the root zone within the field ii) hydraulic heads in deeper aquifers and iii) groundwater levels in neighbouring fields. The water supply to the field is measured continuously at the wastewater treatment plant.

We used the Soil Water Atmosphere Plant model (SWAP; Kroes et al. (2009)) to describe the interacting processes in the soil-water-plant-atmosphere system. SWAP uses as input meteorological conditions, soil physical parameters, hydraulic head and a resistance to describe seepage/infiltration, a schematization of the drainage to local surface water and crop characteristics. Relevant output is groundwater level, soil moisture conditions in the root zone, soil temperature and reduction of the potential transpiration to the actual transpiration due to either too dry or too wet conditions in the root zone.

SWAP is combined with PEST (Doherty 2010) to calibrate the SWAP model against measured groundwater levels and soil moisture conditions at 40 and 60 cm-s.s. for the years 2015-2017. Soil physical parameters, vertical resistance of the aquitard, drainage resistances to the surface waters and drainage and infiltration resistance of the drainage/subirrigation system were fitted.

Results and Discussion

In 2015, the year without subirrigation, groundwater levels in summer dropped to about 250 cm-s.s. 2016 was not representative for a drought study, due to excessive rainfall in June/July. In 2017, a total of 430 mm of excess TWW was delivered to the field and groundwater levels raised to 50-100cm-s.s. Time series of groundwater levels indicate that the effect of subirrigation was limited to the target field; groundwater levels in neighbouring fields were not affected.

Subirrigation raised the groundwater level by 100–150 cm compared with the reference without subirrigation (Figure 2). According to the SWAP simulations, this shallow groundwater level optimized the soil moisture conditions for crop growth, i.e. transpiration reduction due to drought equaled zero for the situation with subirrigation and thus no drought stress occurred.

From the first calibration step, using SWAP-PEST, followed that the model performs well on average, but that simulated groundwater levels were too deep during subirrigation in 2016 and too shallow for 2017. The measurements indicate that the infiltration resistance is not a constant, but increases in time, because an increasing water level is needed in the control pit (Figure 1) and infiltration rates decrease over time. Therefore, in a second calibration step, we fitted the infiltration resistance for

each month, while keeping the other fitted parameters to their values of the first calibration step. This gives a good agreement between the modeling results and the measurements (Figure 2). The gradual increase of the infiltration resistance is caused by clogging, and hampers optimal management of the groundwater level and herewith soil moisture conditions in the field. Nevertheless, alternating drainage and infiltration regimes will likely prevent clogging.

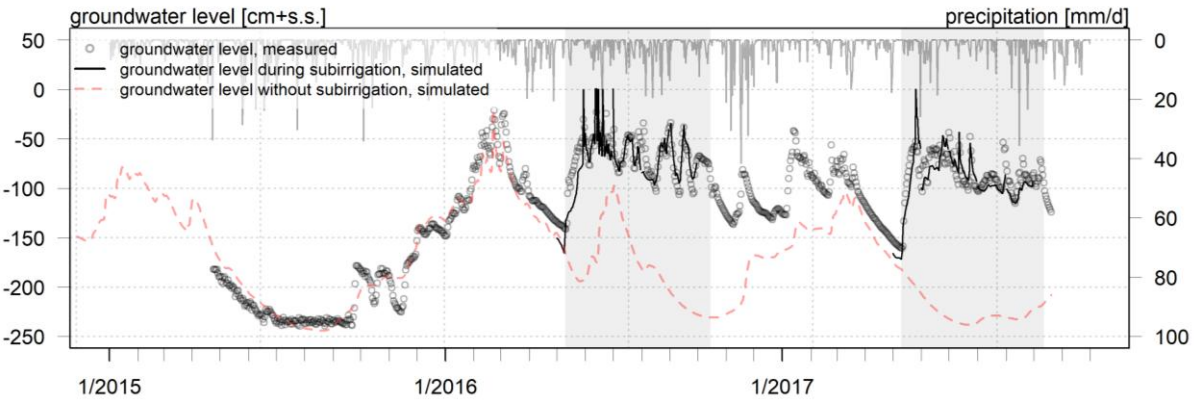


Figure 2 Precipitation and measured and simulated groundwater levels. The grey areas indicate the subirrigation periods.

Besides industrial wastewater treatment plants, domestic wastewater treatment plants across the Netherlands produce annually 40-50 mm freshwater which is discharged on surface water. Unlike most industrial effluent, domestic wastewater contains a variety of micro pollutants. Additionally, direct reuse of domestic TWW for agriculture is part of the EU regulation on water reuse (Dingemans et al. 2018). A similar pilot project as for Bavaria has been setup in the eastern part of the Netherlands, in which domestic TWW is applied to a corn field by subirrigation during the growing season from 2015 onwards, using a climate adaptive drainage system (Bartholomeus et al. 2017). Focus of this pilot study is on i) quantifying potential contamination of both the root zone and the deeper groundwater with emerging contaminants like pharmaceutical residues and ii) analyzing the effect of soil passage on surface water quality.

Conclusions

In this paper we focus on the water quantity effects of reusing treated wastewater for subirrigation purposes. The Bavaria-case indicates that subirrigation with TWW may

be an effective method to i) increase groundwater levels, even at sites with normally relatively deep groundwater levels ii) optimize soil moisture conditions for crop growth and prevent drought stress. It should be noted, however, that the local soil conditions are important to prevent quick losses due to deep percolation and that clogging may be a serious risk. Utilizing available alternative water flows for agricultural water supply can reduce the demand for groundwater for sprinkling purposes, which spares the groundwater for more high-grade applications.

References

Ayars, J. E., E. W. Christen and J. W. Hornbuckle (2006). Controlled drainage for improved water management in arid regions irrigated agriculture. Agricultural Water Management **86**(1–2): 128-139.

Bartholomeus, R. P., S. F. Stofberg, G. A. P. H. Van den Eertwegh and D. G. Cirkel (2017). Hergebruik restwater voor zoetwatervoorziening in het landelijk gebied: Monitoring sub-irrigatie met RWZI-effluent Haaksbergen - 2016. Nieuwegein, KWR.

Bartholomeus, R. P., A. H. Van Loon and M. H. J. Van Huijgevoort (2018). Hergebruik van industrieel restwater voor de watervoorziening van de landbouw - Praktijkproef subirrigatie met gezuiverd restwater van Bavaria. KWR 2018.089. Nieuwegein, KWR.

Bigah, Y., A. N. Rousseau and S. J. Gumiere (2019). Development of a steady-state model to predict daily water table depth and root zone soil matric potential of a cranberry field with a subirrigation system. Agricultural Water Management **213**: 1016-1027.

Dingemans, M., R. Bartholomeus and G. Medema (2018). Evaluation of the proposed EU regulation on minimum requirements for water reuse for irrigation. KWR 2018.075.

Doherty, J. (2010). PEST: Model independent parameter estimation, Watermark Numer. Comput., Brisbane, Queensland, Australia.

Kroes, J. G., J. C. Van Dam, P. Groenendijk, R. F. A. Hendriks and C. M. J. Jacobs (2009). SWAP version 3.2, Theory description and user manual. Wageningen, Wageningen University and Research Centre.

Smart Ferti Tool: a smart fertigation solution as a decision support tool to irrigate with treated wastewater

Helmi K.[1], *Grellier S.*[1], *Ayache C.*[1], *Teiser B.*[2], *Dockhorn T.*[3], *Siemers C.*[4], *Courault D.*[5], , *Ruy S.*[5], *Michel E.*[5], *Albert I.*[6], *Cheviron B.*[7], *Tomas S.*[7], *Lorain O.*[8], *Bayle X.*[9], *Poitrenaud M.*[10], *Capdevielle A.*[11], *Condom N.*[12], *Bernat P.*[13]

[1] Veolia recherche & Innovation, Maisons-Laffitte, France, karim.helmi@veolia.com

[2] Abwasserverband Braunschweig, Braunschweig, Germany

[3] Technische Universität Braunschweig, Braunschweig, Germany

[4] Stadtentwässerung Braunschweig, Braunschweig, Germany

[5] Institut National de la Recherche Agronomique, Avignon, France

[6] Institut National de la Recherche Agronomique, Paris, France

[7] L'Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture, Montpellier, France

[8] Polymem, Castanet Tolosan, France

[9] BIO-UV, Lunel, France

[10] SEDE, Cergy, France

[11] Compagnie d'Aménagement des Côteaux de Gascogne, Tarbes, France

[12] ECOFILAE, Montpellier, France

[13] Veolia, Ibos, France

Abstract:

The Smart Ferti Tool project aims to provide a fertigation solution to jointly optimize irrigation and fertilizer application, for a better agricultural productivity, according to farmer constraints and regulation requirements. The final solution should match plant demands at best and adapt reclaimed water quantity based on extensive monitoring of soils, water and crops (here winter wheat, maize and beetroot). In order to assess the efficiency of this tool, experimental and reference plots are monitored over 3 years in France and Germany (irrigated water, soil water, soil, crop) and yields are compared at the end of the season. The first year (2018) aimed to validate the experimental protocol in terms of monitoring of matrices, sensors selection and agronomic model optimization.

Keywords: reuse; fertigation; water; crops ; monitoring ; modelling.

Introduction

Population growth with an increasing water demand, is expected to severely reduce water availability but also to create stress on biodiversity in the global ecosystem. The ability to reuse resources found in effluent of wastewater treatment plants is important to compensate natural resource scarcity. Wastewater is the only water resource which volume increases proportionally to economic development and consumption and constitutes a largely unexploited opportunity (less 2% worldwide). Agriculture is the main water user, with a consumption of about 70% of freshwater worldwide. The reuse of treated wastewater in agriculture, and namely enabling smart agriculture practices related to water and fertilizer management could allow to propose integration of solutions in accordance with both farmer needs and regulation requirements. In this context, the Smart Ferti Tool project combines wastewater irrigation and liquid fertilization: fertigation. The fertigation solution should optimize fertilizer dose and application of treated wastewater based on monitoring of soils, water, crops and fertilizer. It is actually tested in parallel in France and Germany, during 3 irrigation seasons (2018, 2019, 2020) on different cultivars including, maize (in France and Germany), winter wheat and sugar beet (in Germany). An agronomic model will be used to optimize the fertigation strategy by matching at best the water and nutrient demands of the crops. From a larger point of view, the Smart Ferti Tool project aims to develop a smart tool to assess and control the needs on water and nutrients of the agricultural crops over three irrigation campaigns in France and Germany by comparison between a controlled fertigation and the actual irrigation method using experimental and reference plots, respectively. For both countries, the fertigation impact is assessed on the one hand, for crop yields and on the other hand for safety aspects. Regarding water quality regulation, in Germany, treated wastewater can be directly used for field irrigation. Conversely, in our project context, in France the fields are irrigated with groundwater in the reference case whereas criteria have to be met before irrigation, especially but not only in terms of microbial content, for wastewater reuse.

Material and Methods

First and foremost, it is important to notice that the objectives of year 2018 were to understand farmer’s usual technical itinerary, to test monitoring methods and to

collect data in order to calibrate the agronomic model (same irrigation water for experimental and reference plots). Table 1 summarizes the applied protocol in terms of agronomic and sanitary monitoring, with the respect to regulation requirements.

Table 1. Irrigation, fertilization and monitoring protocol applied for monitored sites

		France		Germany	
		Reference plot	***Experimental plot***	***Reference plot***	***Experimental plot***
Irrigation period	2018	Maize / groundwater / organic and mineral amendment		Winter wheat / wastewater / sludge and mineral amendment	
	2019	Maize / groundwater / organic and mineral amendment		Sugar beet / wastewater / sludge	Sugar beet / wastewater / mineral fertilizer
	2020	Maize / groundwater / organic and mineral amendment	Maize / wastewater fertigation	Maize / wastewater / sludge	Maize / wastewater fertigation
Water pre-treatment		None (groundwater)	Filtration / UV / Chlorination	None (wastewater)	None (wastewater)
Agronomic monitoring	Soil	Texture, pH, dry matter, Cationic Exchange Capacity, available water capacity, nitrogen, potassium, phosphorus, exchangeable trace elements, ions, exchangeable bases		Texture, pH, dry matter, Cationic Exchange Capacity, available water capacity, nitrogen, potassium, phosphorus, exchangeable trace elements, ions, exchangeable bases	
	Soil water	Nitrogen, potassium, phosphorus		Nitrogen, potassium, phosphorus	
	Crop	Plant growth, chlorophyll content, weight		Plant growth, chlorophyll content, weight	
	Weather	Rainfall, temperature, wind speed, air humidity, solar irradiance		Rainfall, temperature, wind speed, air humidity, solar irradiance	
Chemical monitoring (Sanitary aspects)	Soil	Heavy metals, PolyChlorinated Biphenyls (PCB), Hydrocarbons Polycyclic Aromatic (PAH), Benzo(a)Pyren		Heavy metals, PolyChlorinated Biphenyls (PCB), Hydrocarbons Polycyclic Aromatic (PAH), Benzo(a)Pyren	
	Irrigation water	Quantitative methods: Heavy metals, PolyChlorinated Biphenyls (PCB), Hydrocarbons Polycyclic Aromatic (PAH), Trihalomethane (THM), Benzo(a)Pyren Qualitative screening method: pharmaceutic, industrial, phytosanitary, synthetic and natural components (4,000 molecules database)		Quantitative methods: Heavy metals	
	Crop	Heavy metals, PolyChlorinated Biphenyls (PCB), Hydrocarbons Polycyclic Aromatic (PAH), Benzo(a)Pyren		None	
Microbiological monitoring	Irrigation water	*Escherichia coli*, coliforms, *enterococci*, sBASR, ARN-F specific bacteriophages, *Giardia*, *Cryptosporidium*		None	
	Air	*Escherichia coli,* bacteriophages, enteric viruses		None	

Soil and soil water sampling consisted of 2 or 3 composite samples per plot (17 sub-samples). Crop monitoring consisted of visual plot observations in several zones, growth measurement (stem length, leaves number and aspect, ear length, step of growth identification…) and yield measurements (biomass yield based on number of plants /m^2, number of ears per plant, number of grain per ear and average weight of one grain). In addition, a local weather station, irrigation water sensors (flow, pressure, conductivity, chlorides, NO_3^-, NH_4^+, P_2O_5, K^+) and soil sensors (humidity, soil temperature, salinity, NO_3^- and K^+) were set up. Regarding microbiology, complementary treatment including filters, UV, and chlorination (final concentration at 0.2 ppm) were installed at the wastewater treatment plant outlet in France in order to reach the required log reduction levels for microbial parameters for water quality ("Decree of 2 August 2010 on the use of water from urban wastewater treatment for the irrigation of crops or green spaces"). Triplicate samples were collected and analyzed using standard methods. In parallel, bioaerosols will be also monitored in order to assess a potential risk of microbial inhalation during irrigation. Concerning physico-chemical parameters and micropollutant detection, usual quantitative methods were performed for both countries and an innovative screening approach (LC-HRMS and GCxGC-MS-TOF) enabling to detect 4,000 chemical components was also performed in France for water monitoring.

Results and Discussion

The measured data and observation collected during 2018 contributed on the one hand to calibrate the agronomic model in terms of crop culture water and nutrient demand and on the other hand to assess the potential health issues related to waterborne substances and microorganisms. Differences between both sites have been highlighted; for instance, the soils of the monitored fields in France are clayey silts while those in Germany are sandy soils. An overview of the first results obtained in 2018 for France and Germany sites is presented in table 2.

Table 2. Preliminary results obtained in 2018 for soil, water and crops

		France		Germany	
		Sample before seedling and irrigation (March 2018)	***Sample after harvest and irrigation (August 2018)***	***Sample before seedling and irrigation (April 2018)***	***Sample after harvest and irrigation (August 2018)***
Soil	**Texture**	Clayey silts	Clayey silts	Sandy soil	Sandy soil
	pH	Acid= 6.3 - 7.0	Acid= 6.3 - 6.6	Acid= 5.6 - 6.2	Acid= 6.0 - 6.3
	Organic matter	Acceptable= 2.4 - 3.4 %	Acceptable= 2.2 - 3.3 %	Low = 3.2%	Low < 2.0%
	Cation exchange capacity	Low= 8.7 - 10.7 meq/100g	Low= 7.8 - 9.9 meq/100g	Low=5.6 - 8.3 meq/100g	Low= 6.3 - 7.5 meq/100g
	Major element NPK	Satisfying = 0.1 et 0.2 % for N	Satisfying = 0.1 et 0.2 % for N	Low =P, N available available potassium satisfying = 150 mg/kg K20)	Low =P, N available available potassium satisfying = 150 mg/kg K20)
	Conductivity	Low= 0.04 - 0.06 mS/cm	Low= 0.05 - 0.08 mS/cm	Low < 0.5 mS/cm	Low < 0.5 mS/cm
	Available water capacity	Satisfying= 1.9 mm/cm	Satisfying= 1.6 - 2.4 mm/cm	Low= 0.5 - 0.6 mm/cm	Low= 0.5 - 0,6 mm/cm
	Heavy Metals	Values < regulatory threshold		*Under completion*	
	Organic pollutants	Values < detection limits		Values < detection limits	
Groundwater (Irrigation water)	**Heavy Metals**	Values < regulatory threshold		NA	
	Organic pollutants	PAH, PCB and THM < detection limits		ND	
	Phytosanitary products (major family)	Metolachlor ESA (0.20 to 0.68 µg/L), chlorfenvinphos (0.16 µg/L), Fluroxypyr (0.71 µg/L), 2,4-D (2.5 µg/L) and Triclopyr (6.8 µg/L)		ND	
	Microorganisms	Minimum value =		NA	
Wastewater (Irrigation water)	**Heavy Metals**	Values < regulatory threshold		ND	
	Organic pollutants	PAH, PCB and THM < detection limits		ND	
	Pharmaceutical products (major family)	45 molecules detected		ND	
	Microorganisms	Calculated log reduction fitting with regulation requirement for all microorganisms		NA	
Crop (grains)	**Heavy Metals**	Values < regulatory threshold		ND	

ND: not determined, NA: not applicable

In terms of sanitary impact regarding wastewater effluent and groundwater monitoring In France, no compounds from the PAH (Polycyclic aromatic hydrocarbons), PCB (Polychlorinated biphenyls) and THM (Trihalomethanes) families were quantified while between 4 and 16 plant protection products were detected

mainly with very low concentration (<0.05 µg/L). In parallel, using the qualitative screening method, it has been confirmed that the main product family identified in groundwater was phytosanitary products while in wastewater effluent, pharmaceutical products represented the main part. As a result, this latter category will be monitored in both wastewater and groundwater during the remainder of the project to assess whether the pharmaceutical molecules will transfer from wastewater to groundwater during irrigation. In maize grains, the values of metallic trace elements were below the thresholds of the regulations for human food ("Commission Regulations (EC) No 466/2001 of 8 March 2001, and No 1881/2006 of 19 December 2006") animal fodder and feed ("Decree of 05/08/2003 amending the Decree of 12/01/2001"). In addition, according to the expected log reduction provided by the different treatment steps of the pilot (filtration, UV, chlorination), we expect that all microorganisms measured at the pilot inlet (wastewater treatment plant outlet) will be eliminated from the effluent. This hypothesis will be verified during 2019 before irrigation period. In Germany, monitoring is limited to measurement of heavy metals in wastewater used for irrigation. They were in accordance with usual levels in soil (ongoing interpretation) and no organic pollutants (PAH, PCB, THM) were detected.

Conclusions

During the first year of the project, 2018, the smart fertigation tool methodology was tested in France and in Germany, under different conditions and context depending on regulation, cultivar, usual farming practices or climate. The agronomic (plant growth, soil characteristics, …) and sanitary (micropollutants, microorganisms,…) monitoring has been validated. In 2019, a panel of innovative sensors is still under testing in order to obtain the most accurate data (weather, nutrients…) to feed the model and develop the future decision support tool. The main objective for 2020 is to provide a reliable fertigation planning to farmers.

Constructed Wetlands in Italy between National and proposed EU Reuse Regulations: Viable Option for Water Reuse in Agriculture?

Stevo Lavrnić and Attilio Toscano

Alma Mater Studiorum - University of Bologna, Department of Agricultural and Food Sciences, Viale Giuseppe Fanin 44, Bologna 40127, Italy.

Abstract: Constructed wetlands are a type of nature-based solutions that have been successfully used for treatment of different kinds of wastewater. Being less costly and more environmental friendly than conventional wastewater treatment plants, they are particularly suitable for smaller communities and could represent an important tool to increase reuse of treated wastewater. However, due to the strict regulations, these systems often cannot satisfy the limits for reuse. This paper examines if introduction of the newly proposed EU regulations could change the current situation and enable wider use of constructed wetlands as a part of wastewater reuse schemes in Italy. In fact, it was found that systems considered were much more likely to reach the flexible EU than the stricter national limits for agricultural reuse.

Keywords: Constructed wetlands, Irrigation, Reuse standards, Wastewater reuse.

Introduction

Constructed wetlands (CWs) are man-made and engineered systems that are mimicking processes occurring in natural wetlands and applying them for wastewater treatment. Different studies have shown that they have smaller environmental impact and operation costs than conventional wastewater treatment plants (Nivala et al. 2012). However, Lavrnić and Mancini (2016) showed that CWs used as secondary wastewater treatment step had difficulties reaching wastewater reuse limits in Southern Europe. The goal of this study is to assess how Italian CWs fit between Italian national (DM, 2003) and newly proposed EU regulations (EC, 2018) for water reuse in agriculture.

Materials and methods

Recently (2013-2017) published studies involving the use of CWs for wastewater treatment were reviewed and effluent concentrations compared to the limits for reuse required by the Italian and proposed EU regulations. Out of 9 systems taken into

consideration, 4 of them were treating domestic wastewater, 3 were fed with an effluent coming from food industry and 2 as an influent had anaerobic digestate. Only studies that reported sufficient number of parameters important for reuse (e.g. chemical oxygen demand - COD, biological oxygen demand - BOD, total nitrogen - TN, total phosphorus - TP, total suspended solids - TSS, *E. coli*) were considered.

Results and Conclusions

Both single stage and hybrid CWs located in Italy had problems with removing organic pollution (COD and BOD) and TN load from non-domestic wastewater. Moreover, the systems that were treating domestic wastewater were in general more successful in reaching reuse limits, and the biggest problem represented *E. coli* removal. Effluent from only two systems (both single stage treating domestic wastewater) was suitable for agricultural reuse according to the Italian standards, that have already been reported to be too strict and limiting wastewater reuse practices (Cirelli et al, 2012). On the other hand, only one system's effluents was not suitable for any of the four types of agricultural reuse given by the proposed EU regulations. This fact shows the nonconformity of the two standards, but also a potential that CWs have as a part of water reuse scheme.

References

DM (Ministerial Decree) (2003) Number 185. Ministry of the Environment and Protection of Land, Italy (In Italian).

Cirelli, G.L., Consoli, S., Licciardello, F., Aiello, R., Giuffrida, F., Leonardi, C. (2012). Treated municipal wastewater reuse in vegetable production. Agricultural Water Management 104, 163–170.

European Commission (EC) (2018) Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on minimum requirements for water reuse.

Lavrnić, S. and Mancini, M.L. (2016) Can constructed wetlands treat wastewater for reuse in agriculture? Review of guidelines and examples in South Europe. Water Science and Technology 73(11), 2616-2626.

Nivala, J., Knowles, P., Dotro, G., García, J., Wallace, S. (2012) Clogging in subsurface-flow treatment wetlands: Measurement, modeling and management. Water Research 46(6): 1625-1640.

Potential of electrically driven membrane processes for water reuse applications

Londoño D., EnviroChemie GmbH, Rossdorf, Germany; Gilbert E.M, EnviroChemie GmbH, Rossdorf, Germany;

Many regions in the world are already suffering from water scarcity problems, due to the lack of sufficient water bodies or to the bad quality of the available sources. In order to avoid these problems or alleviate their consequences to the population itself and its economy, it is now more than ever necessary to implement integrated water resource management projects. The use of non-conventional salty water bodies for the supply of fresh water or the reuse of wastewater from industrial production sites either for the production itself or for other out of the factory applications represent some of the measures which can be implemented to tackle this problematic. However, the implementation of these measures requires the application of innovative water treatment technologies such as the electrically driven membrane processes. The use of these membrane processes for the maximization of the permeate yield from reverse osmosis (RO) plants and for the desalination of industrial wastewater effluents as a necessary pretreatment for reuse applications have been investigated within the research project WaReIp (Water Reuse in Industrial Parks). In this project, funded by the German Federal Ministry of Education and Research, the possibilities of closing water reuse loops inside industrial parks of the chemical and pharmaceutical industry are being currently studied.

Maximization of permeate yield from a reverse osmosis plant used for process water treatment

The first set of trials was carried out with reverse osmosis concentrates originating from the process water treatment plant of a company which regenerates used ion exchange resins. Tap water is treated with a combination of ultrafiltration and a three-stage reverse osmosis to produce desalinated water in the quality necessary for the resin regeneration. The concentrates of the reverse osmosis plant, which have an electrical conductivity of around 800 – 1,200 µS/cm, are currently being discharged to a municipal wastewater sewage system. The discharge is however linked with high costs due to the elevated salt content. In order to minimize the volume of concentrate being generated and thus the discharge costs, a treatment with two different

electrically driven membrane processes – electrodialysis (ED) and membrane capacitive deionization (MCDI) – was studied. Though both technologies are able to reduce the salt content of the RO concentrate to the value corresponding to the RO permeate, a complete desalination is connected to high energy costs as the energy applied to transport the salt ions inside an electrical field is proportional to the salt load being removed. Instead the RO concentrate was only desalinated up to the electrical conductivity value of the tap water used to feed the RO plant (approx. 200 µS/cm, see Figure). The desalinated water could then be reused as RO feed and an increase of the permeate yield parting from the same tap water quantity could be achieved. A reduction of approx. 50 % of the concentrate volume was obtained, while the energy consumption for the additional treatment step lied at about 0.8 – 2.0 kWh/m^3.

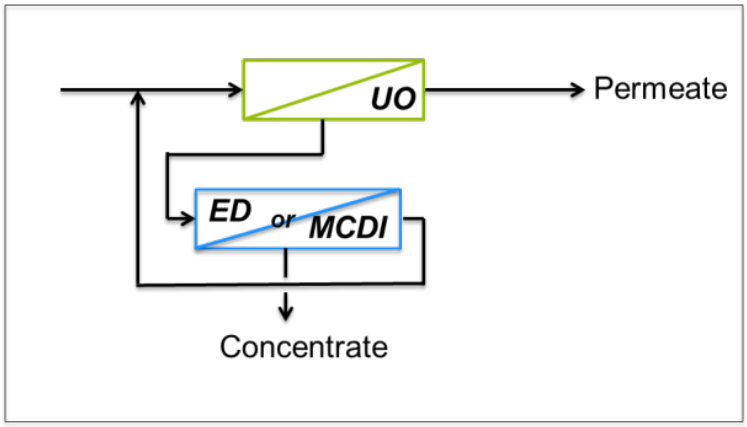


Figure: Schematic representation of the interconnection of RO and ED or MCDI modules

Desalination of industrial effluents from the chemical-pharmaceutical industry

A second set of trials was being carried out for the desalination of a wastewater effluent coming from the production of chemical-pharmaceutical products. This wastewater has a high salt content (10 – 12 mS/cm) and a relatively low organic load (100 mg/l), which makes its treatment with typical wastewater technologies quite challenging. This stream is currently being treated at a centralized biological industrial wastewater treatment plant. However, after desalination with ED or MCDI, this water has a water quality which allows its reuse inside the industrial site. Through a carefully aimed desalination grade, taking into account the water quantity and quality required for water reuse, it is possible to close water loops inside industrial sites and thus reduce their water footprint.

Reuse of Municipal Wastewater for Different Purposes Based on a Modular Treatment Concept

Barbara Zimmermann, Andreas Nahrstedt, Anja Rohn, Anil Gaba, IWW Zentrum Wasser, Mülheim an der Ruhr, Germany; Kerstin Krömer, Yannick Tiemann, OOWV Oldenburgisch-Ostfriesischer Wasserverband, Brake, Germany; Christina Starke, Patrick Buchta, inge GmbH, Greifenberg, Germany; Jens Lipnizki, Ulrich Dölchow, LANXESS Deutschland GmbH, Köln, Germany; Katharina Mende, De.EnCon GmbH, Oldenburg, Germany; a.nahrstedt@iww-online.de

Abstract:

Treated wastewater like the tertiary effluent of the municipal WWTP in Nordenham is an important part of the water cycle. It is usually fed into the river Weser. The main aim of the MULTI-ReUse project is the development, demonstration and evaluation of a modular water treatment system, in order to offer service water in different qualities and quantities for the different purposes and to competitive prices. During the first phase of the project stable processes could be established leading to 3 different water qualities with the highest grade for industrial purposes.

Keywords: Water Reuse; Municipal Waste Water; Tertiary Effluent; Ultrafiltration; Reverse Osmosis; Granular Activated Carbon

Introduction

Mainly caused by geological and meteorological reasons, in some German regions groundwater and river water resources are limited. Several driving forces like climate change (particular during summer 2018) or the economic development of cities with a growing number of inhabitants and rising industrial sites increasing the imbalance of water need and water resources. In this case several parties like households, agriculture or industrial sectors are competing water consumers, very often with different specific expectations or requirements for the water quality. The MULTI-ReUse project (Modular Water Treatment and Monitoring for Wastewater Reuse, 2016-2019) started to develop solutions for such a typical conflict, exemplarily for the city Nordenham, which is located between the mouths of two rivers, both affected by the salty water at the North Sea coast. Here, the water company *Oldenburgisch-*

Ostfriesischer Wasserverband (*OOWV*) ensures water supply for municipal and industrial customers, but their more intense use of groundwater is restricted by salt water intrusion into the aquifer. On the other hand, day by day a high flux of tertiary effluent from the Nordenham wastewater treatment plant (WWT) is discharged directly into the river Weser, whereas treated wastewater is expected to become an even more important part as additional water resource (Krömer et al. 2019).

Material and Methods

The German research project MULTI-ReUse installed a pilot plant with modular designed sequences of three treatment processes to recycle tertiary treated wastewater (COD: 27-59 mg/L; DOC: 7.9-14 mg/L; SAC_{254}: 21-47.7 m^{-1}; TSS: 5-12 mg/L; pH: 6.0-7.0; conduct.: 726-2,300 µS/cm; NH4-N: 3.0-8.4 mg/L; P_{total}: 0.2-0.7 mg/L) for industrial and agricultural purposes, groundwater recharge and municipal water need, as shown in Fig. 1.

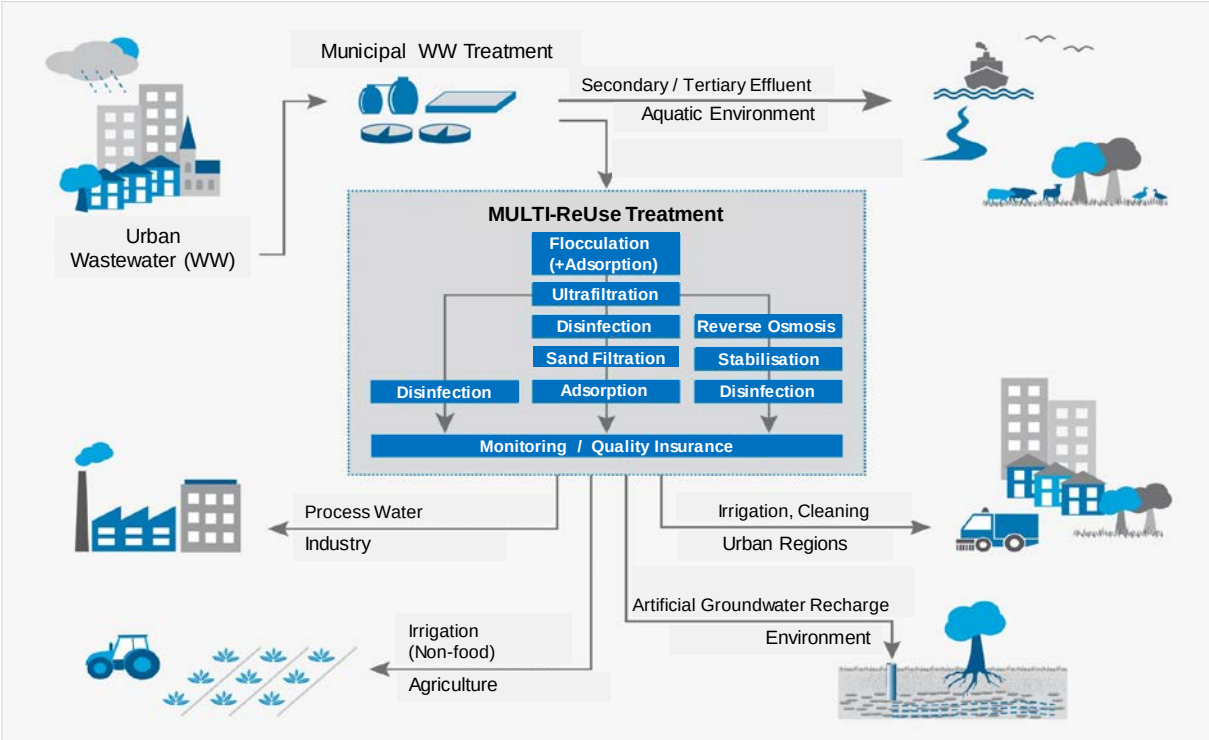


Figure 1: Modular design of MULTI-ReUse treatment to achieve different water qualities for different purposes (classified into 4 categories).

Sequence 1: sieve filtration, powdered activated carbon adsorption (optional), flocculation, ultrafiltration (UF) and UV disinfection

Sequence 2: sieve filtration, flocculation, UF, UV disinfection, sand filtration and granular activated carbon filtration

Sequence 3: sieve filtration,powdered activated carbon adsorption (optional) and with two lines: flocculation, UF, chemical disinfection, RO, UV disinfection

For the protection of the UF modules a 150 µm screen filter was used with a Δp and Δt controlled backwash. To achieve UF hybrid processes for PO_4-P and DOC removal and to reach a higher backwash efficiency $FeCl_3$ (Fe dosage 5-10 mg/L) or polyaluminium chloride (PAC, Al-dosage 2-3 mg/L) were dosed (pH after flocc.: 6.8-7.1; temp.: 8-25 °C; flocc. time: 40 s). Powdered activated carbon (5-15 mg/L) was optionally dosed into the UF feed (in sequences 1 and 3) for the removal of organic micropollutants. Two UF modules (dizzer XL 0.9 MB 80 WT, INGE; PES, Multibore®, inner capillar diam.: 0.9 mm; pore size: 0.02 µm; membrane area: 80 m²; CIP cycle: 6 month; see Fig. 2) have been used with a flux of 60-70 L/(m²·h), 30 min filtration time and a recovery of 89 % leading to a transmembrane pressure (TMP) in the range between 400-900 mbar with the use of the flocculant $FeCl_3$ and between 200-500 mbar with PACl. A chemical enhanced backwash (CEB) is performed with filtrate once or twice a day (acidic: H_2SO_4 at pH 1.9; alkaline: NaOH at pH 12). The last step in sequence 1 is a UV disinfection (turbidity not detectable; SAC_{254}: 11-32 m^{-1}).

Figure 2: Pilot plant with UF (left), RO (middle), quartz sand filters and granular activated carbon (GAC) filters (right).

In sequence 2 deep bed filters (quartz sand, d_{grain} = 1-2 mm; total bed height: 2 m; filtration rate 5.5 m/h; backwash cycle once in 2 or 3 weeks; see Fig. 2) follows the UV radiation for bio-catalytic removal of solute manganese (Mn^{2+}: 0.01-0.5 mg/L). In the last step, organic micropollutants as well as parts of the DOC adsorb in granular

activated carbon filters (Hydraffin AR, 8x30 mesh, Donau Carbon; total bed height: 2 m; total empty bed contact time: 20 min; backwash cycle 2-3 weeks; see Fig. 2). Both filtration steps are also important for the biological degradation of BDOC and the growth of autochthonic bacteria (microbiol. stabilization of the produced water).

In sequence 3 sodium hypochlorite and ammonia chloride was periodically added into the filtrate of UF of line 1 to build monochloramine (2 mg/L) followed by anti-scalant dosage (3.7 mg/L). Fabric cartridge filters were chosen to protect the feed of 2 parallel 4" RO modules (parallel comparison of different module types: Lewabrane B085 ULP 4040 vs. B085 FR 4040 vs. B085 LE 4040, LANXESS; flux: 20 L/(m²·h); concentrate recycling into feed for a recovery of 75 %; TMP with preliminary fabric filter 7-14 bar; CIP cycle: 2-3 month; see Fig. 2). Sequence 3 ends with a redundant UV disinfection.

Results and Discussion

Between August 2017 and December 2018 the project focused the start and optimization of single treatment modules and their combination. Since January 2019 the demo Process is running. During this complete period, the UF ensures a sterile filtrate, which means that it is free of *E.coli*, coliform bacteria, intestinal enterococci and *C. perfringens* (< 1 MPN/100 mL or < 1 CFU/100 mL). With feed concentrations e. g. for intestinal enterococci up to $2.2 \cdot 10^6$ CFU/100 mL the UF achieves a log removal value LRV > 10^6 for bacteria. Consequently none of these bacteria were detected in the filtrate of the sand- or GAC-filter as well as in in the permeate of both RO modules, which emphasizes the integrity of the UF and the latter ones. Caused by precipitation effects during flocculation with FeCl3 the mean DOC and P_{total} concentration in the UF filtrate were 8.6 mg/L (25-30 % removal) and 0.08 mg/L, respectively. In sequence 3, the permeate of the RO (ULP module) leads to a remaining DOC concentration of 0.1 mg/L (detection limit) or less and to a conductivity of 15-30 µS/cm (salt passage ULP module: 1.2-1.7 %; LE module: 2.9-4.4 %). The ULP module also offers a very good rejection for a wide spectrum of organic micropollutants (95 until > 99.9 %, see Fig. 3) except for the corrosion inhibitor 1-H-Benzo-triazole (59 %) and its metabolites.

The DOC concentration after GAC-filtration was dependent on the treated bed volumina (BVT, i.e. the ratio volume filtrate/volume GAC bed), starting from 5.5 mg/L

at the beginning and dropping continuously down to 9.9 mg/l after 15,000 BVT caused by the GAC load with adsorbed organics. In the same matter the retention efficiencies for organic micropollutants decreased. In Fig. 3 the GAC removal efficiency after 6.700 BVT (runtime of 4 month) is plotted in comparison to the results for the RO (ULP module). For two micropollutants (EDTA, Ampa) a release of the previously adsorbed mass have been measured. Iomeprol and acesulfame are removed in a range of 60-70 % and all other compounds between 80 % and more than 99.9 %.

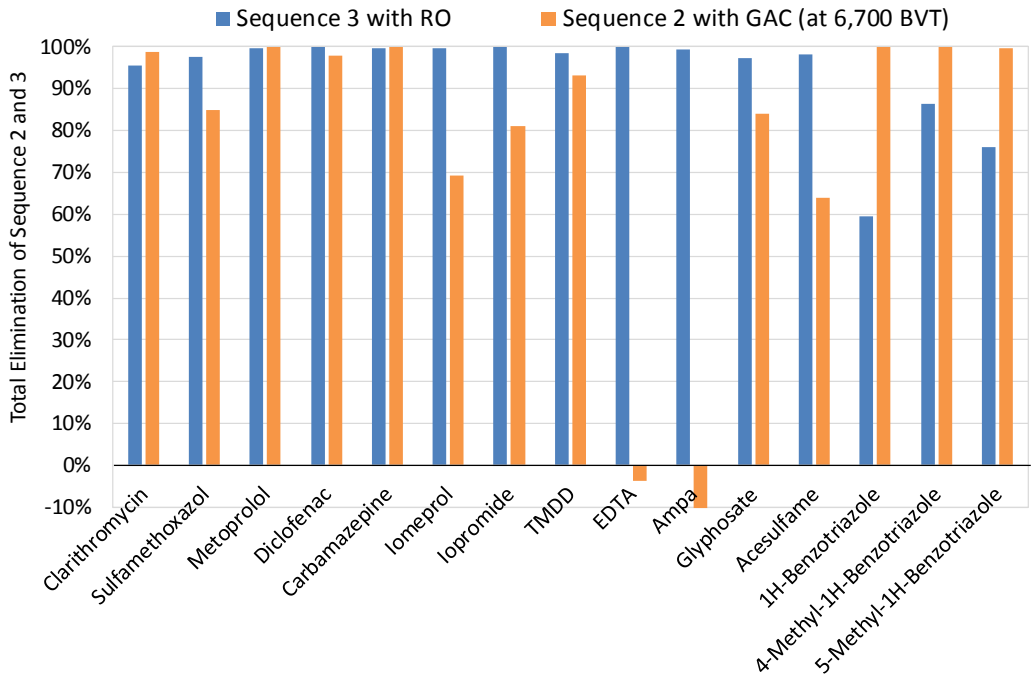


Figure 3: Total removal efficiency for sequence 3 (with RO) in comparison to sequence 2 (with GAC filter at 6.700 bed volumes treated, BVT).

With a flux of 60 L/(m²·h), a dosage of $FeCl_3$ (7.5 mg Fe/L) and CEB procedures once or twice a day a stable UF process could be established with TMP profiles in a range between 400-900 mbar and a normalized (@20°C) permeability between 100 and 150 L/(m²·h·bar) (see Fig.4).

The periodical cleaning in place (CIP) procedures (intervals of 2 or 3 months) for the RO modules reduce the TMP from 14 bar back to 7 bar successfully. The preliminary cartridge filters are replaced monthly.

Conclusions

The current established modular processes ensure safe and reliable water qualities for three different purposes. Further optimization has to focus on

- the short CIP intervals for the RO with downtimes of 24 h (particular during the summertime with microbiological fouling), because they are causing a redundant and therefore expensive design of the membrane area.
- microbiological and chemical (corrosion) stability of the RO permeate during a transport to industrial clients.

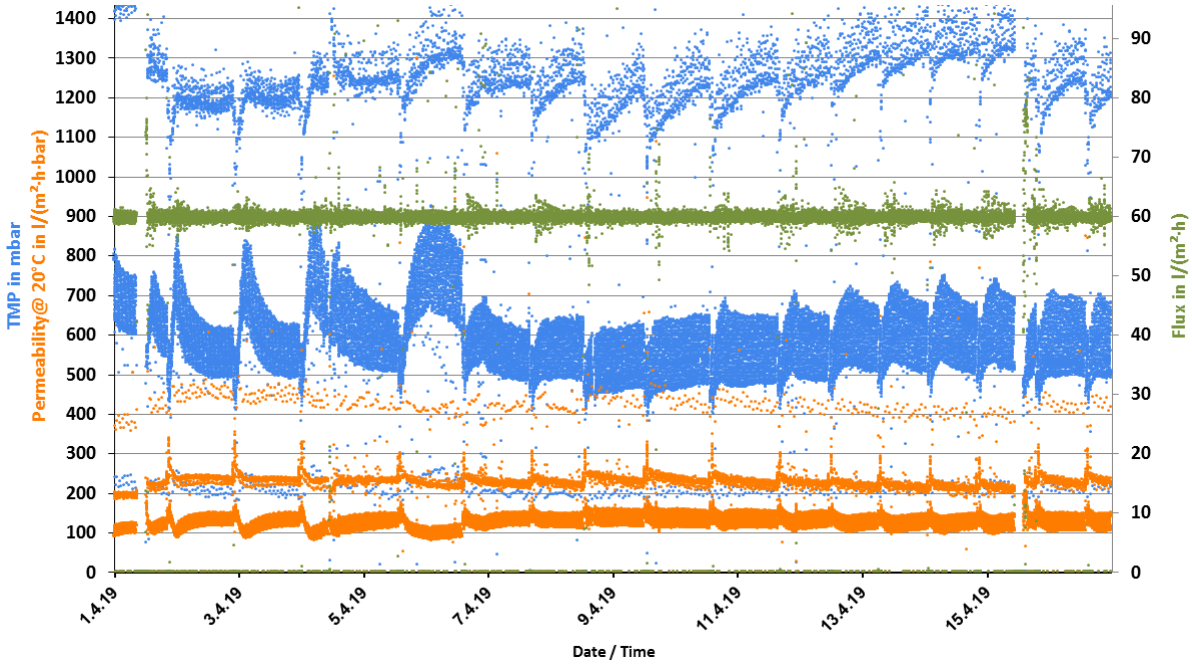


Figure 4: Process data for the UF in line 1 (flocculation with $FeCl_3$).

Acknowledgements

The project MULTI-ReUse has received funding from the German Federal Ministry of Education and Research as part of the funding measure “Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (**WavE**)”, *https://water-multi-reuse.org/en/*.

References

Krömer, K.; Tiemann, Y.; Zimmermann, B.; Rohn, A. Gaba, A.; Nahrstedt, A. (2019): MULTI-ReUse: Wasserwiederverwendung in den Sektoren Industrie, Landwirtschaft, Siedlungswasserwirtschaft und Grundwasseranreicherung. Korrespondenz Wasser-Abwasser. Submission April 2019.

Drewes, J.E.; Becker, D.; Jungfer, C.; Krömer, K.; Mohr, M.; Nahrstedt, A.; Schramm, E.; Winker, M.; Zimmermann M. (2018): Mindestanforderungen an eine Wasserwiederverwendung: Hinweise aus Sicht der WavE-Forschungsprojekte des Bundesministeriums für Bildung und Forschung (BMBF). gwf-Wasser | Abwasser No. 12, 50-59

Aquifer storage and recovery (ASR) to enable water reuse across sectors: wastewater from food industry turned into irrigation water for greenhouses

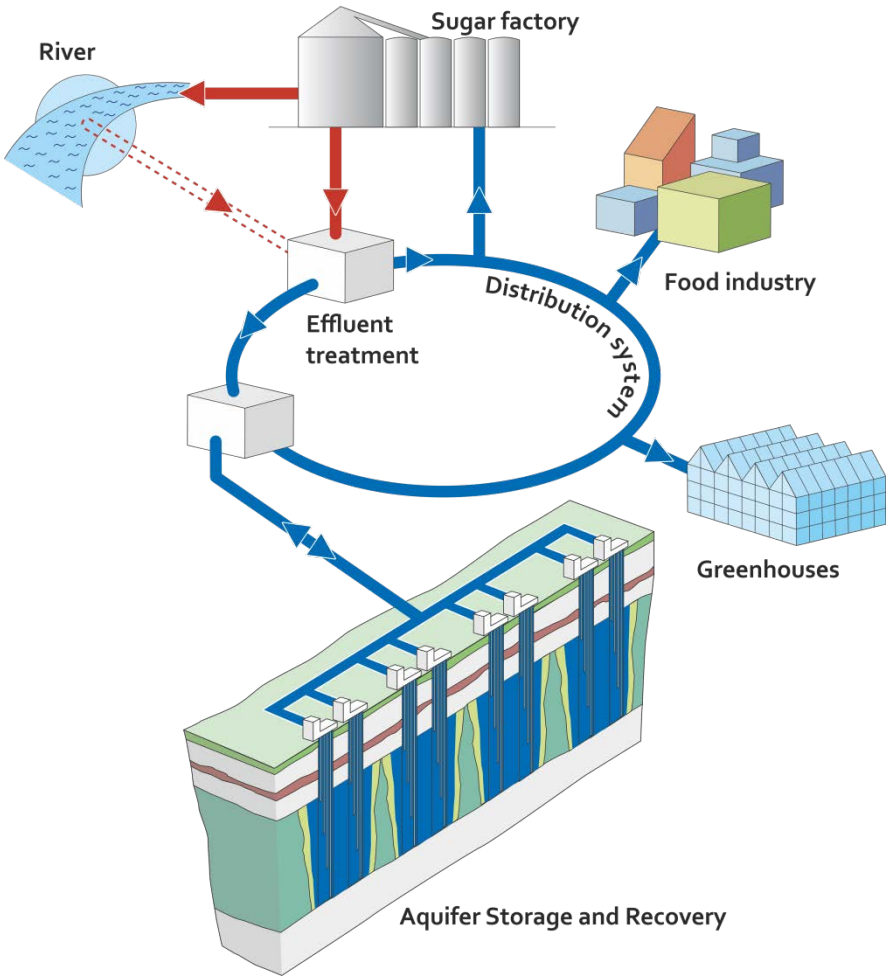
Klaasjan J. Raat, KWR Watercycle Research Institute, Nieuwegein, the Netherlands; Koen G. Zuurbier, Allied Waters, Nieuwegein, the Netherlands; Piet Janmaat, Tuinbouwontwikkelingsmaatschappij,'s Hertogenbosch, the Netherlands; Gerard A. van den Berg, KWR Watercycle Research Institute, Nieuwegein, the Netherlands

The continuous availability of freshwater of very good and reliable quality is a precondition for modern intensive greenhouse horticulture. For Dinteloord, the Netherlands, a 260 hectares greenhouse area under development, the freshwater availability was not self-evident. Although the water needs are largely satisfied through the collection of rainwater and its storage in surface basins, serious shortages arise during drought periods.

To guarantee the supply of irrigation water at all times, an advanced sustainable freshwater supply was realized. Effluent from the neighboring sugar factory is converted into large volumes of high-quality irrigation water in 3 treatment steps: rapid sand filtration, ultra-filtration, reverse osmosis. Aquifer storage and recovery (ASR) is applied to balance the availability of this reuse water in Autumn and Winter with the demand for additional irrigation water by the local farmers in Spring and Summer.

The ASR system has been in full operation since February 2018 and provides local farmers with 300.000 m^3 of freshwater per year, in addition to the rainwater that is already harvested and stored in aboveground basins. This additional freshwater is stored underground using eight ASR wells. The sugar factory, farmers and the ASR system are connected by a 5km distribution loop, guaranteeing a maximum supply of 200m^3 of fresh irrigation water per hour during dry spells. Consequently, farmers enjoy a year-round supply of sufficient high-quality irrigation water, without the need for a heavy load on the already minimal above-ground space. As well as delivering irrigation water to farmers, water is also re-distributed to the sugar factory and to nearby food processing industries.

The system is an example of hybrid grey and green infrastructure, demonstrating how the underground can contribute to water reuse in the circular economy: farmers grow their tomatoes and egg plants on reuse water from sugar beets. The system is collectively owned by the greenhouse farmers and costs are covered by a pay-per-use system.



Use of salty groundwater for toilet flushing to substitute drinking water – water and microbial quality

H.-J. Albrechtsen[1]; C.O. Lee[1]; B. Godskesen[1]; M. Vester[2]; H. Hoffmann[2]; M. Rygaard[1]; C. Jørgensen[3]*

[1]Technical University of Denmark (DTU), Kgs. Lyngby, Denmark; [2]HOFOR (Greater Copenhagen Utility), København, Denmark; [3]DHI, Hørsholm, Denmark

**hana@env.dtu.dk*

Background

A substantial part of the water used in householdings is used for toilet flushing, and this may not require drinking water quality. In this project, we have in full scale investigated abstraction of groundwater on the premises for this purpose. Since the groundwater at the specific location is not suited for use and distribution, it was treated and distributed in a separate distribution system to the toilets. The investigation was carried out in a newly (2017) built block of apartments with 95 apartments, at Nordhavn in Copenhagen, Denmark.

Application of any other water source than drinking water is raising a number of questions, and the aim of this investigation was to investigate which quality the water treatment has to reach? Is the wanted quality achieved and sufficient? Which microbial water quality is needed? – and is the toilet flushing with the applied water quality safe?

Water quality

The investigated block of apartments is located next to a harbour. The groundwater was selected as source since it was expected to be a mix of fresh groundwater and intruding salt water from the harbour. However, the abstracted groundwater was very salty and hard, besides it was anaerobic and contained dissolved iron. Subsequently, the water was treated by aeration and sandfiltration, and the water quality was monitored in the effluent from the treatment system during the first year of production.

Microbial quality

The microbial water quality was investigated in the effluent from the treatment system, in samples collected from toilet bowls and in samples collected from the toilet

bowl during flushing, representing water, which has been stored in the distribution system and the cistern. Samples were collected from the system when it initially was supplied with drinking water, and after the production and distribution of the treated salty groundwater was initiated.
The samples were investigated for ATP and heterotrophic plate counts (HPC) at 22°C and 37°C, using PCA or R2A media, as well as the indicator organisms *E. coli* and coliform and *Pseudomonas* and *Aeromonas*.

The number of general bacteria increased to some degree by flushing toilets with salty groundwater compared to flushing with drinking water - especially during stagnation in *e.g.* apartments not in use. However, no annoyances were registered in terms of coloured water, stained toilets or smell.
Neither *Aeromonas*, *Pseudomonas*, *E. coli* nor coliforms were detected in raw water, or in treated water, and *Pseudomonas* was only detected in a sample from a toilet bowl supplied with drinking water. The occurrence of these potential pathogens or indicator organisms was associated to the use of toilets and subsequently to the users. The occurrence and concentration of these bacteria decreased during stagnation since their survival in general is limited in time.

The overall conclusion was that none of the investigated parameters indicated health of aesthetic annoyances by flushing toilets with the abstracted, treated salty groundwater.

References

Albrechtsen, H-J. (2002). Microbiological investigations of rainwater and graywater collected for toilet flushing. *Water Science and Technology*, *46*(6-7), p. 311-316.

Albrechtsen, H-J. (1998). Water consumption in residences. Microbiological investigations of rain and graywater reuse systems, in Danish, 107 p. Report. By- og Boligministeriet and Miljøstyrelsen. ISBN 87-985613-9-1.

Upscaling of Innovative PBM Coating for Polyether Sulfone Membranes within the VicInAqua Pilot Project

E. Gukelberger[a], F. Galiano[b], K. Hoevenaars[c], J.A. Mamo[c], R. Mancuso[a], S.A. Schmidt[d], B. Gabriele[a], J. Hoinkis[d], A. Figoli[c]*

[a]Dep. of Chemistry and Chem. Techn., University of Calabria, Rende (CS), Italy

[b]Institute on Membrane Technology, Rende (CS), Italy

[c]AquaBioTech Group, Mosta, Malta

[d]Karlsruhe University of Applied Sciences, Karlsruhe, Germany;

ephraim.gukelberger@hs-karlsruhe.de

Abstract

This work presents the novel use of a MBR through the coupling with a Recirculation Aquaculture System at the Lake Victoria in Kisumu, Kenya. Thereby, raw domestic wastewater is treated for water reclamation in a hatchery to primarily grow Tilapia fingerlings. Up to 25.000 fingerlings per month can be sold to local farmers around the region for the outgrowth in farming cages and ponds. The concept feasibility has been confirmed by gradually topping off the aquaculture with MBR permeate. In order to reduce fouling of the commercial Polyether sulfone (PES) membranes, an innovative polymerisable bicontinuous microemulsion (PBM) coating was tested. In the current configuration, the PBM membrane showed higher specific pressure increases during the flux step method up to 50 LMH. Initial testing was carried out at low wastewater pollution levels.

Keywords: MBR, RAS, Anti-fouling coating, Sustainability, Lake Victoria

Introduction

An entirely new approach for decentralized membrane bioreactor (MBR) application was realized by coupling an MBR and a recirculation aquaculture system (RAS) within the „Integrated aquaculture based on sustainable water recirculation system for the Victoria Lake Basin" project (VicInAqua, 2016). The project in Kisumu, Kenya, demonstrates how fish can be cultivated on-shore without any fresh water consumption. In this way, the issue of direct wastewater discharge into the Lake Victoria and the increasingly critical depletion of fish stocks is aspired. In long-term, a sustainable strengthening of the local and national economy (Kenya, Uganda, Tanzania) is being sought by establishing similar concepts to the pilot plant (Figure 1).

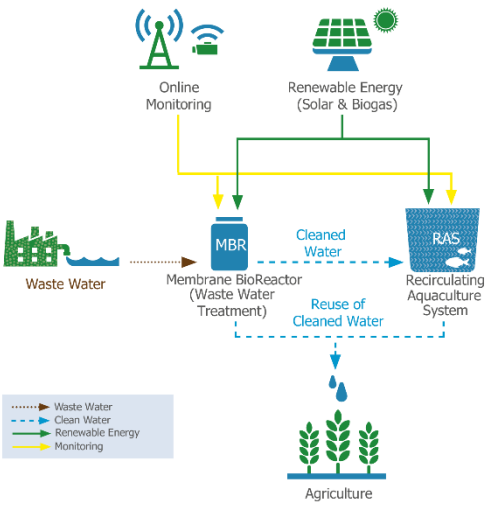


Figure 1: VicInAqua pilot plant in Kisumu, Kenya, schematic layout

As part of this project, an innovative attempt for improving fouling propensity of the MBR is being investigated. Membrane fouling mitigation of commercial Polyethersulfone (PES) membranes was addressed by polymerisable bicontinuous microemulsion (PBM) coatings (Galiano, 2018). The Institute on Membrane Technology (Italy), University of Callabria (Italy) and the University Karlsruhe of Applied Sciences (Germany) incorporated the self-developed and synthesized anti-microbial surfactant acryloyloxyundecyltriethylammonium bromide (AUTEAB) into the final coating layer. Previous work of Deowan et al. (2016) showed promising anti-fouling properties using REDOX based polymerisation. This work addressed the preparation of environmental friendly UV-LED induced polymerisation applied onto one membrane module (3 m^2) and installed in the pilot MBR.

Materials and Methods

Within this work, the self-developed and synthesized anti-microbial surfactant AUTEAB (Figoli, 2014) is incorporated into a microemulsion with the co-surfactant HEMA, which improves the hydrophilic behaviour by its hydroxyl group (-OH). In combination with the cross-linker EGDMA, the polymerisable bicontinuous microemulsion (PBM) is formed. The final PBM is a thermodynamically stable system composed as transparent solution. The photo-initiator Irgacure 184 was induced by UV-LED light at a wave-length of 365-410 nm to start the polymerization reaction. Curing lasted 60 seconds per coating at an irradiation intensity of 300 mW/cm^2 (Galiano, 2018). To achieve even coatings for larger membrane areas, an automated casting coating machine was designed (Figure 2, left). The integration of a temperature control unit, coating speed control using pulse-width-modulation (PWM)

and humidity measurements increased the reproducibility. Following various performance characterisations, 34 commercial PES membrane sheets were coated using the best operating settings and ultimately laminated to a final membrane module of 3 m^2 membrane area (Figure 2, center to right; Martin Systems, 2019).

Figure 2: Automated coating machine (left), laminated membrane sheets (center) and implemented double membrane module (right)

The MBR (Figure 3, left) pilot with an upfront denitrification tank is composed of two separate membrane modules with identical permeate pumps and sensors for transmembrane pressure (TMP) and volume flow measurements. The parallel implementation makes a head-to-head comparison of both membrane modules possible, facilitating an evaluation of the PBM coated module with the commercial module as benchmark. The permeate produced is fed into the recirculation aquaculture system (Figure 3, center) which is constructed as a closed recirculation system, being able to reuse 90-95% of the water volume. Water losses through evaporation and back flushing are compensated by the MBR permeate of 3-4 m^3 daily. Designed for breeding 25.000 Tilapia fingerlings, the system can be simply adapted to nile perch, mudfish or catfish production.

Figure 3: MBR (left), RAS (center) and VicInAqua pilot plant (right) located in Kisumu, Kenya

Membrane performance was studied by flux step tests starting at 5 LMH for both membrane modules, gradually increasing the flux above the critical flux of the PES membrane up to 50 LMH. Each gradual increment consisted of two permeation and two relaxation cycles of 12 min and 3 min, respectively. Finally, flux step tests were reproduced once after an In-Situ cleaning using sodium hypochlorite (NaOCl),

sodium hydroxide (NaOH) and citric acid. Mixed Liquor Suspended Solids (MLSS) was around 6 g/L. Transmembrane pressure values were recorded and compared.

RAS and MBR coupling was done by slowly increasing the MBR permeate amount in an insulated RAS system with Tilapia at different growth states. Subsequently, observation of fish behavior together with ammonia/ammonium sampling was done continuously. In addition, a governmental Kenyan laboratory officially tested MBR effluent quality on reuse in aquaculture and for irrigation purposes

Results and Discussion

A domestic wastewater which is being treated and reused in the RAS (MBR feed, Table 1) was studied. The most critical value for fish farming is the ammonium (NH_4^+) as it cuts off the oxygen supply of the gills above 0.5 mg/L when converted into the highly toxic ammonia (NH_3). Before reaching the MBR as feed, the raw sewage passes through 3 filters with different mesh size (2.5, 1 and 0.8 mm) and is temporary stored in an intake buffer tank, also serving as short-time settling basin.

Table 1: Water analysis of wastewater treatment system using permeate as RAS water

Parameter	Unit	Raw sewage*	MBR feed*	*Permeate**
pH	pH scale	7.6	7.4	7.7
Conductivity	µS/cm	1133.3	1034.0	828.5
COD*	mg/L	683.3	550.5	55.5
TOC	mg/L	98.4	99	11.1
$N – NH_4^+$	mg/L	61.9	55.2	0.3
$N – NO_3^-$	mg/L	1.5	1.1	6.3
$P – PO_4^{3-}$	mg/L	12.5	10.3	4.6

*filtered, 0.45 µm filter sieve

The PBM coating shows lower permeability than the PES membrane since it represents an additional resistance layer. It is striking that the permeability for both membranes increased after the two cleaning procedures as indicated in Figure 4, on the left hand side. The time-dependent pressure loss (Figure 4, right) during the flux step method was calculated by the initial transmembrane pressure of one specific flux-increment and the final pressure at the end of the flux-increment by the equation $\frac{dTMP}{dt} = \frac{dTMP_n - dTMP_{n-1}}{dt}$. Throughout the entire flux step test, the PBM could not achieve competitive performance. However, long-term pilot trials have to be conducted and the PBM coating may show its potential only at higher strength wastewater with greater fouling propensity, as also shown during previous tests when treating wastewater for textile industries (Deowan, 2016).

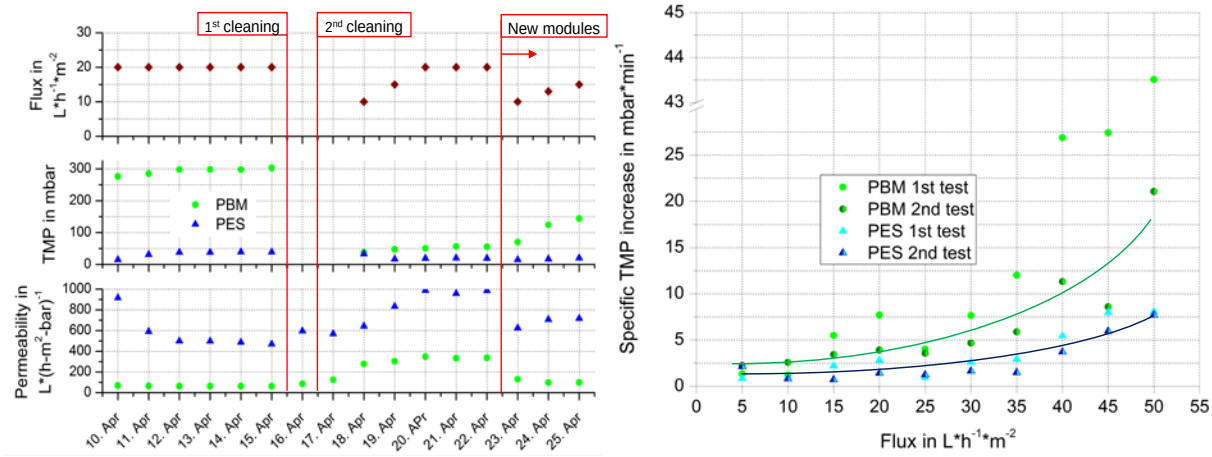


Figure 4: Critical flux determination by incremental flux-step function and pressure loss evaluation

To validate the project's concept, initially, clean water of a 7 m^3 RAS system containing Tilapia broodstock and larvae was slowly exchanged by MBR permeate so the fish could slowly adapt to the new environment. As Figure 5 depicts, the share of MBR water was increased up to 100% within 16 days. The fish showed no signs of physical impairment and the ammonia/ ammonium values remained constant below the legal limit of 0.5 mg/L throughout the test period.

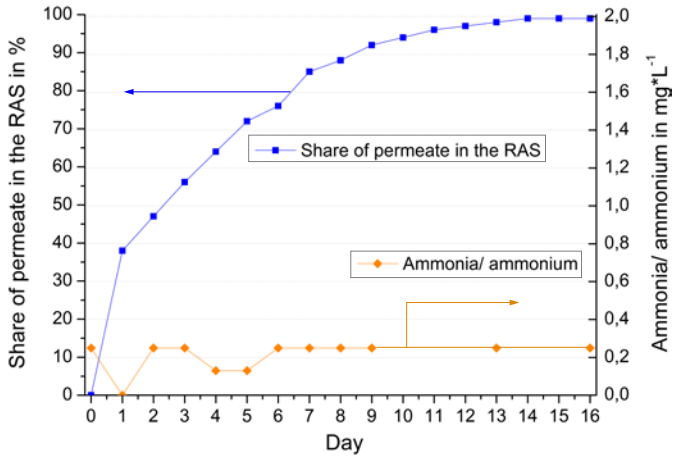


Figure 5: Increasing share of MBR permeate of the insulated RAS

Conclusion

This work showed the first upscaling of PBM membrane coatings polymerised by UV-LED light. A 3 m^2 membrane module was tested in comparison with a commercial PES module by applying stress tests through the flux step method up to 50 LMH. In conclusion, the specific pressure increase for the PBM membrane was consistently higher than for the PES membrane. However, it is expected that the PBM coating achieves better performance at higher water pollution levels with more fouling propensity. Moreover, the water permeability for the PBM and PES module increased

after two cleaning cycles. Hence, the question arose if dilated pores were caused by the high applied flux rates. Currently, a second PBM membrane module is being tested at a constant 20 LMH flux rate to further investigate potential washing off the PBM coating from the PES structure. Sprayed PBM coating layers could possibly increase flow rate compared to the here applied casting coating technique as previous lab tests already confirmed. Finally, it is pointed out that the concept of coupling an MBR with an aquaculture system was successfully tested within a first 16 days trial run in an insulated 7 m^3 system and is currently extended to a 40 m^3 RAS.

Acknowledgement

The work performed has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 689427 for the project VicInAqua.

References

Deowan S.A., Galiano F., Hoinkis J., Johnson D., Altinkaya S.A., Gabriele B., Hilal N., Drioli E., Figoli A. (2016). Novel low-fouling membrane bioreactor (MBR) for industrial wastewater treatment. In: Journal of Membrane Science, Vol- 510, pp. 523-532, Elsevier

Figoli A., Hoinkis J., Gabriele B., DeLuca G., Galiano F., Deowan S.A (2014). Bicontinuous Microemulsion Polymerised Coating for Water Treatment. Patent Application PCT/EP2014/070603. WO2014/EP070603

Galiano F., Schmidt S., Ye X., Kumar R., Mancuso R., Curcio E., Gabriele B., Hoinkis J., Figoli A. (2018). UV-LED induced bicontinuous microemulsions polymerisation for surface modification of commercial membranes – Enhancing the antifouling properties. In: Separation and Purification Technology, Vol. 194, pp. 149-460, Elsevier

MARTIN Systems GmbH, Friedrichstr. 95, 10117 Berlin

VicInAqua (2016) *Sustainable, innovative solution for water sanitation, clean water, Lake Victoria - VicInAqua*. Available at: http://www.vicinaqua.eu/ (Accessed: 24 September 2017), Germany.

The status of de facto potable reuse – A national reconnaissance of Germany

S. Karakurt, L. Schmid, U. Hübner, J.E. Drewes

Chair of Urban Water Systems Engineering, Technical University of Munich, Am Coulombwall 3, 85748 Garching, Germany; sema.karakurt@tum.de

Abstract

The contributions of wastewater treatment plant (WWTP) effluent discharges in surface water can become relevant for downstream drinking water supply via bank filtration, if health-based monitoring trigger levels (MTL) of wastewater-derived chemicals are exceeded in bank-filtered water. This study represents the first national reconnaissance quantifying WWTP effluent contributions under low and average discharge conditions in German rivers based on an automated assessment using ArcGIS as well as its consequences on indirect usage as drinking water source. In urban areas with sparse natural discharge, WWTP effluent contributions of more than 30-50% were determined under low flow conditions. By applying a conceptual model, critical bank filtrate shares were estimated resulting in MTL exceedances for health-relevant chemicals.

Keywords: bank filtration; *de facto* reuse; drinking water supply; health relevant trace organic chemicals; potable water reuse; surface water augmentation

Introduction

In many countries worldwide, drinking water supply heavily relies on indirect use of surface water via induced bank filtration (IBF) and aquifer recharge (AR). Especially in highly populated areas and where substantial natural base discharge is lacking, microbiological and chemical quality of surface water can be substantially affected by contributions from various point and non-point sources (e.g., WWTP effluents, agricultural drainages) (Bradley et al., 2016; Glassmeyer et al., 2005; Hass et al., 2012; Reemtsma et al., 2016). Considering more frequent or extended low-flow conditions in streams due to climate change impacts, this situation will likely become more prevalent in the future in many regions worldwide.

Occurrence of WWTP effluent in a stream that is subsequently used for drinking water abstraction has been previously referred to as *de facto* potable water reuse (NRC, 2012; Rice and Westerhoff, 2015). High WWTP effluent contributions in streams,

which are used as a source of drinking water supply, have been documented nationwide in the USA and in a few regional scale studies by simple flow balances (Mujeriego et al., 2017; Rice and Westerhoff, 2015; Wang et al., 2017). So far, these studies did not consider the removal efficacy of drinking water treatment or naturally occurring attenuation processes during IBF and AR, both reducing the consumer exposure to contaminants. Assessing the degree of impact of WWTP effluents on drinking water quality is not trivial since it requires an understanding of stream flow dynamics, attenuation processes in the subsurface, and contributions of augmented groundwater in a drinking water production well. This comprehensive study is the first to quantify nationwide the relative contribution of WWTP effluents to streams under varying discharge conditions and to provide a conceptual impact assessment of *de facto* reuse for downstream drinking water abstraction via bank filtration or aquifer recharge.

Material and Methods

Long-term mean annual discharge (MAD) and mean minimum annual discharge (MMAD) from gauging stations at rivers in Germany and relevant streams in neighboring countries were gathered. The spatial and operational data for more than 7,700 WWTPs (i.e., location of the WWTP, point and amount of discharge, capacity and level of treatment) and stream gauging station runoff data of the German national river network were incorporated into an ArcGIS data model in collaboration with DHI WASY.

The WWTP effluents upstream of a river segment were cumulated and assigned to the following gauging station. The percentage of WWTP effluent contribution at each individual gauging station ($WW_{effluent}$ [%]) was than determined for MAD and MMAD conditions by calculating the ratio of the total discharge rate of upstream WWTPs ($\sum Q_{WW\ effluent}$) and the discharge data at the respective gauging station ($Q_{gauging\ station}$) using equation 1, which was coded into GIS using Python scripts. For rivers with more than two gauging stations, the MAD or MMAD along a river were first determined by linear interpolation, and the relative WWTP effluent contributions were subsequently calculated for these fictitious gauging stations with varying discharge conditions by the automated assessment as described. Due to lack of data, direct discharge of industrial WWTPs, agricultural drainage, and combined sewer and stormwater overflows were

not included into this assessment. In addition, complete mixing at the point of discharge of WWTP effluent into the receiving river was assumed.

$$WW_{effluent}\,[\%] = \frac{\sum Q_{\,WW\,effluent}}{Q_{\,gauging\,station}} \cdot 100\% \qquad [1]$$

There are no uniform databases of the origin and quality of raw water of individual waterworks available in Germany. For this reason, instead of a nationwide impact assessment, a conceptual approach estimating the relevance of elevated WWTP effluent contributions in rivers, coupled with the percent bank filtrate in raw water was developed. Conservative health relevant wastewater-derived chemicals, present at elevated concentrations in wastewater effluents and exhibiting persistent behavior under aerobic-anoxic conditions, were considered as indicator chemicals (Dickenson et al., 2011; Funke et al., 2015). Pathogenic risks were not considered in this study since German waterworks commonly apply IBF or AR with hydraulic retention times > 50 days, which can be considered an effective barrier for pathogens. For WWTP effluent contribution scenarios ranging from 0-100%, critical bank filtrate contributions ($\%\,BF_{critical}$) in drinking water wells (i.e. raw water) were determined where monitoring trigger levels (MTLs) of indicator chemicals ($MTL_{indicator\,chemical}$) in raw water could be exceeded applying equation 2. If advanced treatment processes are employed subsequent to the conventional treatment processes (i.e., ozonation, activated carbon filtration), these processes might provide additional barriers to health-relevant chemicals and therefore additional margins of safety.

$$\text{Min.}\,\%\,BF_{critical} = \frac{MTL_{indicator\,chemical}}{\%\,WW_{effluent} * C_{WW\,effluent\,indicator}} * 100\% \qquad [2]$$

Results and Discussion

Based on the results of this study, the contributions from WWTP effluents during MAD conditions vary only between 0-5% for more than 50% of the gauging stations of individual river basins nationwide except for the Neckar river basin, where more than 90% of the gauging stations exceeded 5% wastewater contributions also at MAD conditions. However, contributions from more than 20% are still dominating in river basins up- and downstream of urban centers, as well as river stretches characterized by generally low-discharge conditions, e.g. Rhine, Neckar, Main and Havel. During

MMAD conditions, WWTP effluent contributions of more than 20% are dominating nationwide in a large number of river basins, e.g. Neckar, Rhine, Ems, Weser and Main. 60% of gauging stations in Neckar and more than 20% of gauging stations in Rhine and Ems exhibit WWTP effluent contributions of even more than 50% under MMAD conditions, which often prevail for longer periods between May and September.

Table 1: Distribution of the WWTP effluent contributions for the selected river basins under MMAD and MAD discharge for all gauging stations (data shown as % gauging stations exceeding specific contributions).

River basins	MMAD Conditions			MAD Conditions		
	>5%	>20%	>50%	>5%	>20%	>50%
Neckar	98	96	60	91	23	0
Rhine	73	51	25	45	8	2
Ems	68	49	22	46	4	0
Weser	72	34	12	35	4	0
Main	72	44	7	41	1	0
Havel	38	17	9	15	4	3
Elbe-Saale	44	19	2	19	2	1
Danube	43	8	2	12	1	0
Eastern coastal area	27	7	2	2	1	1

Critical bank filtrate shares in wells, in which the MTL values for each of the three indicator chemicals (i.e., oxypurinol, OXY; carbamazepine, CBZ; valsartanic acid, VSA) are exceeded, were calculated for different WWTP effluent contributions ranging from 0-100%. Based on this conceptual approach, the MTL of oxypurinol exhibiting high average WWTP effluent concentrations would be exceeded in a scenario with only 5% bank filtrate and 60% WWTP effluent contribution in the stream. For carbamazepine, which exhibited lower WWTP effluent concentrations, MTL exceedances would occur when both the WWTP effluent contribution to the stream and the bank filtrate share were about 60%. Where elevated WWTP effluent contributions dominate, elevated concentration of conservative health relevant chemicals can be expected in abstraction wells. For sites where the determined bank filtrate shares and relative effluent contributions would suggest potential exceedances of health advisory values, *de facto* reuse conditions were confirmed and additional mitigation measures should be taken.

Conclusions

The findings of this study reveal a high degree of WWTP effluent impact on streams, which also serve as an important source for drinking water abstraction, industrial usage or irrigation purposes, particularly in urbanized areas across Germany. The developed conceptual approach provides a universal qualitative assessment for any location worldwide to qualify possible *de facto* reuse conditions. With the assistance of this conceptual approach, possible hot spots of *de facto* reuse can be identified, if the site-specific data on indicator chemical concentrations in WWTP effluent and the degree of bank filtration are known. The proposed workflow can guide water utilities and regulators to assess the impact of wastewater-derived contaminations and to identify sites where comprehensive monitoring and additional mitigation strategies are needed to assure proper risk management.

References

Bradley, P.M., Barber, L.B., Clark, J.M., Duris, J.W., Foreman, W.T., Furlong, E.T., Givens, C.E., Hubbard, L.E., Hutchinson, K.J., Journey, C.A., Keefe, S.H., Kolpin, D.W., 2016. Pre/post-closure assessment of groundwater pharmaceutical fate in a wastewater-facility-impacted stream reach. Sci. Total Environ. 568, 916–925.

Dickenson, E.R.V., Snyder, S.A., Sedlak, D.L., Drewes, J.E., 2011. Indicator compounds for assessment of wastewater effluent contributions to flow and water quality. Water Res. 45 (3), 1199–1212.

Funke, J., Prasse, C., Lütke Eversloh, C., Ternes, T.A., 2015. Oxypurinol - A novel marker for wastewater contamination of the aquatic environment. Water Res. 74, 257–265.

Glassmeyer, S.T., Furlong, E.T., Kolpin, D.W., Cahill, J.D., Zaugg, S.D., Werner, S.L., Meyer, M.T., Kryak, D.D., 2005. Transport of chemical and microbial compounds from known wastewater discharges: Potential for use as indicators of human fecal contamination. Environ. Sci. Technol. 39 (14), 5157–5169.

Hass, U., Duennbier, U., Massmann, G., 2012. Occurrence and distribution of psychoactive compounds and their metabolites in the urban water cycle of Berlin (Germany). Water Res. 46 (18), 6013–6022.

Loos, R., Carvalho, R., António, D.C., Comero, S., Locoro, G., Tavazzi, S., Paracchini, B., Ghiani, M., Lettieri, T., Blaha, L., Jarosova, B., Voorspoels, S., Servaes, K., Haglund, P., Fick, J., Lindberg, R.H., Schwesig, D., Gawlik, B.M., 2013.

EU-wide monitoring survey on emerging polar organic contaminants in wastewater treatment plant effluents. Water Res. 47 (17), 6475–6487.

Mujeriego, R., Gullón, M., Lobato, S., 2017. Incidental potable water reuse in a Catalonian basin: Living downstream. Journal of Water Reuse and Desalination 7 (3), 253–263.

Nödler, K., Hillebrand, O., Idzik, K., Strathmann, M., Schiperski, F., Zirlewagen, J., Licha, T., 2013. Occurrence and fate of the angiotensin II receptor antagonist transformation product valsartan acid in the water cycle-a comparative study with selected β-blockers and the persistent anthropogenic wastewater indicators carbamazepine and acesulfame. Water research 47 (17), 6650–6659.

NRC, 2012. Water reuse: Potential for expanding the nation's water supply through reuse of municipal wastewater, Washington D.C., xiii, 262.

Reemtsma, T., Berger, U., Arp, H.P.H., Gallard, H., Knepper, T.P., Neumann, M., Quintana, J.B., Voogt, P.d., 2016. Mind the gap: Persistent and mobile organic compounds-Water contaminants that slip through. Environ. Sci. Technol. 50 (19), 10308–10315.

Rice, J., Westerhoff, P., 2015. Spatial and temporal variation in de facto wastewater reuse in drinking water systems across the U.S.A. Environ. Sci. Technol. 49 (2), 982–989.

Wang, Z., Shao, D., Westerhoff, P., 2017. Wastewater discharge impact on drinking water sources along the Yangtze River (China). Sci. Total Environ. 599-600, 1399–1407.

Risk Management for Drinking Water Production in a Partially Closed Water Cycle – The Berlin Case

G. Gruetzmacher, S. Schimmelpfennig, G. Lorenzen, D. Petersohn & J. Feddern
Berliner Wasserbetriebe, Berlin, Germany;
gesche.gruetzmacher@bwb.de

Abstract:

A substantial part of Berlin's drinking water is produced from groundwater influenced by surface water with relevant shares of treated waste water. Thus, risk management needs to take into account the performance of different barriers towards waste-water-related contaminants like persistent pharmaceuticals or pathogens. In order to prioritize and manage the risks related to the semi-closed water cycle the Berliner Wasserbetriebe, the local water and waste water service provider, have set up Water Safety Plans for each of the nine water works. Microbial contamination and persistent organic trace substances were identified main risks for water works with high percentages of treated waste water in the related surface water resource.

Keywords: partially closed water cycle, Berlin, bank filtration, risk management

Introduction

Drinking water production for Berlin's 3.7 Mil. inhabitants relies completely on groundwater pumped from nearly 700 wells located predominantly along the city's abundant lakes and rivers. The groundwater is replenished to varying degrees by infiltrating surface water – either by induced bank filtration or aquifer recharge via infiltration ponds. This system is decisive for water availability in this region of Germany with only 530 mm precipitation per year and adds to the robustness of the system towards climatic extremes like drought conditions.

Drinking water treatment consists of aeration and rapid sand filtration for removal of iron and manganese. The surface water bodies are characterized by comparatively low average discharges and the water levels are controlled by weirs. Waste water treatment plant effluents contribute to the surface water bodies (figure 1), as well as stormwater and combined sewer overflows. Thus, some of the substances present in stormwater and treated waste water can be detected in groundwater as well as treated drinking water.

Material and Methods

Since 2014 Berliner Wasserbetriebe have set up Water Safety Plans according to WHO (2013) for each of its nine water works. Potential hazards were identified from a catalogue of 103 possible hazards listed by Schmoll et al. (2013). Microbiological contaminations are always rated with a high initial risk, regardless of the likeliness of its occurrence.

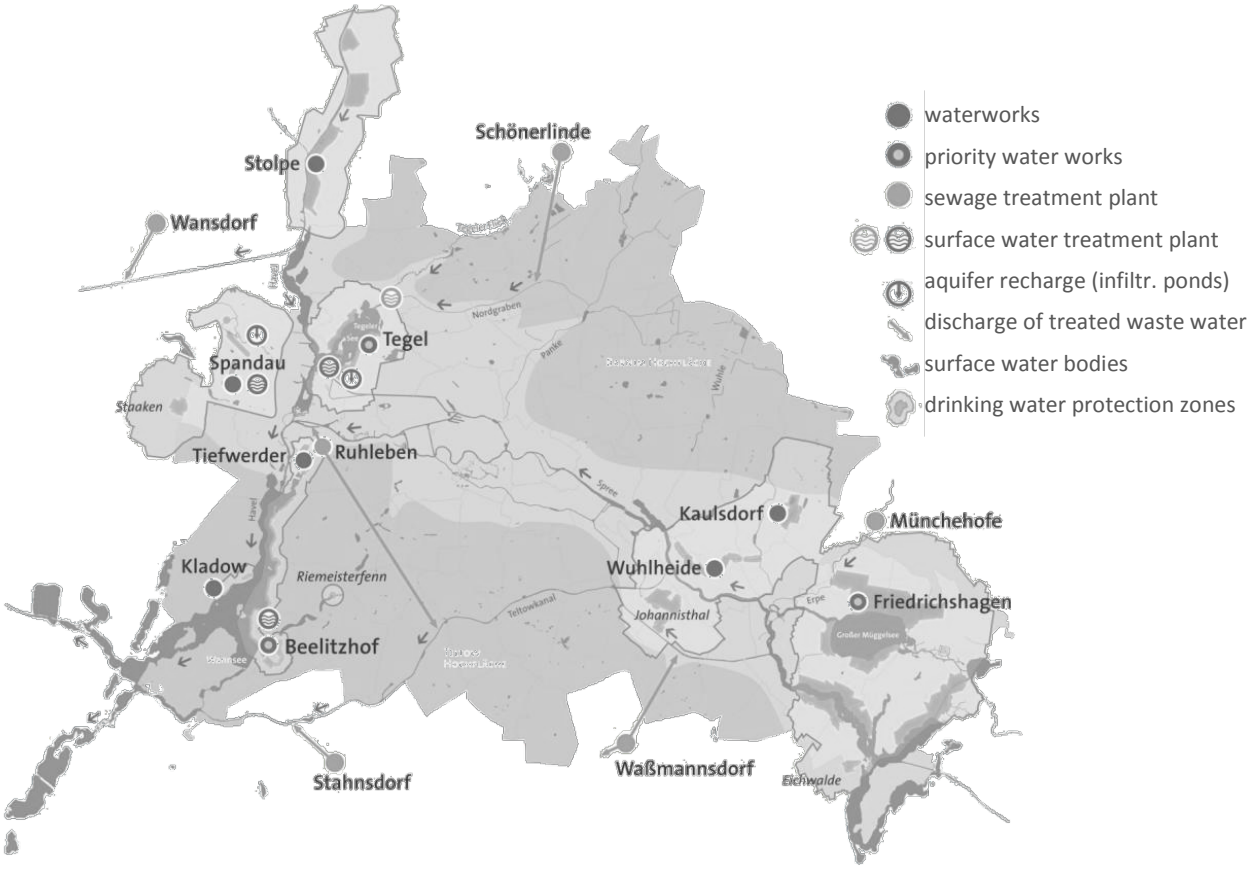


Figure 1 Water supply regions and waste water treatment plants in the city of Berlin (source: Berliner Wasserbetriebe).

Results and Discussion

The water works with the highest share of treated sewage plant effluent in its water resource is located along close to Lake Tegel in the northwestern part of the city and supplies water to nearly one million customers. Of all 82 hazards identified for this water works, 31 were attributed to the water resource and well fields and six were classified with high initial risk (figure 2), one of them being hydraulic interaction between potentially impacted surface water and groundwater. For this scenario pathogens and persistent organic contaminants were identified to have the highest relevance for drinking water.

Conclusions

The Berliner Wasserbetriebe developed a strategy for dealing with trace organic substances following a precautionary approach (Grützmacher et al. 2018). Apart from avoidance and reduction at the source the main focus of action is to decouple waste water and drinking water resources as far as possible. For conventional water treatment systems in Berlin a maximum share of 5% treated waste water in the surface water resource was regarded as uncritical. In case decoupling is not possible (e.g. in order to sustain sufficient flows) additional barriers are necessary. These should be installed as close to the source as possible (i.e. at the waste water treatment plant), in order to additionally protect surface water environments as well as to leave time and possibilities for further action, if necessary.

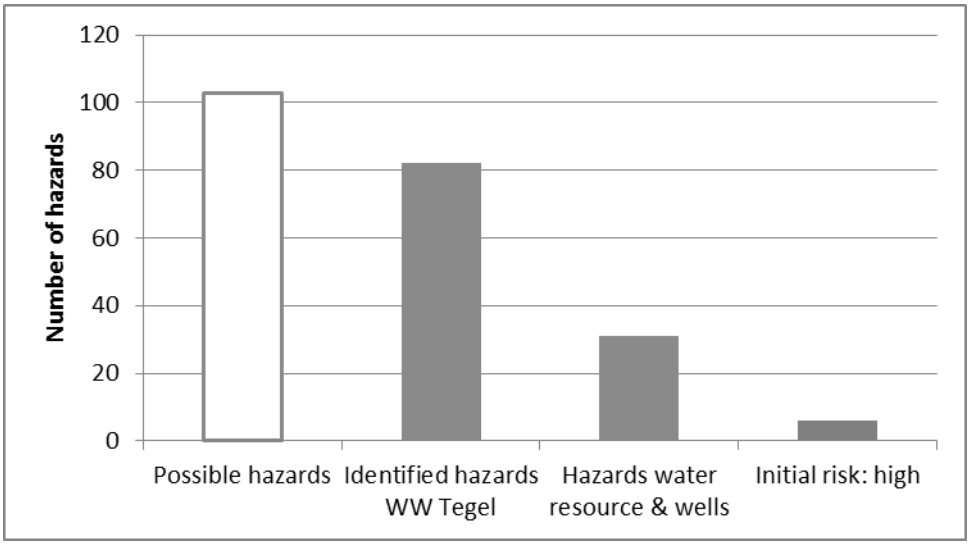


Figure 2 Possible and identified hazards for water works (WW) Tegel, according to Water Safety Plan analysis 2017.

For removal of pathogens subsurface passage is generally known to be very efficient, depending on travel time and environmental conditions, such as redox conditions and aquifer matrix. In Germany, a travel time 50 days travel in the subsurface is generally considered to guarantee microbiological purity according to drinking water standards. For risk control, the Berliner Wasserbetriebe have therefore introduced field tests to estimate travel time at bank filtration sites. A method was developed (Sprenger et al. 2016) to allow monitoring of travel times under steady state conditions. In order to transfer this into practice, transient conditions will need to be taken into account and new analytical methods will bring additional security. Experience has shown, however, that well fields with high shares of aquifer recharge

via infiltration ponds and low travel times do not show higher findings of indicator parameters such as coliform bacteria compared to well fields with high shares of ambient groundwater or bank filtrate, which generally have higher residence times in the subsurface (figure 3). This confirms that infiltration and subsurface passage in both cases is a safe method for pathogen removal within the Berlin waterworks setting. Findings can rather be explained by other effects, such as occasional leaks in the underground well construction, contamination during maintenance work or false positives.

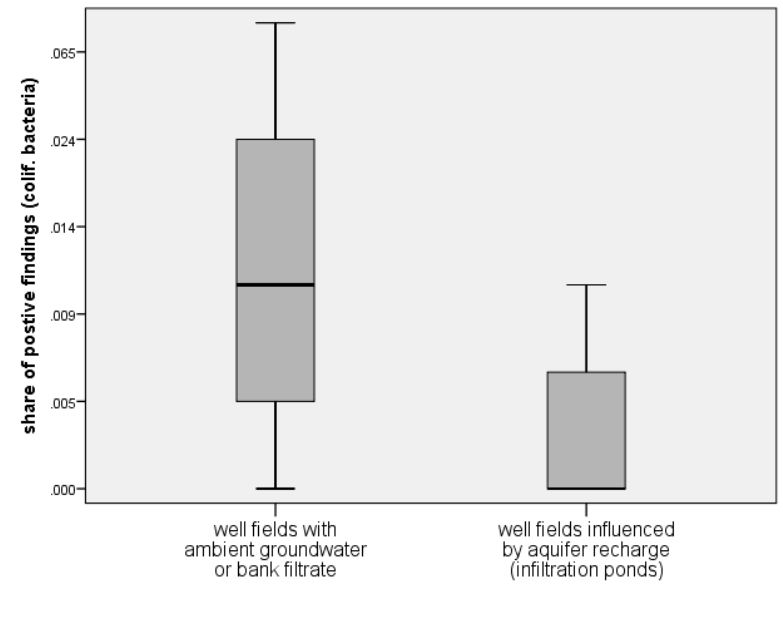


Figure 3 Positive findings of coliforme bacteria in well field mains with low (left) and high (right) shares of aquifer recharge by infiltration ponds (n = 3253 and n = 269, respectively).

Challenges

Risk management according to the Water Safety Plan procedure has shown to be useful in identifying and prioritizing hazards and risks also at water works showing distinctive urban influence. In order to guarantee safe drinking water supply in the future, climatic changes with direct (higher temperatures) and indirect (deteriorating water quality) consequences need to be assessed. The water supply system of Berlin has shown to be robust with regard to dry weather conditions as in 2018, also due to a comparatively high share of “recycled” water in the rivers – although quality changes were clearly observable (figure 4). This strength needs to be developed

further (e.g. by implementing additional barriers) and closely monitored in order to be prepared for future developments.

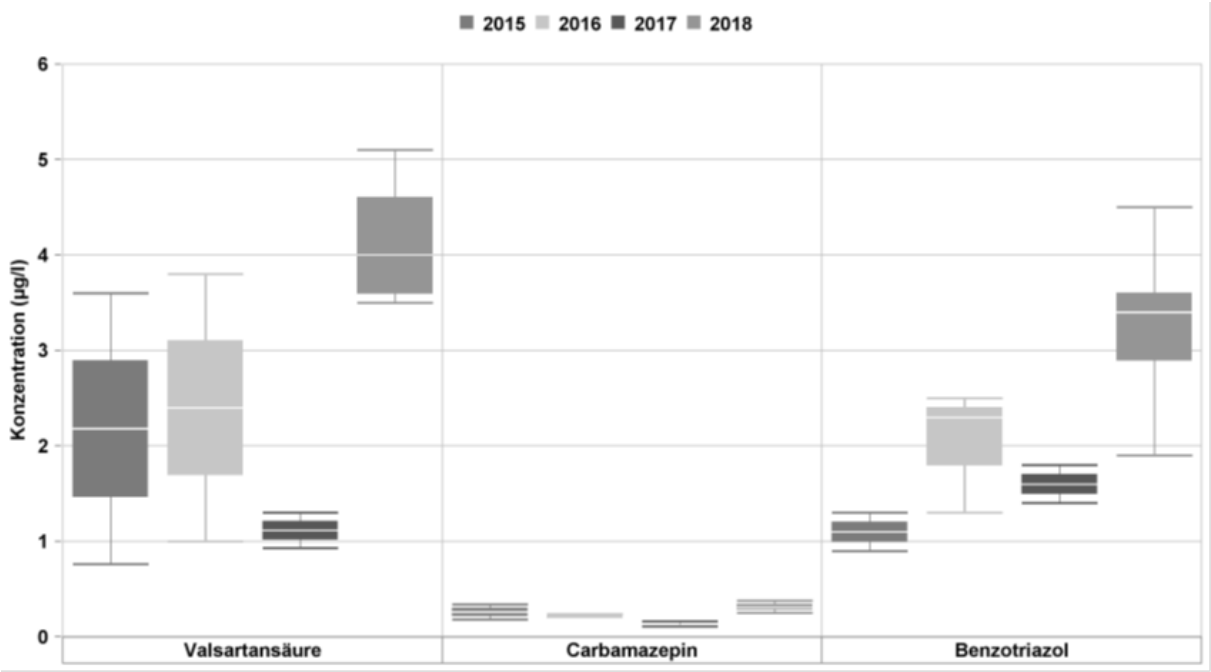


Figure 4 Surface water concentrations of selected trace organics at Lake Wannsee in the years 2015 to 2018 (2017 being an extremely wet and 2018 an extremely dry year).

References

Schmoll, O., Bethmann, D., Sturm, D. & Schnabel, B (2014): Das Water-Safety-Plan-Konzept – ein Handbuch für kleine Wasserversorger. – Umweltbundesamt, 118 p.

Grützmacher, G., Schimmelpfennig, S., Sieker, C., Gnirss, R., Bartholomäus, C., Thorbeck, N. & Dünnbier, U. (2018): Die Strategie der Berliner Wasserbetriebe zum Umgang mit abwasserbürtigen, anthropogenen, Spurenstoffen. Gewässerschutz Wasser Abwasser (247): 51/1 – 52/2.

Sprenger, C., Schwarzmüller, H., Lorenzen, G., Gnirss, R. & Grützmacher, G. (2016): Temperature measurement during Managed Aquifer Recharge for safeguarding subsurface travel times. – Presentation at ISMAR9, Mexico City.

Safe wastewater reuse in the United Arab Emirates; safety assessment from concept to realisation

Patrick W.M.H. Smeets, KWR Watercycle Research Institute, Nieuwegein, The Netherlands; Milou M.L. Dingemans, KWR Watercycle Research Institute, Nieuwegein, The Netherlands; Michael Stenzel, TANQIA SIYANA, Fujairah, United Arab Emirates;

Introduction

In the Middle East fresh water is scarce and often produced from seawater at high costs. Currently, used drinking water is regarded as wastewater and, after treatment, discharged to the sea. Recently the Government of Fujairah (UAE) has developed a water distribution system to facilitate wastewater reuse for irrigation. Before putting this system into use, the TANQIA wastewater treatment company has performed a safety assessment of the existing and planned water reclamation system. Together with KWR Watercycle Research Institute a stepwise approach to reach safe water reuse has been developed and executed.

Stepwise approach to safe water reuse

The water reuse project is part of various developments at the TANQIA wastewater treatment site. The capacity of the existing system will be increased to match the increased wastewater flow. At the same time the treatment process will be extended with processes for reclamation of wastewater. In addition, two container systems for small scale decentralized wastewater reuse have been developed. KWR and TANQIA took a phased approach to reach safe water reuse as shown in Figure 1.

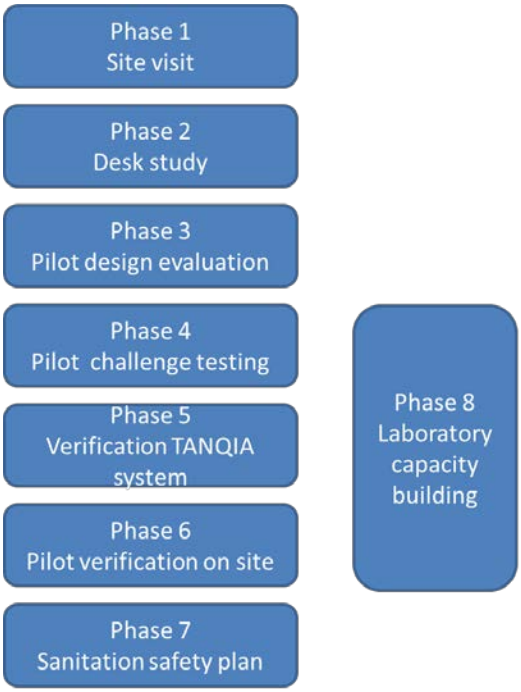


Figure 1 Stepwise approach to safe water reuse

The site visit in phase 1 created mutual understanding of the project goals and of the actual system. It included an inspection of technical status, operation, procedures, monitoring and record keeping. Inspection results were included in the desk study

risk assessment of the current and planned system in phase 2. The designs of the pilot systems were evaluated in phase 3, leading to improvements. The pilot systems will be validated by challenge testing (phase 4) before shipment to the UAE, making use of advanced laboratory capacities in the Netherlands. Local laboratory capacities in the UAE will be developed in phase 8, since these will be needed for verification of performance of the full scale and pilot treatment systems in operation. Close collaboration with the KWR laboratory during the verification phases 5 and 6 allows for effective and practical knowledge exchange and training. Finally, in phase 7 all experiences will be captured in a Sanitation Safety Plan (SSP), including procedures for operation and monitoring that secure safe reclaimed water.

Results of safety assessment

The safety of the current and extended treatment system were assessed based on the WHO guidelines for safe use of wastewater in agriculture. In phase 2 the microbial wastewater composition and effect of treatment were estimated based on literature. Using minimal and maximum expected performance, the 'worst' and 'best' situation were estimated. Figure 2 shows the total performance for viruses, bacteria and protozoa, evaluated against various health-based targets for restricted and unrestricted irrigation and even potable reuse. In the worst case the system won't meet safety targets for viruses and protozoa, but with proper design and operation the extended system could even reach potable water quality. Figure 2 illustrates the various challenges per organism. Chlorination is important for controlling viruses and bacteria, while the inspection revealed that operation, monitoring and record keeping for chlorination needs improvement. Verification through on-site microbial monitoring is needed in phase 5 to verify that the system is meeting the targets.

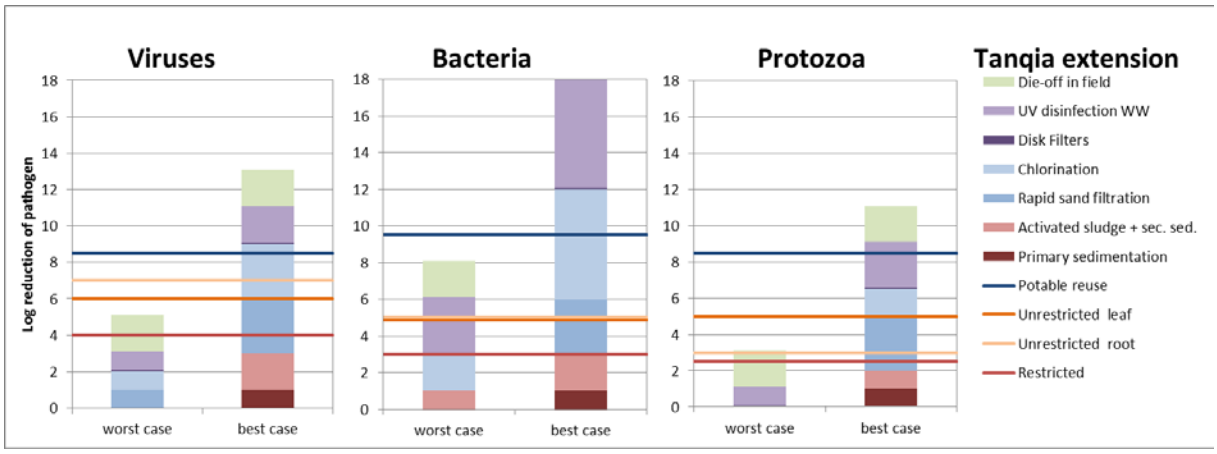


Figure 2 Expected treatment performance under worst and best case assumptions and health based targets as log removal values.

Outlook

At the moment of writing (October 2018) phase 4, validating the pilot container systems, is on-going. At the time of the conference (June 2019) we expect to present the results of phase 4, 5 and 6 (full scale verification) and to report on phase 8.

Water reuse as a sustainable water scarcity risk reduction measure: Integrating risk and sustainability assessment frameworks

Andrea Müller, TU Dresden[1] & UNU-FLORES[2]; Dresden, Germany; Tamara Avellán, UNU-FLORES, Dresden, Germany; Jochen Schanze, TU Dresden & IOER[3], Dresden, Germany

[1] Technische Universität Dresden, Chair of Environmental Development and Risk Management;

[2] United Nations University – Institute for Integrated Management of Material Fluxes and of Resources

[3] Leibniz Institute of Ecological Urban and Regional Development

Keywords: water scarcity; water reuse; risk assessment; sustainability assessment.

Abstract

This work aims at exploring the joint application of risk and sustainability assessments to support decision-making related to the selection of water reuse measures under water scarce conditions. The results focus on identifying the different components involved in such decisions, highlighting the key support that assessments provide in analysing and evaluating the related information. The conclusions point out challenges related to: (i) working with different terms and definitions; (ii) mapping the associated components and how a multi-layer approach is of use; and (iii) the meaning of a single layer representing the information relevant for decision making, based on observations and data.

Introduction

Water scarcity is currently affecting millions of people, and by 2050 this situation is likely to become more critical (McDonald et al., 2011; WWAP, 2018). Therefore, management of water resources is a significant challenge, especially for growing cities located in water-poor regions. In that context, water reuse points towards more efficient management of water resources by reducing freshwater withdrawals and recycling nutrients (El Moussaoui et al., 2017; WWAP, 2017; Sgroi et al., 2018). So far, primarily regions undergoing water scarcity implement these measures (Voulvoulis, 2018). The implementation of water reuse is challenging as it demands a cross-sectoral collaboration at least between the water supply and sanitation sectors and also requires participation of the community (Garcia and Pargament, 2015; Ricart and Rico, 2019). Accordingly, decision-makers face complicated situations, where finding the most beneficial alternative is not straightforward. Rational decision-

making in a water scarce region or a region that may face water scarcity in the future needs to consider the multitude of associated components related to this risk. At the same time, the sustainability of the measure to be selected has to be ensured. Rational decision hence should reduce risks and foster sustainable development, but integrating risk reduction and sustainable development is challenging (UN, 2015; UNISDR, 2015). Understanding risk and sustainability in the selection of water reuse measures to cope with water scarcity may serve as an example of how to integrate both risk and sustainability assessments. This contribution aims to explore how risk and sustainability assessment can be combined to support the decision-making towards using water reuse as a sustainable means of reducing risks of water scarcity.

Approach

The first step (**A**) is a non-systematic literature review focused on the concepts of 'water scarcity', 'water reuse', 'risk', 'risk assessment', 'sustainability' and 'sustainability assessment'. The second step (**B**) is the delineation and description of the system based on the aim of this research. The third step (**C**) is the identification of the associated elements that relate to the system. This comprises: (i) conceptualising water scarcity as a risk and water reuse as a sustainable measure; and (ii) identifying interrelations between the system elements to depict the full scope of the issues decision-makers have to face. The conceptualisation helps to identify the relevant elements involved in water scarcity (e.g. freshwater source) and water reuse (e.g. wastewater treatment plant) and their relations. A conceptual mapping of the elements categorised according to the three pillars of sustainability (social, economic and environmental dimensions) is the basis for the identification of connections. The last step (**D**) focuses on the derivation of how assessments (risk and sustainability) can support decision-making referring to the selection of the measure of water reuse. This involves a non-systematic literature review on decision theory to identify the phases of decision-making where the assessments may support.

Results and discussion

(**A**) Among many definitions, 'water scarcity' can relate to the lack of adequate water quantities to meet human demand (FAO, n.d.; Schulte and Morrison, 2014; Vanham et al., 2018). 'Water reuse' refers, in general terms, to "*the use of treated wastewater for a beneficial use, such as agricultural irrigation and industrial cooling*" (Asano et

al., 2007). According to many publications, the term ‘risk’ indicates the probability of negative consequences when a vulnerable subject, object or system is exposed to a hazard (Schanze, 2016). Hence, water scarcity can be designated as a risk, namely the risk of access to adequate water quantities to meet human needs. The term ‘sustainability’ ”*strives for the maintenance of economic well-being, protection of the environment and prudent use of natural resources, and equitable social progress which recognises the just needs of all individuals, communities, and the environment*” (Muga and Mihelcic, 2008) in ”*a continuous search for a delicate equilibrium in a dynamic setting”* (Waas et al., 2011). This ‘continuous search’ aligns with the cross-generational nature of sustainable development (WCED, 1987). ‘Risk assessment’ covers the analysis of a system exposed to a hazard and the evaluation of the resulting risks (Blanco-Vogt & Schanze, 2014). Its operationalisation encompasses three dimensions: (1) hazard in terms of severity and probability of occurrence; (2) exposure; and (3) vulnerability in terms of the susceptibility, the value or function and the coping capacity (resilience) of the system (ibid.). This way, risk assessment provides the basis for the design of risk reduction measures through, e.g. water reuse. In contrast, ‘sustainability assessment’ addresses a measure, project or product, in terms of its social, economic and environmental impacts. It is based on the operationalisation through indicators and targets using various approaches (Pope et al., 2004; Hacking and Guthrie, 2008). Both assessments are based on components of analysis and evaluation.

(**B**) For this research, the system considers a community facing risk of water scarcity and that is considering implementing or has already implemented a water reuse measure. This system is dynamic and involves not only biophysical elements, but also the social and economic elements that interact and influence its delineation and dynamic. Given the extent number of elements involved in such a system, the further description requires advancing priory on step (**C**).

(**C**) The relationship between water scarcity, water reuse and risk and sustainability results as follows: sustainable water reuse may reduce the need for fresh water, lowering the vulnerability of the system, and thus reduce the risk of experiencing water scarcity. In other words, it is difficult for water reuse measures, which are implemented to reduce the risk of water scarcity, to actually reduce it in the long run if they are not conceived to be sustainable; while it is also challenging to implement

water reuse as sustainable measure if it does not reduce the risk of experiencing water scarcity.

Decisions account for and thus should consider different interests related to social, economic and environmental dimensions (Wilcox et al., 2016), e.g. willingness to pay, affordability of wastewater treatment, and discharge water quality. Decision-makers have to face all the elements involved in these dimensions simultaneously. A following challenge is the to depict this simultaneity, i.e. all the elements considering all dimensions in a single conceptual map. The sustainability dimensions allow categorising these various elements to avoid confusion between the characteristics of each dimension, while supporting a holistic view of the system. In this case, the elements are represented in different layers as follows: a social layer involving, e.g. population and behavioural components; an economic layer showing, e.g. financial figures; and an environmental layer showing biophysical components; (see Figure 1a for a schematic view).

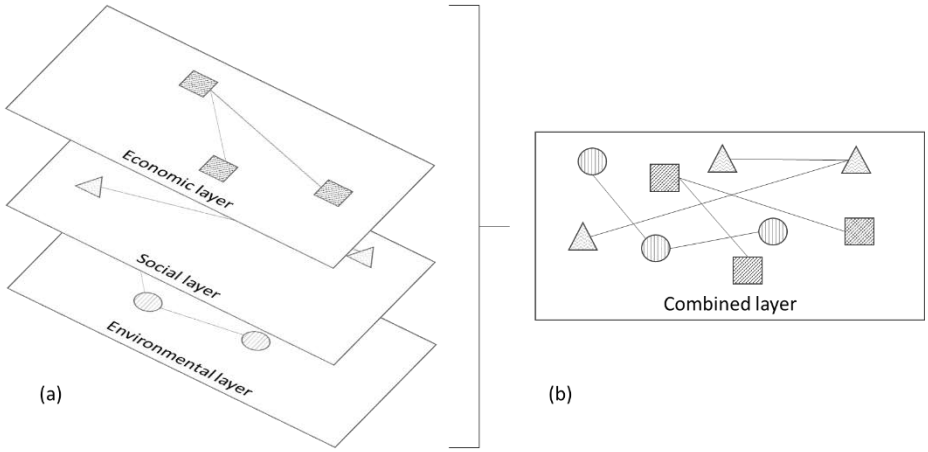


Figure 1 Schematic represenation of the layers. (a) Sustainability dimension layers including the different environmental elements related (e.g. freshwater source, ecosystem water demand, wastewater treatment plant), social elements (e.g. types of human water use - domestic, agricultural and industrial-, water demand), and economic elements (e.g. affordability of wastewater treatment, water supply fees). (b) Overlap of all three layers based on data and indicators for each of the elements.

(**D**) The assessment of water scarcity risk and sustainability of the water reuse measure in an integrated manner follows the layer distribution used for the conceptual mapping. In this case, the assessments use indicators for the evaluation based on data of the different layer elements. In other words, by using indicators, the layers can be translated into a single interphase of information that combines all the previous separated layers in one, as shown in Figure 1b (schematic view). For the

assessment, it is ultimately about the information that can be provided by social, economic and biophysical data. The data transferred to indicators is then evaluated under risk or sustainability criteria, accordingly, giving information about the status (of risk and sustainability). This evaluation focuses on fulfilment of social, economic and environmental goals, to lower the risk to water scarcity and implement an efficient and long-lasting water reuse measure. The results are envisaged to create the basis for developing a more detailed conceptual framework for water scarcity risk reduction through sustainable water reuse measures.

Conclusions

An integrated risk and sustainability assessment involves the components of analysing elements and evaluating data related to the risks of water scarcity while measuring the impacts of a water reuse measure. The main conclusions are: (i) a joint application of risk and sustainability assessment deals with a variety of terms and definitions; (ii) identifying and mapping the involved elements represents a significant challenge for which a multi-layer approach based on the sustainability dimensions is of use; (iii) for the evaluation component of the assessment, it is critical to recognise the importance of data and how to depict in one layer all the data and potential information related to the elements. The operationalisation of this data comprises indicators and methods according to the different disciplines involved in each of the dimensions.

References

Asano, T., Burton, F. L., Levernz, H. L., Tsuchihashi, R., and Tchobanoglous, G. (2007). Water reuse: issues, technologies, and applications. New York: McGraw-Hill.

Blanco-Vogt, A., and Schanze, J. (2014). Assessment of the physical flood susceptibility of buildings on a large scale – conceptual and methodological frameworks. Natural Hazards and Earth System Science, 14(8), 2105–2117. https://doi.org/10.5194/nhess-14-2105-2014

El Moussaoui, T., Wahbi, S., Mandi, L., Masi, S., and Ouazzani, N. (2017). Reuse study of sustainable wastewater in agroforestry domain of Marrakesh city. Journal of the Saudi Society of Agricultural Sciences. https://doi.org/10.1016/j.jssas.2017.08.004

FAO, Food and Agriculture Organisation of the United Nations. (n.d.) AQUASTAT Data Glossary.

Garcia, X., and Pargament, D. (2015). Reusing wastewater to cope with water scarcity: Economic, social and environmental considerations for decision-making. Resources, Conservation and Recycling, 101, 154–166. https://doi.org/10.1016/j.resconrec.2015.05.015

Hacking, T., and Guthrie, P. (2008). A framework for clarifying the meaning of Triple Bottom-Line, Integrated, and Sustainability Assessment. Environmental Impact Assessment Review, 28(2–3), 73–89. https://doi.org/10.1016/j.eiar.2007.03.002

McDonald, R. I., Green, P., Balk, D., Fekete, B. M., Revenga, C., Todd, M., and Montgomery, M. (2011). Urban growth, climate change, and freshwater availability. Proceedings of the National Academy of Sciences, 108(15), 6312–6317. https://doi.org/10.1073/pnas.1011615108

Muga, H. E., and Mihelcic, J. R. (2008). Sustainability of wastewater treatment technologies. Journal of Environmental Management, 88(3), 437–447. https://doi.org/10.1016/j.jenvman.2007.03.008

Pope, J., Annandale, D., and Morrison-Saunders, A. (2004). Conceptualising sustainability assessment. Environmental Impact Assessment Review, 24(6), 595–616. https://doi.org/10.1016/j.eiar.2004.03.001

Ricart, S., and Rico, A. M. (2019). Assessing technical and social driving factors of water reuse in agriculture: A review on risks, regulation and the yuck factor. Agricultural Water Management, 217, 426–439. https://doi.org/10.1016/j.agwat.2019.03.017

Schanze, J. (2016). Resilience in flood risk management – Exploring its added value for science and practice. E3S Web of Conferences, 7, 08003. https://doi.org/10.1051/e3sconf/20160708003

Schulte, P., and Morrison, J. (2014). Driving Harmonization of Water-Related Terminology. Discussion Paper. In The CEO Water Mandate (Ed.).

Sgroi, M., Vagliasindi, F. G. A., and Roccaro, P. (2018). Feasibility, sustainability and circular economy concepts in water reuse. Current Opinion in Environmental Science & Health, 2, 20–25. https://doi.org/10.1016/j.coesh.2018.01.004

UN, United Nations (2015). Transforming Our World: The 2030 Agenda for Sustainable Development (Resolution adopted by the General Assembly on 25 September 2015 No. A/RES/70/1).

UNISDR, United Nations International Strategy for Disaster Reduction (2015). Making development sustainable: the future of disaster risk management. Geneva: United Nations.

Vanham, D., Hoekstra, A. Y., Wada, Y., Bouraoui, F., de Roo, A., Mekonnen, M. M., … Bidoglio, G. (2018). Physical water scarcity metrics for monitoring progress towards SDG target 6.4: An evaluation of indicator 6.4.2 “Level of water stress”. Science of The Total Environment, 613–614, 218–232. https://doi.org/10.1016/j.scitotenv.2017.09.056

Voulvoulis, N. (2018). Water reuse from a circular economy perspective and potential risks from an unregulated approach. Current Opinion in Environmental Science & Health, 2, 32–45. https://doi.org/10.1016/j.coesh.2018.01.005

Waas, T., Hugé, J., Verbruggen, A., and Wright, T. (2011). Sustainable Development: A Bird’s Eye View. Sustainability, 3(10), 1637–1661. https://doi.org/10.3390/su3101637

WCED, United Nations World Commission on Environment and Development (1987). Our Common Future (Report of the World Commission on Environment and Development (WCED)) (p. 374). Oslo, Norway. Retrieved from https://sustainabledevelopment.un.org/milestones/wced

Wilcox, J., Nasiri, F., Bell, S., and Rahaman, M. S. (2016). Urban water reuse: A triple bottom line assessment framework and review. Sustainable Cities and Society, 27, 448–456. https://doi.org/10.1016/j.scs.2016.06.021

WWAP, United Nations World Water Assessment Programme (2017). Wastewater: The Untapped Resource. (UNESCO, Ed.). Paris, France.

WWAP, United Nations World Water Assessment Programme (2018). Nature-Based Solutions for Water. (UNESCO, Ed.). Paris, France.

FACİLİTATING ADOPTİON OF MBR FOR WATER REUSE BY İMPROVED RİSK MANAGEMENT AND DEVELOPMENT OF BETTER GUİDANCE

Authors: Amos D. Branch[1], Cedric Robillot[2], Pierre Le-Clech[3]

[1] *School of Civil and Environmental Engineering, UNSW, Australia*
[2] *HeadStart Development; Brisbane, Australia; cedric@headstartdevelopment.com*
[3] *School of Chemical Engineering, UNSW, Australia*

Presenter: Pierre Le-Clech
Associate Professor,
UNESCO Centre for Membrane Science and Technology;
School of Chemical Engineering, UNSW, Australia
p.le-clech@unsw.edu.au

Membrane bioreactors (MBRs) are increasingly applied to achieve pathogen removal in water recycling schemes. To date, the pathogen log removal performance of MBRs has been validated in an arbitrary manner, which has led to accreditation varying on a scheme-by-scheme basis and consequently an inequitable treatment of potential health risk. In water reuse applications, a thorough understanding of pathogen removal mechanisms and performance is imperative. Any event compromising the pathogen removal efficiency must be detected and quantified to inform appropriate corrective action. Potential loss of containment of pathogens by MBRs has rightly been considered as an important hazardous event, and conservative risk management has limited accredited log removal values (LRV).

To better justify and demonstrate the reliability of MBRs in removing pathogens, an extensive research project was conducted which involved critical review of reported LRV data identifying over 600 LRV data points from MBR and further sampling from over 180 site visits. During the site visits LRV for five different indicator microorganisms was evaluated and statistically compared to operational monitoring data. After interrogation of the significant data set collected, validation guidelines were developed to satisfy the concerns of stakeholders including health regulators and MBR practitioners.

Of importance, the wide ranging review of MBR industry data and specific investigations of full scale facilities in Australia led to the establishment of default LRVs for viruses, protozoa and bacteria of 1.5, 2 and 4, respectively. These default values can only be applied to common MBR systems with nominal pore sizes of 0.04 – 0.1 µm operated under conservative operating conditions (as statistically calculated from operating MBR data).

Finally, the reliability of conventional online monitoring techniques, such as turbidity, has been demonstrated as appropriate membrane integrity monitoring, allowing the validation of the membrane as a critical control point. The demonstrated the limit of detection and correlation of turbidity with LRV.

For more details about the outcomes of this project, visit Water Research Australia' WaterVal website, where the protocol for validation of MBR is available: https://www.waterra.com.au/research/waterval/

Keywords: water recycling; membrane bioreactor; log removal value; validation; indicator; turbidity.

The risk of rainwater reuse in household installations

Louise Vanysacker, De Watergroep, R&D, Vooruitgangstraat 189, 1030 Brussels, Belgium

Bart De Gusseme, FARYS|TMVW, R&D, Stropstraat 1, 9000 Gent – Center for Microbial Ecology and Technology, Ghent University, Coupure Links 653, 9000 Gent, Belgium

Benjamin Buysschaert, FARYS|TMVW, R&D, Stropstraat 1, 9000 Gent, Belgium

Kris Van den Belt, Flanders Environmental Agency, Koning Albert II-laan 20 b, 1000 Brussel, Belgium

Bert De Winter, De Watergroep, Innovation, Vooruitgangstraat 189, 1030 Brussel, Belgium

The use of rainwater for household applications originates from a wastewater management point of view. Due to the increase in hard and impermeable surface areas in Flanders, it was decided to separate rainwater from sewers to prevent sewer overflow in urban areas. Later it was decided to infiltrate or reuse rainwater on a local scale.

In 2012, Flanders fostered initiatives to improve rainwater storage and reuse, in an effort to decrease drinking water consumption and to make people aware of drinking water issues and water scarcity. In this context, public authorities promote the installation of rainwater tanks by households through different policy instruments: subsidies, tax cuts, information campaigns, and requirements in building permits. In Flanders, municipal regulations systematically include the obligation to make such installations part and parcel of every renovated or new building. The minimum reception capacity of rainwater tanks was 3m³ in 2004 and increased to 5m³ with a maximum of 10m³ in 2012. As a result, since 2004 the use of rainwater for different purposes has increased and drinking water and groundwater use has decreased (Figure 1).

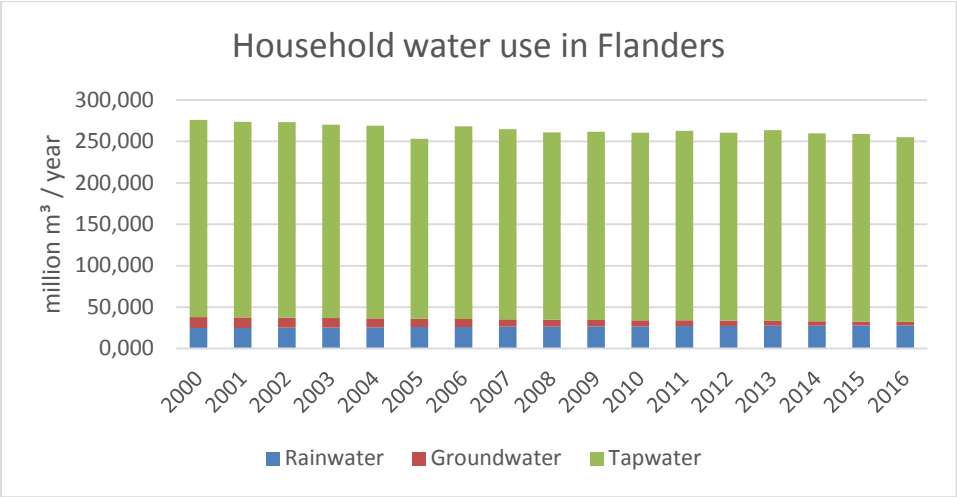


Figure 1: Household water use in Flanders (source: VMM)

Recently the Flanders Environment Agency mapped the different water sources on household level (Table 1). Rainwater is used mainly for toilet flushing, washing machines and gardening. However, in some case rainwater is used for personal hygiene, which is normally not allowed under Flemish regulations.

Table 1: Average water use and origin expressed in L/ day / person (source: Flanders Environmental Agency)

	Total	Tapwater	Groundwater	Rainwater
Toilet	21.3	17.2	0.3	3.9
Bath	5.1	4.8	0.1	0.2
Shower	23.8	23.2	0.2	0.3
Sink	9.4	9.4	0	0
Washing machine	15.5	12.8	0.2	2.5
Hand washing laundry	1.1	1	0	0.1
Dishwasher	2.3	2.2	0	0.1
Dishes (hand)	6	5.6	0.1	0.4
Cooking/drinking	11.1	10.9	0.1	0.1
Cleaning	5.8	4.7	0.1	1
Gardening	7.4	4.1	0.5	2.8
Other	4.7	4.1	0.2	0.5
Leak	0.1	0.1	0	0
Bottled water	0.4			
Total	114	100	1.7	11.9
		88%	2%	10%

Although it is forbidden by law to have connections between rainwater and tap water, drinking water companies noticed more and more cross-connections. Cross-connection may have an effect on the individual level, but more importantly, also on the drinking water distribution network. When the pressure in the distribution system drops and/or when the rainwater pump can overcome the drinking water network

pressure, rainwater may enter the network through the water meter connection, definitely when a proper non-return valve is lacking. This phenomenon is occurring more and more frequently (Figure 2).

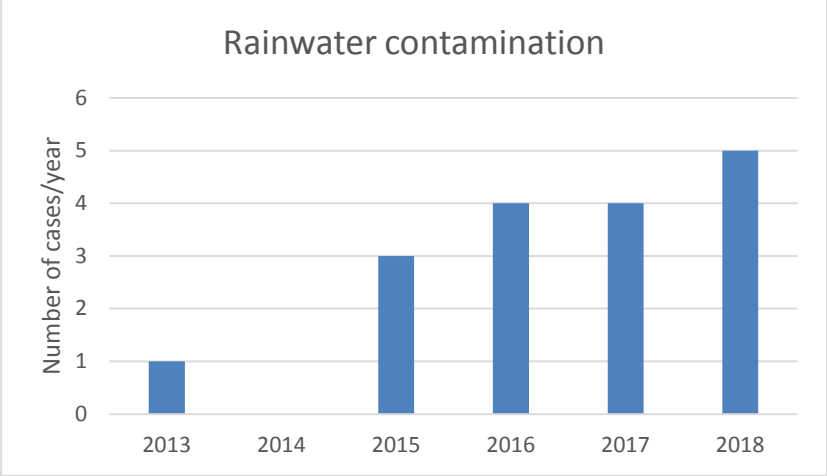


Figure 2: Rainwater intrusion in the drinking water distribution network since 2013.

Intrusion of rainwater into the distribution network can have dramatic effects. At the conference, two different cases of rainwater contamination will be presented. The first one occurred in 2016 in West Flanders and affected 85 houses. Although the contamination source was detected in 3 days, it took more than a week before bacterial contamination was completely solved. A second, more recent case, occurred in East Flanders. This situation was more dramatic as the source could not be directly identified. Two regions of 3222 customers were severely affected. High concentrations of *E. coli*, coliforms and *enterococci* were measured. Different houses were inspected. Of the 427 houses inspected, 72 did not have a non-return valve and 22 houses had a cross-connection between rainwater and tap water.

With this presentation we would like to stress the risk of rainwater reuse and the need for appropriate legislation, a certification body and, more importantly, a recurring control. One development worth mentioning in this area is the smart metering system which immediately detects backflush.

Assessment of elevated risk by antibiotic resistance in indirect reuse of treated livestock wastewater for irrigation

Ryo Honda, Lin Mengyu, Tatsuki Hirata, Hiroe Hara-Yamamura, Ryoko Yamamoto-Ikemoto, Kanazawa University, Japan; Toru Watanabe, Yamagata University, Japan; rhonda@se.kanazawa-u.ac.jp

Abstract:

Annual disease burden caused by antibiotic resistant bacteria was assessed in a case of indirect water reuse of livestock wastewater for irrigation of lotus root. Monitoring of irrigation water showed that irrigation pipeline was not likely to serve as reservoir of ARB in supply of indirect reuse water with a low concentration of ARB. Annual disease burden as DALY per person was applied to QMRA considering possible difficulty of treatment caused by antibiotic resistance. Estimated annual disease burdens of impetigo increased by 0.7% and 2.7% because of LVX- and TC-resistant *S. aureus*, respectively. Increase of annual disease burden by antibiotic resistance largely depends on abundance of antibiotic resistance in the reused water. Health risk can be significantly higher when the reused water contained higher abundance of antibiotic resistance.

Keywords: agricultural water reuse; quantitative microbial risk assessment (QMRA); antimicrobial resistant bacteria, Escherichia coli, Staphylococcus aureus

Introduction

Antibiotic resistant bacteria are enriched in guts of human and animals under dose of antibiotics, then released as wastewater. In many agricultural areas in the world, irrigation water resources are sometimes contaminated with domestic and livestock wastewater (Honda et al. 2010). Water bodies receiving such wastewater reportedly have higher abundance of antibiotic resistant bacteria (Honda et al. 2016). Especially, livestock wastewater often contains very high abundance of antibiotic resistant bacteria. When livestock wastewater is indirectly reused in irrigation, farmers are at risk of infectious diseases caused by antibiotic resistant bacteria. The conventional risk management of infectious diseases is based on quantitative microbial risk assessment (QMRA) as chance of infection. The conventional risk assessment as chance of infection cannot reflect such severity and longer duration of diseases after

infection, which is possibly caused by antibiotic resistant pathogens in reused water. Disability-adjusted life years (DALY) is an index of disease burdens which can include duration and severity of the diseases. Application of DALY to microbial risk assessment enables to quantify disease burden elevated by antibiotic resistant bacteria in reused water.

The objective of this study is to investigate farmers' health risk in indirect reuse of livestock wastewater for irrigation based on QMRA. We conducted field monitoring of antibiotic resistant *E. coli* and *Staphylococcus aureus* in irrigation water, and performed the QMRA based on chance of infection and DALY.

Material and Methods

Sampling and microbial analysis

Kahokugata Lake, Japan was used as irrigation water and received treated wastewater from swine farm, slaughtering factory, etc.. (**Figure 1**). Water samples were taken from waterway near the intake of an irrigation pumping station as point of entry (POE) and the irrigation tap near a lotus cultivation field as end of pipe (EOP). Sampling was conducted twice a month from July 2018 until December 2018.

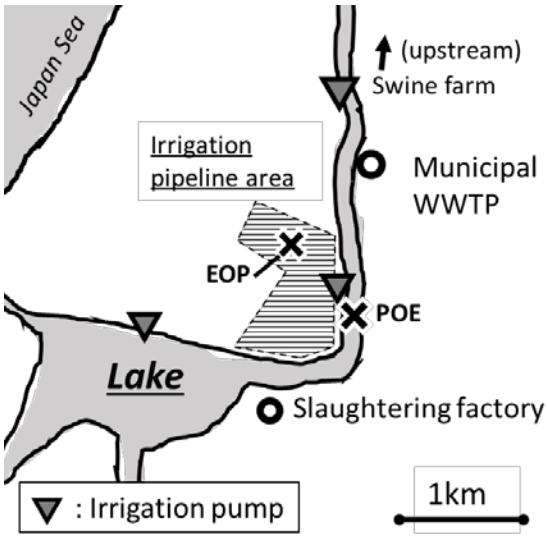


Figure 1 Location of sampling points: point of entry (POE) and end of pipe (EOP).

E. coli and *Stahphylococcus aureus* were cultivated on Chromocult Coliform ES Agar (Merck-Millipore) and CHROMagar Staph aureus (CHROMagar,) after filtrated with 0.45-μm membranes. Levofloxacin (LVX) and tetracycline (TC) were also added in each agar media as well as control with antibiotics. According to the criteria by CLSI (2018), 8 μg/mL and 4 μg/mL of LVX were added in the media for *E. coli* and *S. aureus* cultivation, respectively; 16 μg/mL of TC for both *E. coli* and *S. aureus*.

Quantitative microbial risk assessment (QMRA)

Annual chance of infection and annual disease burden in DALY per person was estimated for diarrhea caused by oral exposure to *E. coli* and impetigo caused by skin exposure to *S. aureus*. Exposure scenario in irrigation was developed based on the interview survey to lotus root farmers (N=22). In growing period in June and July, the median of working time were 0.7 hours/day and 17-18 days/month; in the harvesting period from August until May, 7 hours/day and 25-27 days/month, respectively. The oral exposure to water was estimated as 2.2 mL/hours, equivalent to wading (Dorevitch et al. 2011). Skin exposure to water was expected only on face, whose surface area was estimated as 561 cm^2 (Fujimoto et al. 1968; Kurazumi et al. 1994). The β-poisson model was used as dose-response model for diarrhea caused by *E. coli* and impetigo by *S. aureus*. Chance of infection by *E. coli* per event was calculated using N_{50}=8.60 x 10^6 and α=0.1778 (Haas et al. 2014) and dose *D* as total CFU in a working day, which was the median of E. coli at EOP. For impetigo by *S. aureus*, 6-hour work was considered as one event. Chance of infection by *S. aureus* on unit area (=3 x 3 cm^2) of skin surface per exposure event was calculated using N_{50}=2.38 x 10^5 and α=0.225, according to Kanaya et al. (2018). Dose *D* was as CFU/mL, the median of *S. aureus* at EOP. Chance of infection by *S. aureus* on the whole face skin area per event, P_{face}, was calculated as: $P_{face} = 1 - (1 - P_i)^N$, where: P_i: chance of infection on unit area (= 3x3 cm^2) of skin surface per event, N: the number of unit area in the whole face surface (=561/9). Annual disease burden in DALY was estimated for impetigo by *S. aureus*, according to Kanaya et al. (2018). Briefly, DALY per person was calculated as years lost due to disability (YLD) per person by: $DALY/person \fallingdotseq YLD/populatin = P_R \cdot DW \cdot T_R + (1 - P_R) \cdot DW \cdot T_S$, where P_R: chance of infection by ARB, DW: disability weight, T_R: time duration of disease caused by ARB, T_S: time duration of disease without antibiotic resistance. The disability weight DW of impetigo and diarrhea was 0.008 and 0.188, respectively. Duration for treatment was assumed as 7 days for non-resistant *S. aureus*, 14 days for resistant *S. aureus*, and 3 days for diarrhea by *E. coli*.

Results and Discussion

Antibiotic resistant E. coli and Staphylococcus aureus in irrigation water

About 10% of total *E. coli* in the irrigation water had resistance to LVX or TC at both POE and EOP (**Figure 2**). *E. coli* and resistant *E. coli* in EOP at irrigation site had low

correlation with those in POE at pump intake (R^2=0.60) (**Figure 3**). One possibility of the low correlation is effect of biofilm in the pipeline. Another possible reason is time lag between pumping at POE and sampling at EOP. High correlation of *S. aureus* (R^2=0.92) between POE and EOP suggested that *S. aureus* was not affected by timing of pumping nor irrigation pipeline. However, *E. coli* were likely affected because abundance of resistance decreased at EOP. Therefore, reserve of ARB in the pipeline is not always signification in indirect reuse water when it contains less ARB than directly reused water, in which pipeline of reclaimed water reported ly served as reservoir of ARB.

(a) *E. coli* (b) *Staphylococcus aureus*

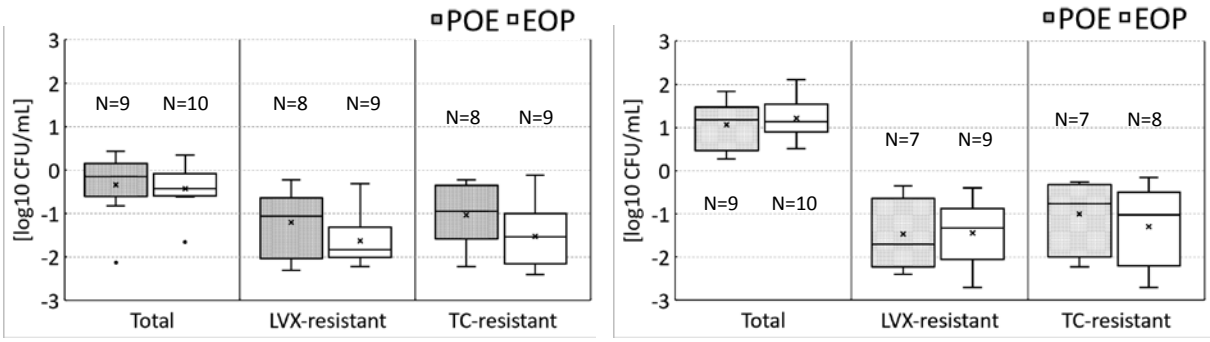


Figure 2 Concentration of (a) *E. coli* and (b) *Staphylococcus aureus* at intake of irrigation pump (POE) and irrigation tank (EOP)

(a) *E. coli* (b) *Staphylococcus aureus*

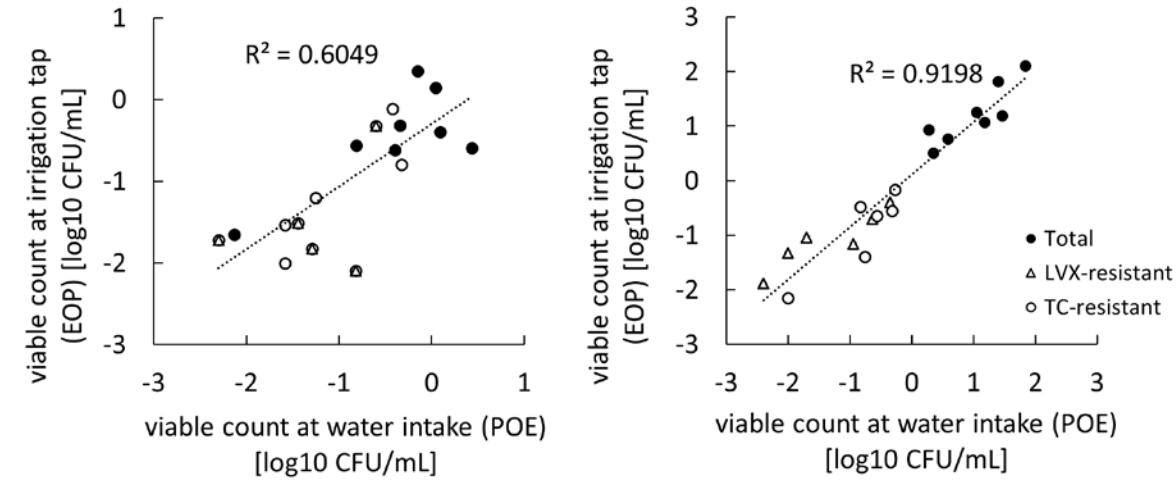


Figure 3 Correlation of (a) *E. coli* and (b) *Staphylococcus aureus* at intake of irrigation pump (POE) and irrigation tank (EOP)

Risk of lotus root farmers in de fact water reuse for irrigation

Estimated risk of diarrhea by *E. coli* was 1.4 x 10^{-4} as annual chance of infection (**Table 1**), which was on the border of acceptable risk by USEPA. Estimated risk of impetigo by *S. aureus* was very high at 5.5 x 10^{-1}, although it was probably highly overestimated due to limitation of available dose-response model (Kanaya et al. 2018)Due to the same reason, annual disease burden was also highly estimated at 1.33 x 10^{-2} [DALY/person] (**Table 1**) when we don't consider longer time for recovery by antibiotic resistance. When we consider antibiotic resistance, annual disease burden increased by 0.7% only with LVX resistance, by 2.7% with TC resistance. In this study, estimated elevated risk by antibiotic resistance was not remarkably high, because abundance of ARB to LVX and TC was about 0.5% and 1.9% respectively.

Table 1 Health risk of farmers by exposure to indirectly reused irrigation water

		Diarrhea by *E. coli*	Impetigo by *S. aureus*
Annual chance of infection	Total, AR not considered	1.36×10^{-4}	5.53×10^{-1}
Annual DALY per person [DALY/person]	Total, AR not considered	2.67×10^{-2}	3.09×10^{-2}
	Total, LVX considered	-	3.12×10^{-2}
	Total, TC considered	-	3.18×10^{-2}

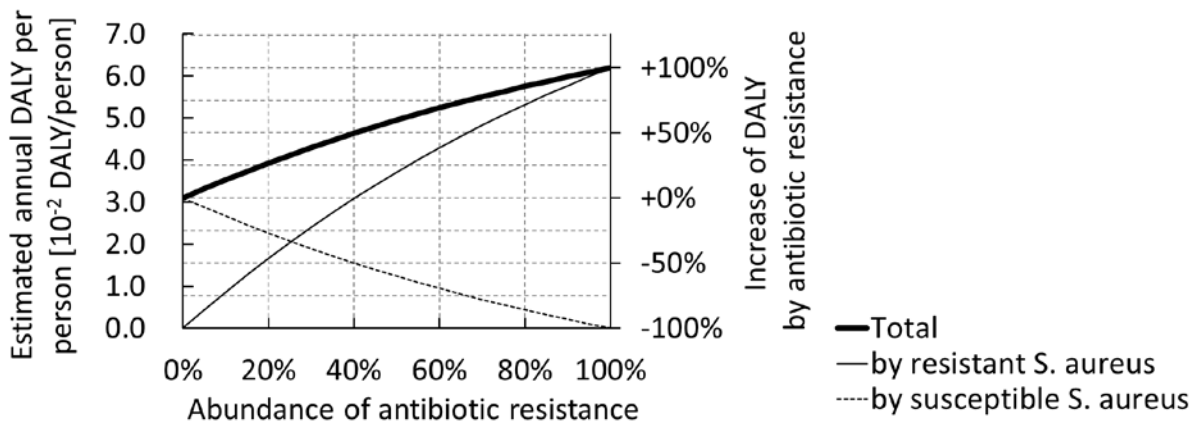


Figure 4 Annual disease burden estimated as DALY per person by increase in abundance of antibiotic resistant *S. aureus*

Annual disease burden would increase as abundance of antibiotic resistance, upto 6.2 x 10^{-2} DALY/person at maximum, equivalent to +100% of that without consideration of antibiotic resistance (**Figure 4**). Susceptibility of the increase in total disease burden by antibiotic resistance largely depends on the ratio of additional time for recovery caused by antibiotic resistance to the typical duration of disease without

antibiotic resistance. Therefore, accuracy of clinical data on duration of disease is essential for accurate estimation of elevated health risk by antibiotic resistance.

Conclusions

Annual disease burden as DALY per person was applied to QMRA considering possible difficulty of treatment caused by antibiotic resistance. Estimated annual disease burdens of impetigo increased by 0.7% and 2.7% because of LVX- and TC-resistant *S. aureus*, respectively.

References

Dorevitch, S., Panthi, S., Huang, Y., Li, H., Michalek, A. M., Pratap, P., Wroblewski, M., Liu, L., Scheff, P. a, and Li, A. (2011) Water ingestion during water recreation. Water research, 45(5), 2020–8.

Fujimoto, S., Watanabe, T., Sakamoto, A., Yukawa, K., and Morimoto, K. (1968) Studies on the Physical Surface Area of Japanese. Nippon Eiseigaku Zasshi (Japanese Journal of Hygiene), 23(5), 443–450.

Haas, C. N., Rose, J. B., and Gerba, C. P. (2014) Quantitative Microbial Risk Assessment: Second Edition, Wiley.

Honda, R., Hara, Y., Sekiyama, M., and Hiramatsu, A. (2010) Impacts of housing development on nutrients flow along canals in a peri-urban area of Bangkok, Thailand. Water Science and Technology, 61(4), 1073–1080.

Honda, R., Watanabe, T., Sawaittayotin, V., Masago, Y., Chulasak, R., Tanong, K., Tushara Chaminda, G., Wongsila, K., Sienglum, C., Sunthonwatthanaphong, V., Poonnotok, A., Chiemchaisri, W., Chiemchaisri, C., Furumai, H., and Yamamoto, K. (2016) Impacts of urbanization on the prevalence of antibioticresistant Escherichia coli in the Chaophraya River and its tributaries. Water Science and Technology, 73(2), 362–374.

Kanaya, Y., Prayoga, W., Pu, J., And Watanabe, T. (2018) estimations of risk of skin infection by waterborne pathogens and its health effects considering antibiotic resistance. Journal of Japan Society of Civil Engineers, Ser. G (Environmental Research), 73(7), III_125-III_137.

Kurazumi, Y., Horikoshi, T., Tsuchikawa, T., and Matsubara, N. (1994) The body surface area of Japanese. Jpn J Biometeorol, 31(1), 5–29.

Quantitative Microbial Risk Assessment of Non-potable Water Reuse by MBR and CAS based on Long-term Virus Monitoring Data

K. Sasaki[1], D. Sugita[1], Y. Tang[1], M. Ihara[1], N. Yamashita[2], H. Tanaka[1]

[1] Kyoto University, Otsu, Shiga Japan, [2]Ehime University, Matsuyama, Ehime, Japan

htanaka@biwa.eqc.kyoto-u.ac.jp

Abstract:

Membrane bioreactor (MBR) has become one of the promising processes than conventional activated sludge process (CAS), but their difference in virus removal has remained unclear. To investigate virus removals by MBR and CAS, this study carried out a two-year monitoring of occurrences in norovirus, aichivirus, PMMoV, and F-specific RNA phages by qPCR method. Virus log10 removal values (LRVs) for each virus were estimated based on influent and effluent statistical virus distribution. As a result, LRVs of all viruses at both the processes followed lognormal distribution and their means of MBR were higher than those of CAS, but their coefficients of variation of MBR were less than those of CAS. Furthermore, quantitative microbial risk assessment (QMRA) based on the statistical analysis data demonstrated that further reduction following both MBR and CAS are necessary for non-potable urban reuse if WHO's tolerable risk level would be applied, but necessary reduction following MBR is two-order magnitude lower than CAS.

Keywords: water reuse; membrane bioreactor (MBR); conventional activated process (CAS); virus removal; log-normal distribution; quantitative microbial risk assessment

Introduction

Water reuse is regarded as an appropriate and cost-effective option to address water shortage. As a promising wastewater treatment process, membrane bioreactor (MBR) takes significant advantages over conventional activated sludge (CAS) process, providing a high-quality effluent within small footprint (Wu et al., 2010). As development of this process, it provided a new insight to enlarge amount of non-potable reclaimed water from municipal wastewater.

While one of the most important concern in water reclamation is guarantee of water quality to protect public health, especially pathogenic viruses. It was reported that

MBR process could perfectly reject bacteria (Ottoson et al., 2006), and some studies demonstrated log-removal values of bacteriophages and pathogenic viruses using MBR process (Simmons el at., 2011), while few studies carried out analyses from a large number of samples. Silva et al. (2008) found that large variations in virus density, which may be partially explained by inhomogeneity of enteric virus particles in the water bodies, owing mainly to the formation of aggregates or binding to suspended solids. However, in order to carry out a reliable risk assessment, it is necessary to construct dataset of virus concentrations based on long-term monitoring and use acceptable statistic methods to analyze.

In this study, long-term monitoring of virus concentrations was carried out at a demonstration-scale MBR and a full-scale CAS process in a sewage treatment plant (STP) in Japan, and quantitative microbial risk assessment (QMRA) was applied to evaluate pathogenic risks of the reclaimed water produced by MBR and CAS in the STP under non-potable water reuse scenarios.

Material and Methods

The information of target monitoring STP and sampling was shown in Table 1. The concentrations of GI-norovirus (GI-NoV), GII-norovirus (GII-NoV), aichivirus (AiV), pepper mild mottle virus (PMMoV), GI-FRNA phage (GI-FRNAPH), GII-FRNAPH and GIII-FRNAPH were quantified by quantitative reverse transcription-polymerase chain reaction (RT-qPCR).

Table 1. Characteristics of STP

Process	HRT (h)	SRT (d)	Inflow rate (m^3/d)	MLSS (mg/L)	Sampling period
MBR	4.3	24	432	6,000-8,000	2014/08-2016/12 (n=156)
CAS	6.3	13	157,000	1,000-1,500	2014/09-2016/12 (n=111)

The monitoring data were assumed to follow log-normal distribution, and then this assumption was validated by Kolmogorov-Smirnov (K-S) to evaluate goodness of fit. In the test of goodness-of-fit, empirical cumulative density function (CDF) was calculated with all monitoring data including negative values which were under the detection limit, however, only positive data were shown in the plot. With regression analysis of virus log concentrations and CDF, means and standard deviations were determined to distributions of virus concentrations in the influent and secondary

effluent for the MBR and CAS process, resulted in calculation of virus log removal values (LRVs), respectively.

Among seven viruses, norovirus, as one of the most important waterborne pathogens and a leading cause of sporadic gastroenteritis (Pang et al., 2014), was chosen to perform QMRA. To compare the safety of the secondary effluent between MBR and CAS processes, it was assumed that GII-NoV concentration was the same in the influent, thus virus concentrations in the effluent could be calculated with responding LRV. Six exposure scenarios included recreation for whole body (scenario I), recreation for hand and foot (scenario II), fall and fountain (scenario III), fishing pond (scenario IV), and environment enhancement (scenario V) (Itoh et al., 2016). Infection probability was provided a dose-response model (Messner et al., 2014) was conducted to provide of GII-Nov for risk assessment. Meanwhile, to make the exposure estimates used in this study reliable, a Monte Carlo procedure was made for 10000 iterations, and disability adjusted life years (DALYs) were computed to evaluate the disease burdens for risk assessment (Lopez et al., 2006).

Results and Discussion

Log-normal distributions of virus monitoring data. The results from the probability plots and goodness-of-fit tests for each virus in the influent and secondary effluent of CAS and MBR process were shown in Figure 1, which indicated that at the 10% significance level, each dataset containing long-term monitoring data of virus concentrations followed the log-normal distribution. Similar conclusion was carried out by Tanaka et al. (1998) that monitoring data on enteric virus concentrations in the secondary effluents in California was seen to behave in the same manner.

Data were fitted to log-normal distributions, and the summary of statistics for mean and standard deviation using regression analysis were shown in Table 2. The results indicated that even though virus concentrations in the influent of MBR process had at least an order of magnitude more than concentrations in the influent of CAS process, concentrations for seven viruses in the secondary effluent of MBR process were lower than that in CAS process.

Virus log removal values (LRVs) on CAS and MBR process. Based on the statistic parameters obtained from long-term monitoring towards virus concentrations

Table 2. Means and standard deviations on log-normal distribution of virus concentrations in influent and secondary effluent for MBR and CAS process

	MBR (n=156[a])				CAS (n=111)			
	Influent (Log copies/L)		Effluent (Log copies/L)		Influent (Log copies/L)		Effluent (Log copies/L)	
	μ[b]	σ[c]	μ	σ	μ	σ	μ	Σ
GI-NoV	3.6	1.3	NA[d]	NA	1.1	2.5	2.4	1.0
GII-NoV	4.6	0.8	1.7	1.6	3.9	1.6	3.2	1.1
AiV	5.2	1.1	0.2	2.1	3.4	1.9	3.0	0.9
PMMoV	7.3	0.9	3.5	0.7	5.9	1.2	6.1	0.8
GI-FRNAPH	4.8	0.8	2.2	1.4	3.6	1.0	3.6	0.7
GII-FRNAPH	6.2	0.8	3.8	0.8	4.8	1.3	4.3	0.7
GIII-FRNAPH	3.9	0.7	0.8	0.8	2.9	1.3	1.3	0.8

[a] number of samples; [b] mean; [c] standard deviation; [d] not available

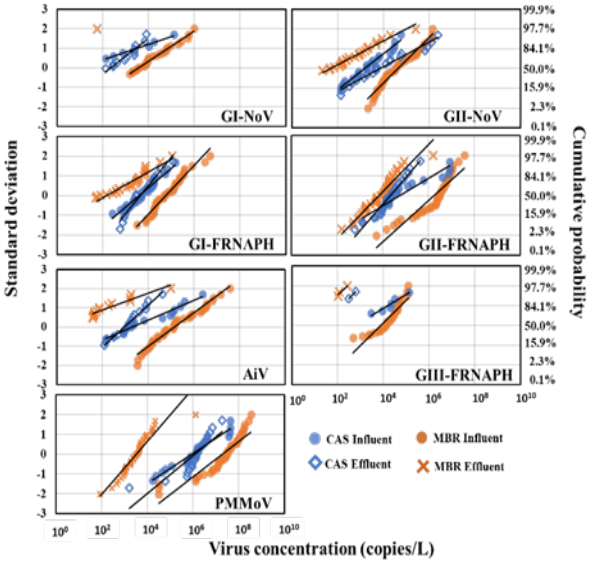


Figure 1. CDF of virus concentrations in influent and secondary effluent for MBR and CAS process

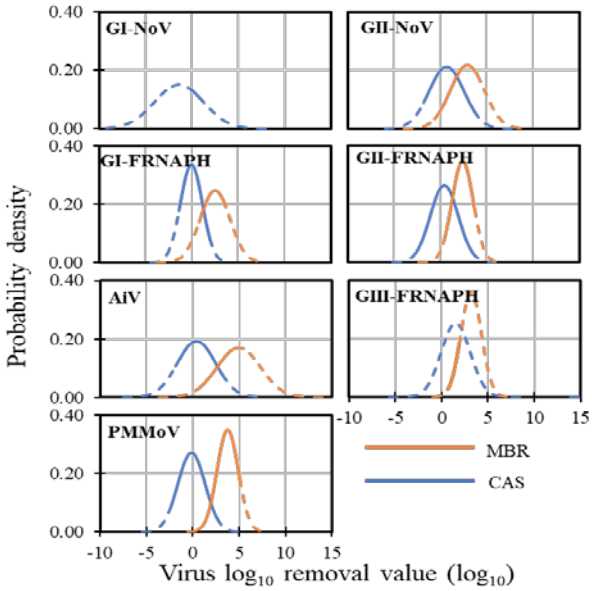


Figure 2. Viruses LRVs for CAS and MBR process

in the influent and secondary effluent, virus removal capabilities of CAS and MBR processes were evaluated with LRV through mathematic calculation. The results were presented in Figure 2. MBR process showed an obvious higher LRV than CAS less fluctuation than CAS process in terms of virus log-removal.

QMRA for non-potable reclaimed water. The result of QMRA concluded 5th, 50th and 95th percentiles values of disability adjusted life time per person per year (DALYpppy) is shown in Figure 3. However, the 95th percentile values which gave an estimate of reasonable maximum of the risk, were mainly concerned in the plot. In addition, if 10^{-6} DALYpppy would be achieved at 95th percentile, necessary LRVs

after MBR and CAS processes were estimated in this study, and were presented in Table 4. As the result, significantly higher LRV needs in CAS, while two-order magnitude lower LRV would need for MBR than CAS.

Table 3. Coefficients of variation on LRVs for MBR and CAS process

	MBR	CAS
GI-NoV	NA	1.9
GII-NoV	0.6	2.8
AiV	0.5	5.3
PMMoV	0.3	9.9
GI-FRNAPH	0.6	32.0
GII-FRNAPH	0.5	3.5
GIII-FRNAPH	0.3	1.0

Table 4. Virus removal values for advanced treatment for MBR and CAS process

Exposure scenarios	MBR LRV	CAS LRV
Recreation (whole body)	4.0	6.4
Recreation (hand and foot)	2.1	4.5
Fall and fountain	2.4	4.8
Fishing pond	1.9	4.3
Environment enhancement	1.6	4.0

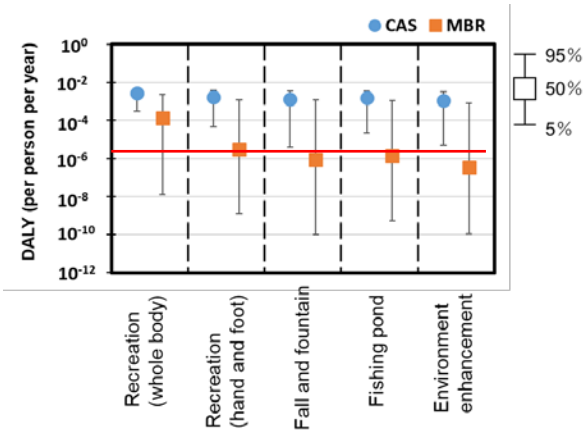


Figure 3. Estimated DALYs pppy of non-potable reclaimed water by MBR and CAS process

Conclusions

As indicated in the two-year monitoring data, virus concentrations in the influent and effluent of MBR and CAS followed log-normal distribution. MBR process performed a better virus removal than CAS process in terms of higher virus removal value and less fluctuation for LRV. Based on the result of QMRA, further viral reduction after MBR and CAS processes is necessary to meet WHO's tolerable risk level for non-potable water reuse. However, MBR needs two-order magnitude lower LRV than CAS in the following process.

Acknowledgements

The authors thank Water Reuse Promotion Center and relevant municipality for allowing us to perform sampling at MBR facility and sewage treatment plants. This research was financially supported by Japan Ministry of Economy, Trade and Industry, and Japan Society for the Promotion of Science.

References

Itoh Y et al., Determination of performance target values for enteric virus removal in wastewater reclamation, J of Japan Society of Civil Engineering G(Env.), 2016, 72(7): III_305-III_313 (in Japanese).

Lopez A D et al. Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data. The Lancet, 2006, 367(9524): 1747-1757.

Messner M J, et al. Fractional Poisson—A simple dose-response model for human norovirus. Risk Analysis, 2014, 34(10): 1820-1829.

Ottoson J, et al. Removal of viruses, parasitic protozoa and microbial indicators in conventional and membrane processes in a wastewater pilot plant. Water Research, 2006, 40(7): 1449-1457.

Pang X L, et al. Enhanced enteric virus detection in sporadic gastroenteritis using a multi-target real-time PCR panel: A one-year study. Journal of Medical Virology, 2014, 86(9): 1594-1601.

Silva A K, et al. Norovirus removal and particle association in a waste stabilization pond. Environmental Science & Technology, 2008, 42(24): 9151-9157.

Simmons F J et al. Removal of human enteric viruses by a full-scale membrane bioreactor during municipal wastewater processing. Water Research, 2011, 45(9): 2739-2750.

Tanaka H, et al. Estimating the safety of wastewater reclamation and reuse using enteric virus monitoring data. Water Environment Research, 1998, 70(1): 39-51.

World Health Organization. Guidelines for Drinking-water Quality. World Health Organization, 2004.

Wu J, et al. Indigenous somatic coliphage removal from a real municipal wastewater by a submerged membrane bioreactor. Water Research, 2010, 44(6): 1853-1862.

Risk-Based Guidance for Onsite Non-Potable Water Systems

Michael Jahne, U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH, USA; Mary Schoen, Soller Environmental, Inc., Berkeley, CA, USA; Jay Garland, U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH; jahne.michael@epa.gov

Abstract:

The U.S. Environmental Protection Agency Office of Research and Development has partnered with water utilities and public health agencies to develop risk-based guidance for onsite non-potable water systems. In this presentation, we will highlight these efforts, including quantitative microbial risk assessment (QMRA) of pathogen log-reduction targets for various source waters and onsite reuse applications; validation of model inputs (pathogen densities); and analysis of proposed treatment trains including failure/cross-connection scenarios. Ongoing work to address remaining research gaps, including additional assessments of alternative source waters and non-potable end-uses, will also be discussed.

Keywords: QMRA, decentralized systems, graywater, wastewater, norovirus, water reuse

Introduction

As increasing water stress continues to pressure existing water infrastructure, communities are exploring decentralized fit-for-purpose water treatment as a means to reduce demands on centralized water/wastewater systems. Onsite non-potable water systems (ONWS) collect and treat alternative water sources, such as locally-collected wastewater, graywater, rainwater, and stormwater, to appropriate quality levels for onsite irrigation, toilet flushing, and other non-potable uses (Sharvelle et al., 2017). These systems are promoted to achieve environmental and cost-efficiency benefits by limiting excess treatment levels and eliminating the need for distribution to/from centralized treatment facilities. However, their practical implementation has been hindered by uncertain human health risks and the lack of a regulatory framework for ensuring public safety (National Academies of Sciences, Engineering, and Medicine, 2016).

Through its Safe and Sustainable Water Resources Program (SSWR), the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD)

has partnered with state and local water utilities and public health agencies to develop risk-based guidance for ONWS programs. The first goal of this collaboration was to determine fit-for-purpose treatment levels, in the form of pathogen log-reduction targets (LRTs), for various combinations of source waters and reuse applications using quantitative microbial risk assessment (QMRA) (Jahne et al., 2017, Schoen et al., 2017). Results of this work were integrated into the WE&RF report Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems (Sharvelle et al., 2017), which disseminated results for direct use by regulatory agencies and other stakeholders. A continuation of this partnership, the National Blue Ribbon Commission for Onsite Non-Potable Water Systems (NBRC), has published further guidance documents to promote and facilitate the adoption of ONWS, including model regulations and ordinances as well as a business case for utilities and guidebook for program implementation (www.uswateralliance.org/initiatives/commission/resources).

Following publication of these guidances, EPA-ORD has continued to address identified research gaps related to ONWS risk. These efforts have included validation of pathogen characterizations for untreated source waters used as model inputs; risk analysis of proposed treatment trains including failure conditions (Schoen et al., 2018b); and QMRA of potential cross-connections in ONWS (Schoen et al., 2018a). Ongoing studies include continued influent pathogen density model validation; alternative source water characterizations; and LRTs for additional end-uses. Throughout this work, the implications of results for regulators and utilities adopting ONWS programs have been shared regularly with the community though SSWR webinars, fact sheets, and public webpages (www.epa.gov/water-research/onsite-non-potable-water-reuse-research), as well as through ongoing collaboration with the NBRC. In this presentation, we will highlight our efforts to provide risk-based guidance for communities adopting ONWS, including modeled pathogen LRTs; subsequent validation of QMRA models; the analysis of treatment trains and failure/cross-connection scenarios; and ongoing work to address remaining research gaps. More information on each of these topics is provided below.

Pathogen Log-Reduction Targets for ONWS

This study included two components: epidemiology-based simulation of influent pathogen densities for onsite-collected wastewater and graywater (Jahne et al., 2017) and QMRA of LRTs for various source waters and end-use applications (Schoen et al., 2017). The former was necessary due to lack of available pathogen measurements in graywater and decentralized wastewater, which differs from combined municipal wastewater due to population scaling and dilution effects, particularly as related to variable frequencies of infection and pathogen shedding among small numbers of system users. Indeed, results demonstrated that the predicted frequency of pathogen occurrences in local wastewaters was generally low due to low infection incidence within small cohort groups, but increased with collection scale (population size) and infection incidence rate (e.g., of norovirus). When pathogens did occur, a decrease in concentrations from 5- to 100- and from 100- to 1,000-person systems was observed. This highlights value of the model over averaging methods, which overestimate the frequency of pathogen occurrence in small systems while underestimating concentration peaks that drive risk periods.

In the second component, these pathogen characterizations and those modeled for additional source waters (roof-collected rainwater and stormwater) were combined with relevant exposure pathways during non-potable uses (unrestricted irrigation, toilet flushing, and clothes washing) though a probabilistic QMRA to estimate the pathogen LRT required to achieve acceptable risk benchmarks (10^{-2} or 10^{-4} infections/person/year). The difference in treatment requirements among source waters was driven by the microbial quality of the water – both the density and occurrence of reference pathogens. Graywater from collection systems with 1,000 people had greater LRTs than those for graywater collected from a smaller population (5 people), which have less frequent pathogen occurrences. Stormwater had highly variable microbial quality, which resulted in a range of possible treatment requirements. The microbial quality of roof runoff, and thus resulting LRTs, was uncertain due limited relevant pathogen data.

Model Validation Measurements

The initial pathogen LRT study found that little direct pathogen monitoring data was available for alternative water sources used in ONWS, and that QMRA results were highly dependent on modeled characterizations. As such, an effort was conducted to quantify key reference pathogens that drive risks in decentralized wastewater and

graywater (manuscript in preparation). In this study, onsite-collected graywater and wastewater samples from three decentralized collection systems were analyzed for two norovirus genogroups and adenovirus using droplet digital polymerase chain reaction (ddPCR). Norovirus GII was routinely quantifiable in combined wastewater (96% of samples) with a density range of 5.2–7.9 $\log_{10}$genome copies/L. These concentrations are greater than typically reported in centralized municipal wastewater, yet agree well with the epidemiology-based model used to develop pathogen LRTs for ONWS. Results emphasize the unique quality of onsite-collected wastewaters, supporting the previous LRTs and further QMRA of decentralized water reuse.

Treatment Train QMRA

Following development of the LRTs, it was of interest to examine the ability of proposed ONWS treatment trains to achieve them. Membrane bioreactors (MBRs) are ideally suited for these applications given their comparatively low capital costs and small physical footprints. As such, we assessed the annual probability of infection resulting from non-potable exposures to graywater and wastewater collected from residential or office buildings and treated by an aerobic MBR followed by chlorination, which would likely be required to protect the quality of distributed water (Schoen et al., 2018b). Predicted risks were less than the selected health benchmark (10^{-4} infections/person/year) for all pathogens except *Cryptosporidium* spp., given the selected exposure (which included occasional, accidental ingestion), dose-response, and treatment performance assumptions. However, available MBR treatment performance data was extremely limited and additional data on MBR removal of protozoan and viral pathogens is needed to further evaluate these processes. As in previous work, the differences in pathogen characterization between collection types and scales drove the differences in predicted risk, and the accidental ingestion event (although modeled as rare) determined the annual probability of infection. High predicted risks resulting from treatment malfunction scenarios indicates that online, real-time monitoring of both the MBR and disinfection processes remains important for non-potable reuse at distributed scales.

Cross-Connections Assessment

In the original LRTs, we included a rare cross-connection or accidental ingestion event affecting 10% of the population for one day per year (2L ingestion) in indoor

exposure estimates. We then re-evaluated this assumption by considering the duration and frequency of these events needed to exceed acceptable risk levels in systems achieving proposed pathogen LRTs (Schoen et al., 2018a). The predicted annual infection risk remained below the selected benchmark (10^{-4} infections/person/year) given isolated, short-duration intrusion (i.e., 5-day) events of reclaimed water into potable water. Whereas, intrusions of wastewater into reclaimed, non-potable water resulted in unacceptable annual risk without large dilutions or pathogen inactivation. Overall, the predicted annual risks support the use of previously derived LRTs for a variety of ONWS sizes and support the prioritization of protective measures to prevent the intrusion of wastewater into domestic ONWS.

Ongoing and Future Work

Current studies are focused on continued QMRA model validation and extension of the risk-based framework to additional source waters and non-potable end-uses. Roof-collected rainwater samples are currently being collected in diverse climate regions throughout the U.S. to improve the pathogen characterization of that water source, for which extremely limited data was available for LRT determination. In future work, stormwater will be assessed in a similar fashion or through source-based modeling. Air conditioning condensate and non-potable showering use are also being examined as alternative water sources and end-uses for ONWS, respectively.

Conclusions

Taken together, this body of work provides scientific insight and practical guidance to support the continued implementation of decentralized water reuse. It emphasizes the unique considerations required for small-scale collection systems such as ONWS and offers a risk-based approach to determining appropriate fit-for-purpose onsite treatment levels. Ongoing collaboration with utilities and public health agencies, such as through the NBRC, ensures the continued impact of this research as well as further development responsive to partner needs.

References

Jahne, M. A., Schoen, M. E., Garland, J. L. and Ashbolt, N. J. (2017). Simulation of enteric pathogen concentrations in locally-collected greywater and wastewater for microbial risk assessments. Microbial Risk Analysis, 5, 44-52.

National Academies of Sciences, Engineering, and Medicine (2016). Using graywater and stormwater to enhance local water supplies: An assessment of risks, costs, and benefits. National Academies Press, Washington, DC.

NSF International (2017). NSF/ANSI Standard 350: Onsite Residential and Commercial Water Reuse Treatment Systems, NSF International, Ann Arbor, Michigan.

Schoen, M. E., Ashbolt, N. J., Jahne, M. A. and Garland, J. (2017). Risk-based enteric pathogen reduction targets for non-potable and direct potable use of roof runoff, stormwater, and greywater. Microbial Risk Analysis, 5, 32-43.

Schoen, M., Jahne, M. and Garland, J. (2018a). Human Health Impact of Cross-Connections in Non-Potable Reuse Systems. Water, 10(10), 1352.

Schoen, M. E., Jahne, M. A. and Garland, J. (2018b). Human health impact of non-potable reuse of distributed wastewater and greywater treated by membrane bioreactors. Microbial Risk Analysis, 9, 72-81.

Sharvelle, S., Ashbolt, N., Clerico, E., Hultquist, R., Leverenz, H. and Olivieri, A. (2017). Risk-Based Framework for the Development of Public Health Guidance for Decentralized Non-Potable Water Systems. Prepared by the National Water Research Institute for the Water Environment & Reuse Foundation, Alexandria, VA.

Murcia´s experience in the use of reclaimed water for agricultural irrigation

Pedro Simón Andreu, ESAMUR, Murcia, Spain

Abstract

Murcia region is one of the driest region in Europe, with an anual rainfall of 350 mm per year. At the same time, due to the warm weather, the agricultural production is very high (more than 2,6 million tons of agricultural products are grown every year in the region). It means we have to obtain the most of every drop of water. One of the safer water sources is reclaimed water. We have a lot of experience about the different technologies to reclaim the water, with an important knowledge about weak and strong points of them. Also the food safety is a priority for us. We make a lot of research about reclamation technologies, reliability of the facilities and effects of the irrigation practice in the crops. It´s being studied not only the effect of possible pathogens, also emerging compounds are considered.

Regarding the new european proposal for a Regulation on minimum requirements for water reuse in agricultural irrigation, the effects of this new regulation for our reclamation facilities have been studied, studying the needed changes in the reclamation plants for meeting it.

Keywords : Reclamation technologies, food safety, regulation on water reuse.

Experience

Murcia is a region in the southeast of Spain with a population around 1,5 million of inhabitants, being agriculture and tourism the main economic pillars in the region.

Due to the water scarcity in Mediterranean regions, and specially in the Segura river basin, water reuse is been practiced for many years in Murcia region.

The most of the 97 WWTPs of the region have advanced tertiary treatment, with disinfection system in all of them. The efficiencies obtained in removal of pollution are very high (around 99 % in BOD5 efficiency), and that is key point for getting a good disinfection.

In Spain there is a regulation for water reuse, which is laid down by the Royal Decree 1620/ 2007. This regulation consider many possible types of water reuse: agricultural irrigation, domestic uses , for landscapes or urban uses, and so on. The most extended use in Murcia region is agricultural irrigation. To get an idea of the strictness of this regulation requirements, the maximum value allowed for irrigation of food crops where the edible portion is in direct contact with reclaimed water and they are consumed raw, is 100 c.f.u. / 100 ml of E.Coli,in the point of use. To put this value in context, we can take into account Commision notice on guidance document on addressing microbiological risks in fresh fruits and vegetables at primary production through good higiene (2017/C 163/01) which considers safe the value of 100 c.f.u. / 100 ml of E.Coli, for the irrigation of these food crops or the Directive 2006/7/EC of 15 February 2006 concerning the management of bathing water quality which considers the limit 500 c.f.u./100 ml of E. Coli like excellent for inland waters.

In Murcia Region we have many different types of tertiary treatments. The most usual processes are : Physico-chemical process, lamellar settlement, filtration and disinfection. Moreover there are 9 MBRs and 1 ultrafiltration. Regarding the filtration, the half of them are open sand filtration, but others types are pressure sand filtration, clothes (MECANA), discfilters (VEOLIA and NORDIC) and ring filters. About the disinfection, the most usual system is UV radiation (open channel and reactor, low and medium pressure), but sometimes is also used chlorine compounds, specially when the water transmittance is low (below 60%).

Figure 1 Open sand filter

Figure 2 UV radiation equipment

Figure 3 Chlorine labyrinth tank

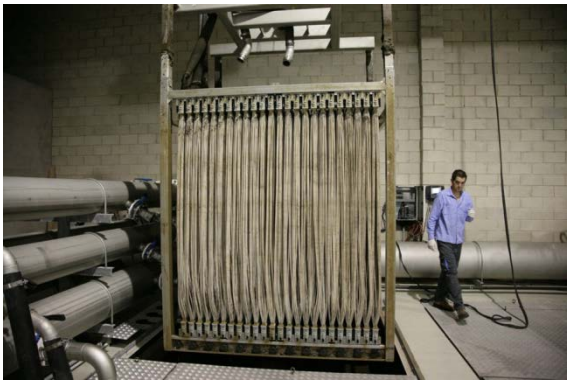


Figure 4 MBR membranes

Main challenges in water reuse

The main challenges we have are :

- To improve every day the treatments reliability, eficiency and harmlessness
- To advance in food safety with affordable treatments
- To research about new threats as emerging compounds, antimicrobial resistance, etc

Reliability is improved by a very strict maintenance, continuous learning of the equipments and troubles and working in fast detection of pathogens. For increasing the efficiency we are working with some technologies as CFD, tracers, size particles studies, etc

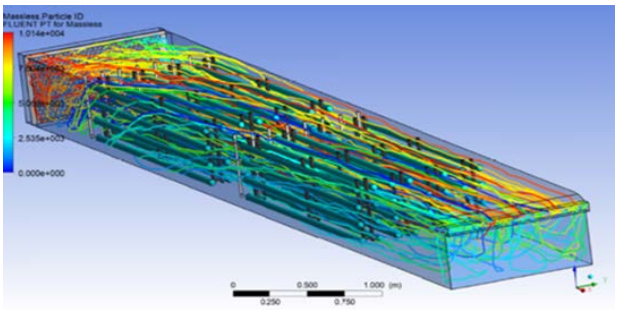


Figure 5 CFD studies **Figure 6 Tracer studies**

Also it´s being studied the byproducts produced by chemicals as chlorine compounds, with a strict control of chemicals storage conditions and dosages.

Regarding food safety, studies have been made in a big greenhouse in a WWTP, checking the effect of irrigation with different types of water in the microbiological condition of the crops. Currently, two large-scale risk assessment studies are running in real crops. In these studies many different and demanding possibilities are being studied. Two different disinfection treatments (UV radiation and sodium hypochlorite), different types of irrigation networks, several irrigation systems (flood, sprinkler and drip). Chosen crops are really demanding (lettuce and spinach), which can be eaten raw and the edible part can be in contact with reclaimed water. We are measuring microbiology in all the phases of irrigation system, from the influent to the WWTP to the harvested product. Measured microbiology is, not only indicators (E. Coli, coliphages and Clostridium spores, also real pathogens (Salmonella, E. Coli 0157: H7, norovirus).

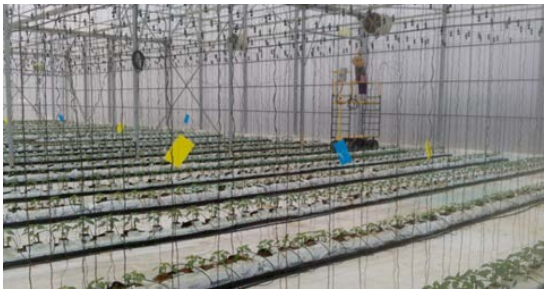


Figure 7 Greenhouse for studies **Figure 8 Risk assessment studies**

Other work lines are related with the study of emerging compounds and antimicrobial resistance in the WWTPs, which are the concentrations in the inlet

and the removal in the facilities. Also several removal systems of emerging compounds are being studied, in pilot plants and also at large scale (ozone and carbon active) in some of our facilities.

Lastly, other of our activities in the last years was the assessment of the european proposal of Regulation on minimum requirements for water reuse. We welcome a new european regulation but this regulation should be safe and also viable. In our opinion, the proposal of EC is not bad, we think it garantees a safe reuse, but some aspects should be improved for improving the viability and affordability. For example to charge all the responsability in the operator of the reclamation plant is a mistake because the main interest in the water reuse is for the end user who is going to use this water. Operator is not interested to ask for the reuse permit or to make the required risk assessment or following risk management, specially because the operator hasn´t any authority once he has delivered the reclaimed water. Other matter should be improved is the validation process for class A, to make it more viable, because selection of Clostridium spores as indicator of protozoa is a very bad selection. This parameter is a bad indicator of protozoa and, moreover, is much more difficult to remove than any protozoa.

Summarizing, in Murcia Region there is a huge experience in water reuse since many years ago, there has not been any problem with this practice in terms of food safety and we are working and working every day on it to improve this practice every day.

Water Reseach Foundation's Agricultural Water Reuse Research Efforts

Kristan C. VandenHeuvel, The Water Research Foundation, Alexandria, Virginia, USA

The potential for use of recycled water for agricultural irrigation is especially promising in the air and semi-arid regions of the world where groundwater depletion is an issue. This potential remains underutilized due to various challenges to agricultural reuse. To address this need, The Water Research Foundation (WRF) is currently funding a series of agricultural water reuse research projects and developing an agricultural water reuse research agenda to address timely research needs.

WRF is a nonprofit research cooperative officially formed in January 2018 as the result of the integration of the Water Environment & Reuse Foundation and the Water Research Foundation, with the mission of providing exceptional water research to advance science and technology. The new Foundation serves all areas of drinking water, wastewater, stormwater, and reuse through innovative, actionable research. The Foundation also plays an important role in the translation and dissemination of applied research, technology demonstration, and education through creation of research-based educational tools and technology exchange opportunities.

The WRF agricultural water reuse research portfolio includes fifteen projects covering topics in economics and policy, sustainable practices, and management approaches. Several research efforts are currently underway. The ongoing projects provide information on the status of irrigated agricultural water reuse in the United States and abroad (Reuse-15-08), economic benefits of reuse for agriculture (Reuse-16-06), and the impacts of the FDA Food Safety Modernizations Act Produce Safety Rule on reuse (Reuse-16-07). A summary of findings from ongoing WRF agricultural water reuse research projects will be presented.

Planned indirect potable water reuse to overcome water deficit in Vendée (France): "Jourdain" project as an experimental demonstrator

Jérôme Bortoli, VENDEE EAU, La Roche sur Yon, France, Julien Orsoni, VENDEE EAU, La Roche sur Yon, France, Julien.orsoni@vendee-eau.fr

Abstract:

Currently the Vendée coastal area is suffering high water stress. New national studies estimated the anthropic pressure and the future water needs taking into account the population growth, the climate change and the adaptation and mitigation measures at 2070 time horizon. At the moment conventional solutions are already implemented for short-term risk mitigation. In addition, Vendée Eau develop a non-conventional solution of indirect potable reuse from a coastal WWTP as a surface water augmentation of a fresh water reservoir used for drinking water production. The implementation of a 1:4-scale demonstrator ("JOURDAIN") is the first step of the reuse solution because of the absence of regulations and unprecedented cases of IPR in France.

Water reuse; Indirect Potable Reuse; Demonstrator

Introduction

Vendée Eau, the French public body in charge of production and distribution of drinking water for 650 000 inhabitants on the west coast of France (46 million m3 of drinking water produced per year), develops different solutions to anticipate the water scarcity risk increase because of climate change and demographic pressure.

The current situation of water availability in Vendée is approached by the WULCA working group that developed the AWARE index to describe the pressure on the water resource all over the world. AWARE is to be used as a water use midpoint indicator representing the relative Available WAter REmaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met. The last AWARE publication (Boulay, 2016) highlights the high water stress in the Vendée coastal area.

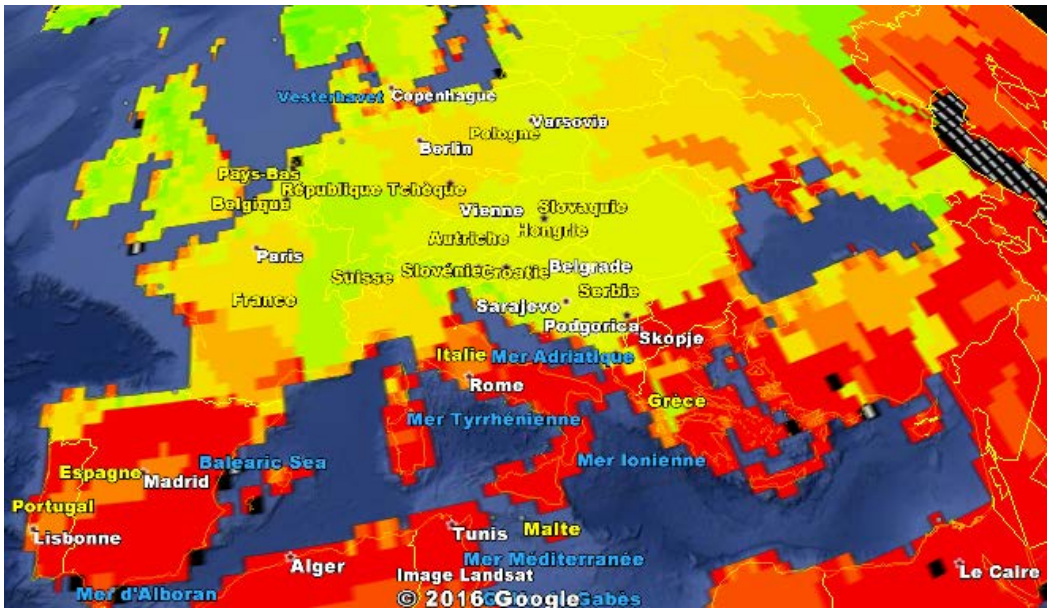


Figure 1 - Map of AWARE Index of water stress in Western Europe

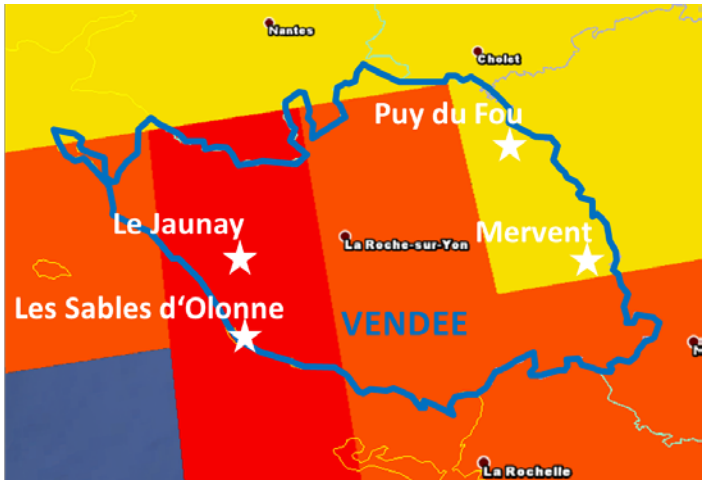


Figure 2 - Map of AWARE Index of water stress in Vendée (France)

Furthermore the French Environment Ministry lead in 2013 a big prospective study in order to estimate the anthropic pressure and the future water needs taking into account the population growth, the climate change and the adaptation and mitigation measures at 2070 time horizon. Vendée appears as a region where freshwater withdrawals for drinking water needs are to increase. Hence, regardless of the adaptation to climate change scenario, in 2070, the Vendée coastal area will be the only area of France where drinking water demand outstrips supply.

Vendée Eau has developed since 2010 a range of solutions to balance the risk of water shortage for future generations. It includes at first measures to achieve and

maintain high standard of performance on the drinking water facilities (drinking water treatment plants and water distribution networks). Besides conventional solutions has been developed and set up such as: drinking water transfer, implementation of new groundwater facilities, raw freshwater storage using former mining quarries, elevation of water dams to increase the storage capacity…

Finally, two non-conventional solutions have been investigated:

- Seawater desalination: a feasibility study (2013) pointed out high technical, environmental, economic and energetic constraints that lead Vendée Eau to postpone this solution.
- Waste water reuse : the wastewater reclamation of a coastal WWTP (Olonnes) affords a capacity of 1.0 to 1.5 million of m3 to increase the refilling of the Jaunay reservoir used for drinking water production.

Indirect potable reuse (IPR) is an interesting track to explore, considering the large volume of treated wastewater discharged directly in the ocean from the large coastal touristic zones during the summer period.

From 2014 to 2016, Vendée Eau was involved in the DEMOWARE European research program as a greenfield site to evaluate the feasibility and the impacts of an indirect potable reuse scheme. The results of DEMOWARE program conclude that the technical practicability needs to be consolidated by an experimental phase with a reduced scale demonstrator.

Material and Methods

Vendée Eau plans to install a demonstrator site at the outlet of the wastewater treatment plant near Les Sables-d'Olonne, dubbed the "Jourdain" project. Once treated, the water will be carried via a new pipeline to the Jaunay river, around 20 km northwest, where it will be used to produce drinking water. The treated water will provide an additional resource to help meet future needs in the coastal region. The demonstrator will incorporate the full range of aspects involved in this type of project, including treatment technologies, risk management, health and environmental impact analysis, injection point optimization and social acceptance.

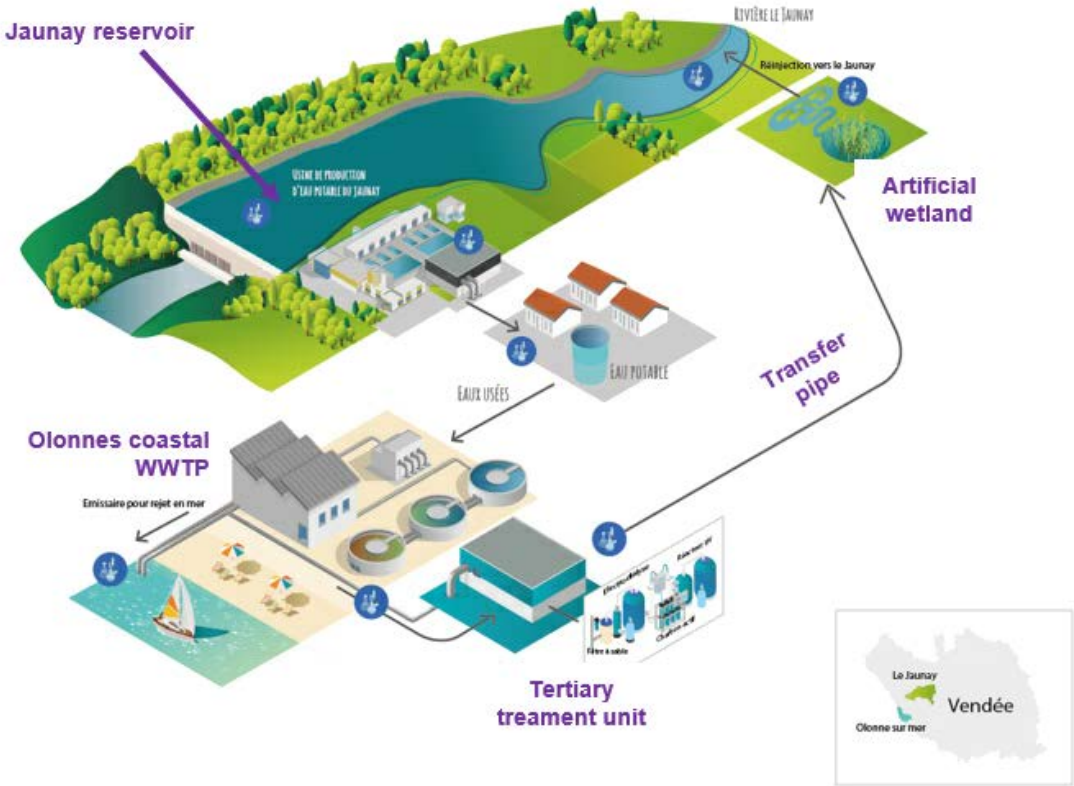


Figure 3 – Illustration of the Jourdain demonstrator project

The demonstration step will give the opportunity to have a complete reuse scheme (tertiary treatment plant, transfer pipe, plus eventual additional wetland before discharge in the river or reservoir) that will be operated during 5 years to precisely define the impacts of the reuse discharge in the aquatic compartments and to demonstrate that this system meets all the sanitary and environment requirements.

This innovative project will be strictly monitored and supervised to constantly check on the quality of the refined water and to protect altogether the drinking water purpose and the good ecological status achievement for the Jaunay reservoir.

Results and Discussion

Since the end of the DEMOWARE program (end of 2016), the JOURDAIN project has been labeled by the French competitivity cluster « Dream » of innovation in water field and Vendée Eau has launched the first steering committee of the project in May 2018. Additional studies are currently unfolding to prepare the construction of the demonstrator in 2021.

For the next months, Vendée Eau will focus on conducting large analytical campaigns in the Jaunay reservoir to reinforce the description of the initial state of the system. The analytical strategy set up encompasses different approaches: physicochemical analysis, residues of medicinal products and emerging pollutants, non-target analysis, bioindicators, bioassays, …

In 2018, during 6 months, a small pilot was in place in the WWTP to test and evaluate the efficiency of an electrodialysis unit coupled to an activated carbon reactor. This industrial pilot scale of a water treatment process has been a good opportunity to test new analytical methods.

The next phases of the Jourdain project are:

2019-2020: Additional studies:

- Additional analytical campaigns to consolidate the initial state.
- Detailed design of the reuse scheme.
- Regulatory studies relating to all the components of the project (tertiary treatment unit, transfer pipe, wetland, discharge in the river/reservoir …)
- Additional technical studies in particular quality modelling in the river/reservoir to precisely define the spreading and the dilution effects
- Continuing the actions for social acceptance.

2021: Construction of the tertiary treatment unit (150 m3/h) at the outlet of the Olonnes WWTP. Tender process under French Code of Public Procurement contracts

2022: first year of operating the treatment unit by discharging the effluent in the sea outfall pipe of the Olonnes WWTP. This first year will permit to validate and consolidate the efficiency of the unit and optimizing the risk management and operational safety approaches.

2022: simultaneously, construction of the transfer pipe to the Jaunay and implementation of a wetland.

2022-2026:

- Operating of the global reuse scheme with discharge in the Jaunay and comprehensive monitoring of the performance and the impacts.

- Multi-stakeholder research programs to enhance knowledge of such systems (French and European scales)
- Final evaluation

Over 2026: Based on the demonstrator results:

- Debate about a new regulation
- If results are compliant, possible implementation at full-scale of the Reuse system.

The total budget of the Jourdain project is estimated to be 17 million euros including 10 million euros of infrastructure costs and 7 million euros of 8-year monitoring and associated research programs.

Conclusions

Reuse of treated wastewater for all types of use (not only irrigation and watering) should be part of the solutions for adaptation to climate change for the French and European territories. The example of the JOURDAIN project of indirect potable reuse demonstrator in Vendée is intended to expose the approach undertaken by the territorial community and the difficulties to overcome for the implementation of such an innovative solution.

Challenges of Jourdain project go beyond the crucial needs in terms of water supply for the local territory. Indeed, wastewater reuse appears to be a valuable lever to face water scarcity in the whole department of Vendée, and other wastewater reuse projects could emerge and be integrated within an overall water circular economy strategy. Moreover, since the project will likely be the first reference in Europe of controlled and monitored surface water recharge for indirect potable reuse, the project has the ambition to become a research and demonstration application tool.

References

Boulay, A.-M., Bare, J., Benini, L., Berger, M., Lathuilliere, M., Manzardo, A., … Pfister, S. (2016). Consensus-based water scarcity footprint method from WULCA: the AWARE model. International Journal of Life Cycle Assessment

Startup, Operation, and Optimization of HRSD's 3.8 MLD SWIFT Research Center for Advanced Water Treatment and Managed Aquifer Recharge

Samantha Hogard (presenting author), Virginia Tech, Blacksburg, USA and HRSD, Virginia Beach, USA; Robert Pearce, Virginia Tech, Blacksburg, USA and HRSD, Virginia Beach, USA, Peter Buehlmann, Virginia Tech, Blacksburg, USA and HRSD, Virginia Beach, USA; Germano Salazar-Benites, HRSD, Virginia Beach, USA; Tyler Nading, Jacobs, Denver, USA; Chris Wilson, HRSD, Virginia Beach, USA; Charles Bott, HRSD, Virginia Beach, USA

Abstract:

The Sustainable Water Initiative for Tomorrow (SWIFT) is the effort of HRSD to combat the detrimental environmental impacts facing the southeast Virginia region associated with water overuse and saltwater intrusion. The SWIFT Research Center treats 3.8 MLD of secondary effluent with a carbon-based advanced water treatment train. During startup of this facility, efforts were made to monitor the formation of disinfection byproducts including bromate and NDMA. Control strategies were implemented to limit bromate formation and to ensure the removal of NDMA in the treatment process.

Keywords: Potable reuse; ozone; bromate; N-nitrosodimethylamine; disinfection byproducts

Introduction

The Potomac Aquifer System in Eastern Virginia faces challenges including decreasing aquifer levels, land subsidence and saltwater intrusion. The Hampton Roads Sanitation District (HRSD) has developed an innovative program called the Sustainable Water Initiative for Tomorrow (SWIFT) that will address these challenges by implementing advanced water treatment at seven of HRSD's existing treatment plants. This initiative is being demonstrated at the SWIFT Research Center (SWIFTRC) which treats 3.8 MLD of Nansemond Treatment Plant (NTP) secondary effluent. The treatment process includes coagulation-flocculation-sedimentation (floc/sed), ozone oxidation and disinfection, biologically active filtration (BAF), granular active carbon (GAC) adsorption, ultraviolet disinfection, and chloramine

disinfection. This facility began aquifer recharge in May 2018 after establishing stable operation. During start up several parameters were evaluated in order to optimize the treatment process including disinfection byproduct (DBP) formation suppression and contaminant removal through the biofilters.

N-nitrisodimethylamine (NDMA) is a disinfection byproduct commonly formed by chloramination and ozonation which is included in the Unregulated Contaminant Monitoring Rule. While NDMA is not subject to the national drinking water standards, several states have established notification limits. Common removal mechanisms of NDMA include biological treatment or UV photolysis (Sgroi et al., 2018). Elevated NDMA concentration after ozonation is of particular concern at the SWIFTRC due to the time required for BAF acclimation and biological removal.

Another challenge encountered during startup was the formation of bromate: a regulated disinfection byproduct (DBP) with a maximum contaminant level of 10 µg/L (EPA, 1998). Bromate forms during ozonation of bromide-containing waters and this is problematic at the SWIFTRC due to the high bromide load from local landfill leachate that is discharged to NTP. At the SWIFTRC, preformed monochloramine is added prior to ozonation to suppress bromate formation. However, due to the elevated bromide concentration, further bromate suppression methods were needed during SWIFTRC startup.

Material and Methods

The SWIFTRC facility has been operating since May 2018 and data has been collected throughout the duration of operation. The ozonation system was primarily operated in residual control mode in order to achieve 3-log removal of viruses which resulted in a typical applied ozone dose of 5-7 mg/L. The biofilters operated with an empty bed contact time of approximately 12 minutes with all filters in service. Samples were collected weekly for NDMA analysis in the ozone effluent, BAF effluent, GAC effluent and finished water. NDMA was analyzed by HRSD's Central Environmental Laboratory (CEL) according to EPA method 521. Ozone effluent bromate and bromide were also analyzed by the CEL daily according to EPA method 302 and 300 respectively.

Monochloramine is added to the ozone influent at a typical concentration of 3 mg/L for the purpose of bromate suppression. While preoxidizing with free chlorine, 12% sodium hypochlorite solution was dosed to the influent before flocculation/sedimentation.

Results and Discussion

NDMA was formed at an average concentration of approximately 40 ng/L in the ozone effluent at the SWIFTRC. The observation of biological nitrification in the BAF coincided with observed removal of NDMA which is biodegraded in this process. NDMA is also removed in the SWIFT process by direct photolysis by a relatively high dose of UV irradiation, however the operational concern is that biological treatment must be established in the BAFs prior to the time when the UV system is unable to deliver the high dose required for NDMA removal (as a result of UVT decreasing as the GAC is exhausted). The startup of the SWIFTRC provided valuable information about NDMA removal during BAF acclimation that will benefit future SWIFT facilities.

While receiving landfill leachate, bromide concentration in the influent ranged from 0.3 to 0.7 mg/L. A correlation has been observed between applied ozone dose and bromate formation at the SWIFTRC which has motivated testing to reduce ozone demand via preoxidation. Testing has shown that preoxidizing with free chlorine is effective in reducing the ozone demand and thereby further suppressing bromate formation. Additionally, preliminary testing suggests that chlorination of the secondary effluent results in minimal halogenated DBP formation. Further testing will be performed to establish the most effective method of bromate control.

Conclusions

The increase in potable reuse applications requires effective control of harmful disinfection byproducts produced during advanced water treatment. At the SWIFTRC, there are control methods in place to limit the formation bromate during ozonation and ensure the removal of NDMA in the process. The most effective method to control the formation and removal of these compounds is still under consideration.

References

EPA. (1998). National Primary Drinking Water Regulations: Disinfectants and Disinfection Byproducts.

Sgroi, M., Vagliasindi, F., Snyder, S., Roccaro, P. (2018). N-nitrosodimethylamine (NDMA) and its precursors in wastewater: A review on formation and removal. Chemosphere 191 685-703.

Soil aquifer treatment and subsurface-water interactions during groundwater recharge

Lydia Peri, PE, Krishna Pagilla, PhD, PE, BCEE, University of Nevada, Reno, USA

Abstract

As water scarcity throughout the globe compels regions to implement more sustainable water reuse practices, soil aquifer treatment (SAT) proves to be a cost effective and robust method for groundwater recharge and indirect potable reuse (IPR). Natural treatment methods such as SAT are beneficial due to efficient biological treatment without the need of advanced treatment technologies.

The Cold Springs Water Reclamation Facility (CSWRF) in Reno, Nevada is conducting a demonstration project for IPR utilizing SAT. The objective of the Cold Springs study is to investigate the effectiveness of SAT for the attenuation of contaminants such as total organic carbon (TOC), contaminants of emerging concern (CECs), coliform bacteria, protozoa, bacteria, and others. The facility currently utilizes rapid infiltration basins (RIBs) for secondary effluent disposal. A crucial aspect is to determine how the aquifer influences the physicochemical characteristics of the water being recharged and how it influences the geochemistry of the aquifer formation. The question to be answered is how can RIBs be modified at a secondary effluent facility to achieve IPR through SAT with additional above ground treatment technologies. Soil column experiments and field scale investigations and monitoring will shed light on evaluating SAT efficiencies.

Introduction

The CSWRF is owned and operated by Washoe County and is a 1.2 million liters per day facility. Secondary effluent is currently discharged to a series of 12 RIBs as a method of effluent management. This secondary treatment process includes activated sludge achieving biological oxygen demand (BOD) removal and simultaneous nitrification-denitrification. CSWRF has operated RIBs with secondary effluent for several years; however, if IPR were to be considered for this facility, there would be

necessary treatment upgrades and hydrogeological monitoring requirements in order to achieve this.

The State of Nevada regulations for indirect potable reuse allow for a Category A reclaimed water (commonly used for landscape irrigation) to be applied to a spreading basin with recognized treatment through the vadose zone. (The term RIB is affiliated with effluent disposal with no intention of recovery; the term spreading basin refers to an RIB that is intended for IPR). The infiltrated effluent is required to meet Category A+ quality regulations upon introduction to the shallow aquifer (Figure 1). In Nevada, Category A+ water quality meets all Federal and State drinking water standards and is intended for groundwater augmentation. Category A+ requirements include control of 1) Pathogens, 2) Regulated Contaminants, and 3) Unregulated Constituents. To achieve Category A+ water, the technological and natural treatment must demonstrate 12-log enteric virus reduction, 10-log Giardia cyst reduction, and 10-log Cryptosporidium oocyst reduction.

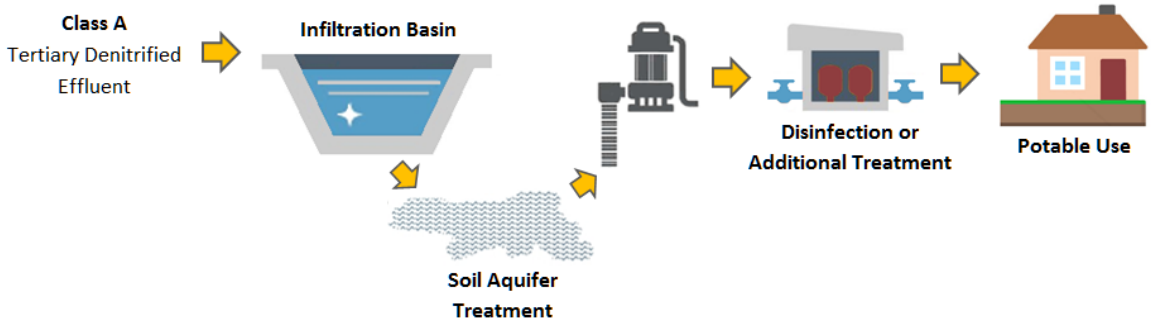


Figure 1: Nevada Class A to Class A+ schematic for indirect potable reuse utilizing infiltration basins and SAT

A main component of this demonstration project is to physically analyze aquifer recharge responses and quality improvements through spreading basins. Classifying hydrogeologic characteristics through field investigations will assist with sizing the demonstration project advanced treatment units as well as determining the suitability of aquifer recharge at each potential site.

Materials and Methods

The depth to groundwater at CSWRF is fairly shallow at an average of 6 m below ground surface. The soil composition is a relatively uniform sandy soil with occasional clay lenses. Each of the 12 basins vary in size from approximately 4,800-8,500 m^2. Infiltration rates range from 0.5-25 cm/hr. Basins are surface scarified and maintained on an annual basins to ensure sustained infiltration.

A driving factor of this demonstration project is to be able to examine the hydraulic responses, characterize SAT at varying depths, monitor recharge water travel time and assess any leaching of natural elements while quantifying attenuation and treatment of major constituents. The point of compliance for sampling of recharge water is at the top of the water table; therefore, recharge water must meet Category A+ at that compliance point. CSWRF has a monitoring network of shallow and deep aquifer monitoring wells that surround the perimeter of the basins. To ensure the proper groundwater formation is sampled, three additional shallow monitoring wells screened across the water table were installed (12 m total depth) surrounding the identified study basin. The monitoring wells will provide various sampling points for indicators of the effectiveness of SAT. Constituents commonly indicative of SAT efficiency are heavy metals, TSS, turbidity, bulk organic matter (DOC/TOC), pathogens, ammonium, phosphate and other organic micropollutants (Sharma et al. 2016).

Inland Empire Utilities Agency (IEUA) of Southern California, USA, has worked tirelessly for years to recharge stormwater, recycled water and imported water. IEUA uses lysimeters to monitor compliance of their recharge permit (Inland Empire Utilities Agency 2005). A lysimeter is a porous stainless steel sampling device that is installed at a specific depth within the vadose soil and collects samples of recharge water prior to it reaching the groundwater table. As recharge water is infiltrating, a vacuum is applied to the lysimeter and the negative air pressure inside draws in pore water. A positive pressure in the lysimeter will then bring the collected pore water to the surface for sampling purposes (Soil Measurement Systems 2005). CSWRF installed 4 lysimeters within the vadose zone of the study basin (1.5 m, 3 m, 4.5 m and 6 m) to gather

additional information of SAT efficiency and the removal of constituents at various depths.

In addition to shallow monitoring wells and lysimeter installation, a soil column assembly was constructed using the borings form the lysimeter boreholes (Figure 2). Columns were designed and constructed based on literature (Demeau 2014) and reviews of similar projects (IEUA flow cell assembly). Utilizing soil columns to mimic a complex natural system is a common practice because experimental conditions can be much better controlled and it can be difficult to link certain observations at the field scale level (Trussell et al. 2018). CSWRF is currently a secondary treatment facility and to achieve Category A water suitable for SAT, recharge water must meet tertiary standards. The soil columns provide an opportunity to potentially treat the low flow feed water to tertiary standards and observe the results, rather than conduction a full scale 1.2 million liters per day facility upgrade.

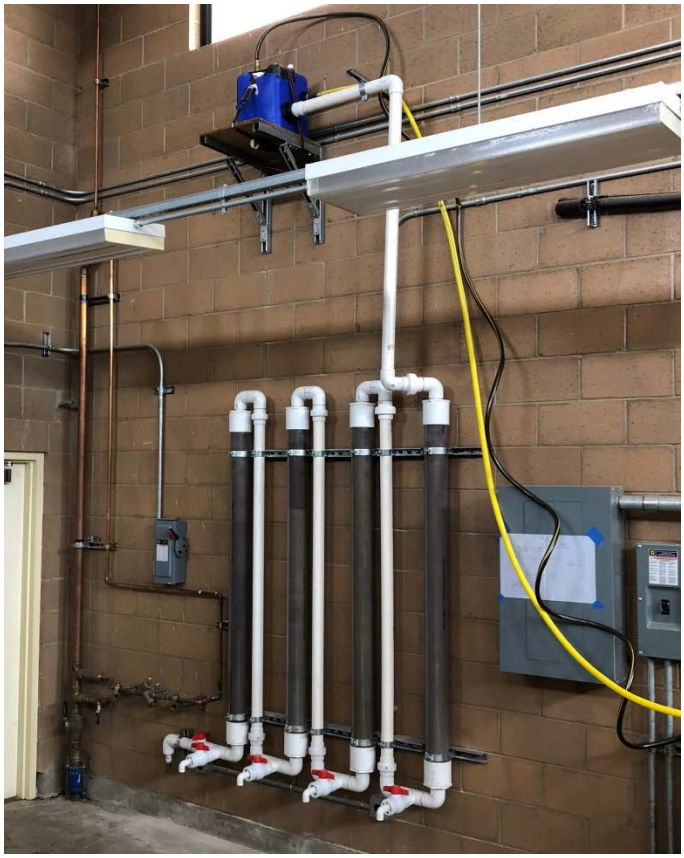


Figure 2: CSWRF soil columns

The columns are approximately 1.6 m in height and were constructed as a gravity flow system to mimic vertical infiltration of recharge water within a basin. The source water reservoir at the highest point maintains a constant water level and feeds the columns based on a pressure gradient. Sampling ports at the bottom of each column reflect the same depths as the field scale lysimeter sampling devices.

Results and Conclusions

The results from this demonstration project will provide guidance on evaluating IPR at a secondary effluent facility and offer suggestions on the variety of additional above ground treatment technologies needed to fully achieve IPR. Field scale monitoring data and soil column experiments will provide suggestions and insufficiencies when evaluating SAT. All groundwater systems are complex and independent; however, understanding how SAT can be achieved through additional treatment technologies and natural treatment processes will offer the ability to demonstrate this reliable IPR method.

References

Demeau (2014) Guide lining protocol for soil-column experiments assessing fate and transport of trace organics

Inland Empire Utilities Agency (2005) Chino Basin Recycled Water Recharge Program. Start-Up Protocol Plan for Banana Basin

Sharma S, Kennedy M (2017) Soil aquifer treatment for wastewater treatment and reuse. International Biodeterioration and Biodegradation 119: 671-677. Doi: 10.1016/j.ibiod.2016.09.013

Soil Measurement Systems (2005) Suction Lysimeters. http://www.soilmeasurement.com/lysimeter.html

Trussell S, Trussell B, Qu Y, Trussell R (2018) Soil Aquifer Treatment Characterization with Soil Columns for Groundwater Recharge in the San Fernando Valley, Extended Testing. The Water Reuse Foundation Project No. 4600

Improving water resiliency and reducing potential water stress by advanced water reclamation and aquifer storage

Krishna Pagilla, University of Nevada, Reno, USA; Rick Warner, OneWater Nevada, Reno, USA

Abstract:

Global water challenges include water stress, urbanization, population increases, inadequate infrastructure and research funding, climate change, and depletion of freshwater supplies. Communities are challenged to create lasting and impactful water solutions, which reflect local community values, regional water markets, sustainable practices, low carbon impacts, and lower total energy consumption.

Sustainable water management practices are being more intentionally considered by developed and emerging economic regions. Indirect potable reuse (IPR) has allowed communities to address water scarcity, improve water security, enhance economic security, drive social and environmental improvements, and expand beneficial management opportunities of conventional and non-conventional water resources. These attributes contribute to the importance of IPR in providing an efficient strategy to manage water.

Faced with many of the most common global water stress conditions, a Reno, Nevada, (USA) regional team consisting of eight public agencies is jointly conducting a feasibility study to examine if IPR offers significant water resource management benefits including improving efficiency, providing flexibility during periods of water scarcity, and diversifying the region's water supply portfolio. The foundational principles of the Regional Team's community engagement work relate to creating "agency legitimacy" – defined as specific and authentic actions a public agency initiates to gain the trust and acceptability from the public. Agency legitimacy is more important as communities consider potable water reuse solutions, which have often been met with public opposition despite having proven the finished water quality meets or exceeds drinking water standards.

Keywords: Sustainability; Water management; Indirect potable reuse; Legitimacy; Collaboration; Triple bottom line; Economic security; Feasibility; Water planning

Introduction

Water reuse has gained significant attention in the recent years in the context of resource recovery from wastewater and emphasis on circular economy. In this context, wastewater is seen as a renewable (reNEWable) resource containing valuable nutrients, energy, and water for reuse. Water becomes very valuable in closed basin watersheds where water quantity is limited. The situation is further worsened in arid and semi-arid regions where water deficit leads to water insecurity and water stress, particularly during prolonged droughts. At the same time, during wet seasons, flooding risks are common in closed basins. Indirect potable reuse is a strategic management practice for augmentation of drinking water supplies. This improves water supply resiliency, reduces water stress, and allows for practical wastewater effluent management. water supply resiliency, reduces water stress, and allows for practical wastewater effluent management. IPR is defined as attaining drinking water quality through advanced treatment of water sourced from wastewater. This paper presents a case study from northern Nevada in the United States of America, a desert region, in which a closed basin watershed poses numerous water management challenges. The region currently practices limited non-potable reuse; however, such a practice is possible only during summer months and is limited to landscape irrigation. Previous work on triple bottom line analysis of IPR has been shown to provide overall benefits to the region through greater social and environmental benefits (Haak et al., 2018). The overall project examines feasibility and justification through sustainability analysis, selection of suitable reclamation technology for producing water for IPR, field-scale demonstrations of the treatment technology trains, multi-agency collaboration and stakeholder engagement for public acceptance, and development of implementation plans. Public acceptance of IPR is often the greatest barrier to implementation. Likelihood of project success is success can be enhanced by creating the conditions for *agency legitimacy*, which addresses the attitudes held by the general public toward IPR project leadership.

Materials and Methods

Project rational and justification evaluations were completed in the overall context of a regional IPR feasibility study. Critical examinations included:

- Determine water treatment technologies and natural purification strategies to produce IPR water quality meeting all applicable United States Environmental Protection Agency (USEPA) regulations for safe drinking water.
- Evaluate low energy treatment technologies, specifically non reverse osmosis-based systems.
- Evaluate IPR relative to the status quo water management strategies with respect to social, environmental, and financial criteria.
- Evaluate IPR relative to the status quo water management strategies with respect to anticipated longer-term local climate change affects.
- Evaluate the impacts to the local water economy markets.
- Determine the regulatory water rights pathway from the wastewater-sourced water to a new drinking water resource.
- Develop an IPR program approach with the foundational principles to create "agency legitimacy" – defined as specific and authentic actions a public agency initiates to gain the trust and acceptability from the public.

Based upon detailed technical and economic analysis, the IPR regional team selected a low-energy ozone-biological activated carbon (Ozone-BAC) technology train (Figure 1) as the main component of the advanced treatment of secondary-treated domestic wastewater effluent for pilot-scale and field-scale groundwater well injection demonstrations. The data being collected from the field scale work includes pathogens, trace organic contaminants, bulk organic matter, specific inorganic constituents (bromate, perchlorate, heavy metals, etc.), and formed organic contaminants (NDMA, NMOR) from sampling points shown in Figure 1. Some of the key challenges of producing IPR purpose water with the selected treatment technology are mitigating formation of ozone oxidation products (NDMA and Bromate) and achieving pathogen levels using minimum of three barriers.

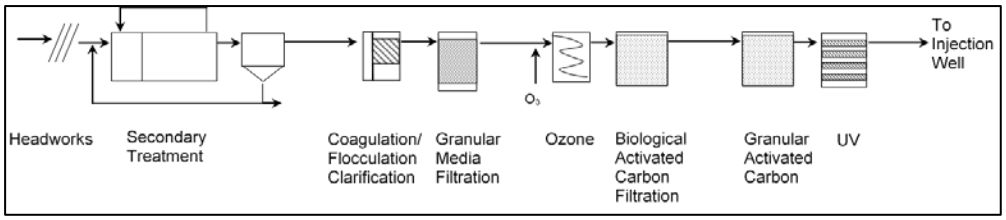


Figure 1. Ozone-BAC Treatment Technology Train

The water produced from the above treatment train utilizes denitrified secondary wastewater sourced effluent followed by coagulation-flocculation-clarification-dual media-granular-filtration; ozonation; biological-activated-carbon-filtration; granular-activated-carbon; and, ultraviolet light. Water quality objectives for drinking water compliance, including pathogen reduction, met and exceeded with data to be validated and peer-reviewed. The benefits of the selected treatment include low energy demand to produce IPR purpose water; no reject or brine streams (such as from reverse osmosis-based treatment); utilizes readily available and proven drinking water treatment technologies; and, water chemistry that is compatible with groundwater chemistry for aquifer storage and recovery.

The key non-technical aspects of this project include a multi-agency collaboration to improve legitimacy of the project with the public and stakeholders; a public education campaign to engage the public throughout the project; and, full-scale demonstration prior to full scale implementation development. Lastly, since IPR options transcends the boundary between wastewater treatment and water supply, collaboration between different agencies involved is critical. In this case, the regional team has unified drinking water, wastewater, reclaimed water agencies together in a regional collaboration to develop strategies to increase water resiliency of the region and reduce water stress during drought periods. The collaboration has formalized under the name "*OneWater Nevada*" to strengthen the inter-agency trust and collaboration and to recognize a new potable water resource would offer significant regional water management benefits. The presentation will carefully highlight those non-technical issues for the benefit of both researchers and practitioners to conduct successful IPR demonstrations and implementations.

Results and Discussion

As illustrated in Figure 2, relative to the predominate status quo (SQ) water management strategies in Reno, Nevada (USA), IPR offers benefits including: averting significant capital costs associated with constructing a distribution system to export reclaimed water; increased local control of water resources; public health impacts neutral; increased available water resources; increased groundwater

supplies; resulted in comparable capital costs; reduced wastewater effluent disposal; and, improved water stress conditions.

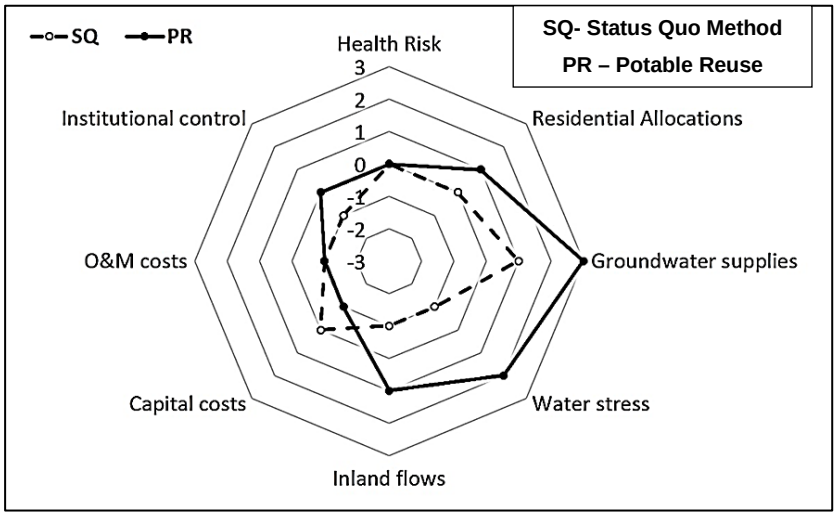


Figure 2. Relative Economic, Environmental, and Social Impacts of Indirect Potable

The foundational organizational leadership principles of *OneWater Nevada* is "agency legitimacy" – defined as specific and authentic actions a public agency initiates to gain the trust and acceptability from the public is critical as the technical evaluations are publicly communicated. Potable reuse projects have often been met with public opposition, despite having proven that the technology and water quality meet or exceed drinking water standards. *OneWater Nevada* leadership recognizes technical professionals such as engineers and scientists believe the public will accept new technologies when it is provided with information through marketing and public education. Such outreach efforts need be authentic to achieve public support. Sequentially illustrated in Figure 3, the three levels of legitimacy need to be addressed to have a successful project:

1. The Pragmatic level focuses on the user's self-interest, seeking to answer questions such as "How do I benefit personally?" and "How am I involved in the decision-making process?"
2. The Moral level deals with social values and welfare, addressing questions like "How is quality and process safety guaranteed?" and "Is the organization trustworthy?"
3. The final level, Cognitive, deals with customs and routines that are taken for granted. "Does the technology fit with my daily life?" and "Is the technology essential, with no feasible alternatives?" are examples of the inquiries that community members need answered.

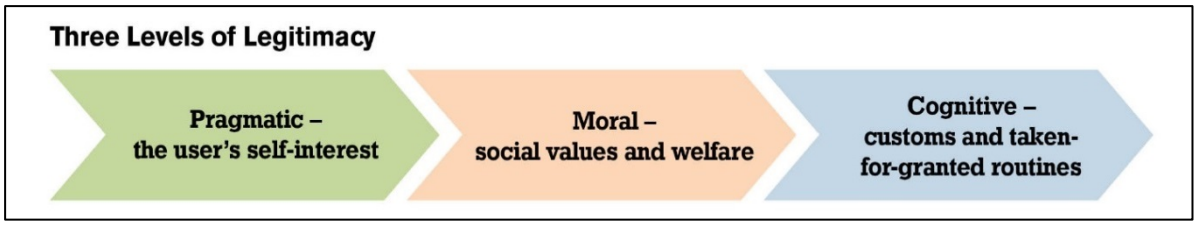


Figure 3. Three Levels of Agency Legitimacy

Conclusions

Through a comprehensive feasibility study based upon a triple-bottom-line approach, *OneWater Nevada* has shown that in the case of a Reno, Nevada (USA) indirect potable reuse project is likely to provide an economically, environmentally, and socially beneficial water management strategy in a closed basin compared to status quo effluent management strategies. Drinking water quality is being evaluated with respect to the goal of meeting all USEPA safe drinking water regulations. Up-to-date peer reviewed data will be presented. *OneWater Nevada* leadership is developing a community engagement plans emphasizing the principals of "agency legitimacy" that includes addressing pragmatic level, morality level, and cognitive level attributes.

References

ECO:Logic (2010) The North Valleys Initiative: Advancing Solutions to Regional Water Issues. Western Regional Water Commission

Haak L, Sundaram V, Pagilla K (2018) Sustainability Assessment for Indirect Potable Reuse: A Case Study from Reno, Nevada. Water Environment Research 748–760. doi: doi/10.2175/106143017X15131012153185

Stantec. (2018). LVWRF Conceptual Study Life-Cycle Cost Memo.

Binz C, Harris-Lovett S, Kiparsky M, Sedlack D (2015) Beyond User Acceptance: A Legitimacy Framework for Potable Reuse in California

Coupling high-rate infiltration trench technology with a plug-flow bioreactor (SMART*plus*) for indirect potable reuse via groundwater recharge

S. Karakurt[a], A. Sanz-Prat[b], M. Ergh[c], U. Hübner[a], J.E. Drewes[a]

[a] Chair of Urban Water Systems Engineering, Technical University of Munich, Garching, Germany; sema.karakurt@tum.de; [b]Institute for Biology and Environmental Sciences, Carl von Ossietzky University of Oldenburg, Oldenburg, Germany; [c]BGS Umwelt GmbH, Darmstadt, Germany

Abstract

Biotransformation of TOrCs during managed aquifer recharge (MAR) can be enhanced through provision of oxic and oligotrophic conditions by the sequential MAR technology (SMART), combining two infiltration steps with an intermediate aeration. Major bottlenecks impeding the widespread application of MAR and SMART in indirect potable reuse are their performance heterogeneity due to site-specific factors and large physical footprint. The aim of this study was to design and test the performance of a novel technology, SMART*plus*, based on SMART that can be deployed independent of local hydrogeological conditions with a significantly reduced physical footprint, controlled redox zonation, and in-situ oxygen delivery for enhanced pathogen and TOrC removal.

Keywords: SMART, plug-flow bioreactor, indirect potable reuse, infiltration trench technology, trace organic chemicals, groundwater recharge

Introduction

Augmentation of drinking water supplies with reclaimed water via an environmental buffer, known as indirect potable reuse (IPR), reduces the dependency and burden on seasonally and climatically changing conventional water sources by shortening the natural hydrological replenishment cycle (Drewes and Khan, 2011). Given the origin of the source water used in IPR schemes, contaminants of concern (e.g., pathogenic microorganisms, trace organic chemicals, etc.) must be removed by reliable and redundant treatment processes to their threshold values and the water quality should be monitored closely. For this reason IPR design is characterized by multi-barrier approaches by applying combinations of advanced water treatment processes (e.g., membrane filtration, activated carbon adsorption, advanced chemical oxidation and biological treatment) and an environmental buffer providing

additional retention and storage function prior to use (National Research Council, 2012). Low-energy managed aquifer recharge (MAR) systems such as soil-aquifer treatment take advantage of natural attenuation processes for chemical and microbial contaminants without any residual generation and chemical addition, while damping varying concentrations, and in many cases resulting in dilution with other water sources (Dillon, 2005; Drewes and Khan, 2011; Sharma and Amy, 2011). The interaction of different removal mechanisms (such as biotransformation, filtration, adsorption and ion exchange) in managed aquifer recharge (MAR) systems provides effective removal of many trace organic chemicals (TOrCs) and offers efficient inactivation of pathogens, especially viruses or protozoa. Previous studies demonstrated that carbon-limited and oxic conditions are favorable for enhanced trace organic chemical transformation (Hoppe-Jones et al., 2012; Rauch-Williams et al., 2010). To take advantage of these favorable conditions, sequential MAR technology (SMART) combining two infiltration steps with an intermediate aeration was developed and validated at pilot- and full-scale in the USA and Germany for the production of drinking water from surface waters impaired by wastewater effluents (Hellauer et al., 2018; Regnery et al., 2016).

Conventional MAR systems and the SMART concept commonly employ open recharge basins to facilitate infiltration of water through the vadose zone, which requires large physical areas and suitable subsurface conditions. In order to establish a sequence of controlled redox conditions during subsequent travel through the saturated zone, homogeneous flow conditions are required. Whereas native subsurface environments are usually characterized by a high degree of side specific heterogeneity, which makes the technology and performance transfer of both MAR systems difficult. Building upon this previous research, the aim of this study was to modify the overall design and improve performance of the SMART concept by an engineered approach that can be deployed independent of local hydrogeological conditions with a significantly reduced physical footprint. This novel SMART*plus* concept is utilizing high-rate infiltration trench technology followed by a biofiltration system with plug-flow conditions characterized by highly controlled redox zonation and an in-situ introduction of electron acceptors as well as online monitoring and control systems. To provide plug-flow conditions and homogenous flow patterns, granular filter media with a high uniformity coefficient is employed in SMART*plus*

bioreactor. Since uncontrolled flow and mixing with native groundwater is not desired, the SMART*plus* concept is designed to be hydraulically decoupled from the native groundwater.

Material and Methods

The SMART*plus* bioreactor consists of a stainless steel tank (6.0 m length x 0.85 m width x 1.4 m height) with five compartments (C1-5), divided by steel mesh sheets (Figure 1). A shaft (0.35 x 0.85 x 1.5 m) is placed on top of the bioreactor at the influent side (C1) mimicking the infiltration trench. Water is distributed at the top of the shaft through a screened PVC pipe, which allows uniform distribution of feed water. A cover plate is used to seal the first 300 cm of the bioreactor. Along the entire length of the bioreactor, 24 sampling ports are installed at different heights and penetration depths.

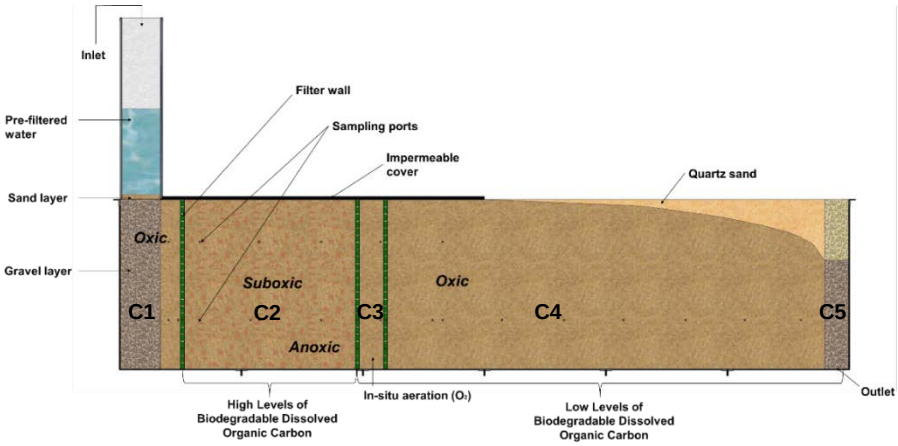


Figure 1: Schematic of the SMART*plus* bioreactor tested at pilot-scale

The bioreactor was continuously fed with tertiary effluent (Q_{SMART}=300 L/h) from a WWTP for more than 24 months in baseline operation. Sequential operation with *in-situ* introduction of oxygen has been initiated recently. To allow rapid vertical infiltration rates and establish plug flow among the SMART*plus* bioreactor, the first compartment (C1, infiltration trench) is filled with gravel (d_{10}=3.40 mm) and with a thin sand layer (d_{10}=0.75 mm) on the top for the retention of any residual suspended solids. C2 and C4 (1st and 2nd infiltration step) are filled with technical sand (d_{10}=0.75 mm). C3 (electron acceptor compartment) is filled with gravel (d_{10}=2.1 mm) and the perforated infiltration wells, in which the oxygen permeable membrane conductors are submerged. The last compartment C5 is filled with gravel (d_{10}=3.4 mm) to allow high drainage rates. In addition, temperature, conductivity, water level and dissolved oxygen are continuously monitored in 6 PVC monitoring

wells along the bioreactor and UV absorbance can be monitored at the influent and effluent of the system.

A 3-D hydraulic flow model was developed to determine the hydraulic retention time (HRT) and characterize the flow field and velocity distribution in the bioreactor. In order to improve the hydraulic parameters taken from the literature by numerical calibration and to validate 3D-Model an impulse tracer test with potassium bromide (Merck, Global) solution was conducted at a constant flow rate of 300 L/h for 12 hours. The tracer dosing was followed by conductivity monitoring every 10 minutes at 6 CTD sensors and effluent for 24 hours.

Water samples were collected weekly to bi-weekly based on estimated HRT in the SMART*plus* at the inlet and outlet of the bioreactor, as well as at the end of the infiltration trench (distance from inlet: 40 cm; depth: 45 cm) and 1st infiltration step (164 cm; 45 cm) for ammonia, nitrate, bulk organic parameters and TOrCs. The DOC samples were analyzed by a vario TOC cube analyzer (Elementar, Germany). The UVA_{254} was measured on a DR 6000™ UV-VIS spectrophotometer (Hach Lange, Germany). Nitrate and ammonia concentrations were determined by cuvette tests LCK 339 and 304 (Hach Lange, Germany) with a DR 6000™ UV-VIS spectrophotometer. TOrCs were quantified using HPLC-MS/MS (Sciex QTRAP5500 & Triple Quad6500) following the method described by (Müller et al., 2017).

Results and Discussion

3D-model results represent a good fitting of the breakthrough curves with experimental data and revealed an average HRT of 11.5 hours. The snapshots at three different times during the simulation of the 12 hours pulse tracer test along the longitudinal cross section in the middle of the SMART*plus* bioreactor are depicted in Figure 2, indicating that the hydraulic conditions are closely approximating plug flow conditions.

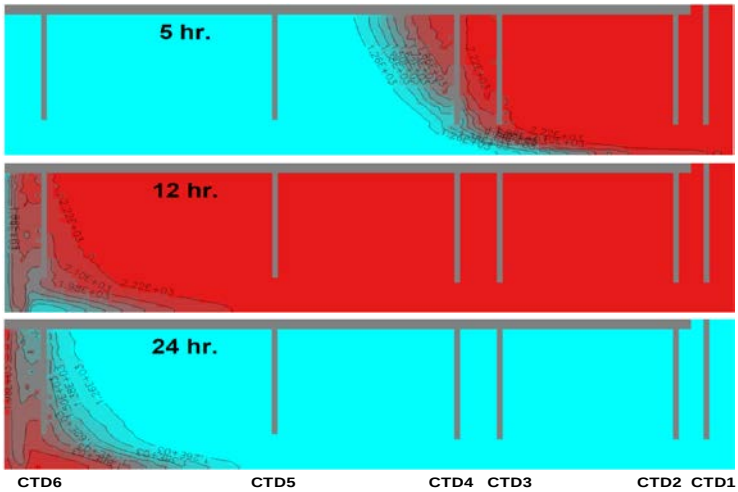


Figure 2. Spatial distribution of the tracer plume at three different times after pulse injection started. The red area corresponds with the high concentration of bromide, and the blue area with the background concentration.

The concentrations of DO, nitrate, DOC and TOrC in the feed water and along the bioreactor measured between a six months period are summarized in Table 1. The feed water quality parameters strongly fluctuate due to the continuous feeding of the SMART*plus* bioreactor with tertiary effluent. Within the first year of operation, microbial activity indicated by dissolved oxygen measurements, significantly increased resulting in complete depletion of oxygen within the first compartment prior to sequential operation. No nitrate reduction (<0.5 mg N/L) and absence of dissolved oxygen (<1 mg/L DO) underlined the presence of suboxic conditions along the rest of the bioreactor. Different indicator trace organic chemicals, representing different degrees of biodegradability (trimethoprim and gabapentin: efficient removal, diclofenac: poor removal, carbamazepine: persistent), showed clear and consistent removal during the baseline operation prior to introduction of dissolved oxygen.

Table 1. Average DO (n=15,512), DOC, and NO_3^--N (n=10-12) concentrations in feed water, at the end of the infiltration trench, 1st infiltration step and in the effluent between April-September 2018 during baseline operation of the SMARTplus bioreactor. The percent removals of TOrCs (n=10-12) are calculated by the TOrC concentrations at the infiltration trench, 1st infiltration step and bioreactor effluent normalized to corresponding feed water concentrations.

	Feed water concentrations	*Infiltration trench*	*1st infiltration step*	*Effluent / Entire bioreactor*
DO	5.1 ± 1.8 mg/L	1.0 ± 0.9 mg/L	0.0 ± 0.0 mg/L	0.0 ± 0.0 mg/L
NO_3^--N	12.6 ± 2.3 mg/L	12.7 ± 2.3 mg/L	12.8 ± 2.4 mg/L	12.7 ± 2.4 mg/L
DOC	10.2 ± 2.4 mg/L	8.1 ± 2.0 mg/L	7.8 ± 1.8 mg/L	7.5 ± 2.0 mg/L
Trimethoprim	45 ± 24 ng/L	85 ± 13 %	82 ± 11 %	85 ± 6 %
Gabapentin	1380 ± 477 ng/L	67 ± 16 %	69 ± 15 %	69 ± 17 %
Diclofenac	1027±113 ng/L	20 ± 8 %	17 ± 12 %	22 ± 16 %
Carbamazepine	453 ± 66 ng/L	< 5 %	< 5 %	< 5 %

Conclusions

The performance of the tracer experiments and their modeling results confirmed the establishment of quasi plug flow conditions under moderate flowrates in the SMART*plus* bioreactor while applying infiltration trench technology and homogenous porous media. Plug flow conditions enables to control well defined redox zonation along the bioreactor to provide a homogenous water quality with enhanced TOrC removal. Establishment of SMART*plus* bioreactor at pilot scale provided sound and reliable proof of concept regarding realization of plug flow conditions under high infiltration rates and in-situ redox zonation. Further investigations are planned to prove long-term removal of pathogen and chemical contaminants under sequential operation as well as different infiltration rates.

References

Dillon, P., 2005. Future management of aquifer recharge. Hydrogeology Journal 13 (1), 313–316.

Drewes, J.E., Khan, S.J., 2011. Water reuse for drinking water augmentation, in: Edzwald, J.K. (Ed.), Water Quality & Treatment, 6th ed. McGraw-Hill, New York, 16.1-16.48.

Hellauer, K., Karakurt, S., Sperlich, A., Burke, V., Massmann, G., Hübner, U., Drewes, J.E., 2018. Establishing sequential managed aquifer recharge technology (SMART) for enhanced removal of trace organic chemicals: Experiences from field studies in Berlin, Germany. Journal of Hydrology 563, 1161–1168.

Hoppe-Jones, C., Dickenson, E.R.V., Drewes, J.E., 2012. The role of microbial adaptation and biodegradable dissolved organic carbon on the attenuation of trace organic chemicals during groundwater recharge. The Science of the Total Environment 437, 137–144.

Müller, J., Drewes, J.E., Hübner, U., 2017. Sequential biofiltration - A novel approach for enhanced biological removal of trace organic chemicals from wastewater treatment plant effluent. Water Research 127, 127–138.

National Research Council (Ed.), 2012. Water reuse: Potential for expanding the nation's water supply through reuse of municipal wastewater. National Academies Press, Washington D.C.

Rauch-Williams, T., Hoppe-Jones, C., Drewes, J.E., 2010. The role of organic matter in the removal of emerging trace organic chemicals during managed aquifer recharge. Water Research 44 (2), 449–460.

Regnery, J., Wing, A., Kautz, J., Drewes, J.E. (2016). Introducing sequential managed aquifer recharge technology (SMART) - From laboratory to full-scale application. *Chemosphere* **154**, 8-16.

Sharma, S.K., Amy, G., 2011. Natural treatment systems, in: Edzwald, J.K. (Ed.), Water Quality & Treatment, 6th ed. McGraw-Hill, New York, 15.1-15.32.

Options for implementing denitrification in Sequential Managed Aquifer Recharge Technology (SMART) systems

Josefine Filter, Christin Bosinsky*; Aki S. Ruhl*; Martin Jekel**

**Technische Universität Berlin, Institute of Environmental Science and Technology, Chair of Water Quality Control, Berlin, Germany*

Josefine.filter@tu-berlin.de

Abstract

High nitrate concentrations in WWTP effluents and aquifers can challenge oxic SMART systems in order to prevent nitrite and gas formation in the sand bed, as well as to achieve the regulated threshold values for water reuse applications. Therefore this study investigates possibilities of implementing an anoxic zone by introducing electron donors, especially focusing on organic fixed bed materials. Laboratory column tests with straw, softwood, peat, PLA, PCL revealed minor or incomplete denitrification with a hydraulic retention time of less than 10 h and high organic carbon leaching especially during the first three months. Therefore, separate denitrification prior to the SMART system or in a defined side-stream treatment is recommended.

Keywords: fixed bed, denitrification, SMART

Introduction

Managed aquifer recharge (MAR) systems allow a brine-free removal of pathogens and dissolved organic compounds with low operational costs. Sequential managed aquifer recharge technologies (SMART) represent an advancement of conventional MAR systems in which beneficial carbon limiting and oxic conditions are established by an intermediate aeration step (Hellauer et al., 2017). However, especially under short hydraulic retention times of less than ten hours, other contaminants such as nitrate, iodinated x-ray contrast agents or carbamazepine, which are predominantly removed under anoxic and anaerobic conditions, may pass the SMART system. This can be critical in direct and indirect potable reuse with a lack of dilution by natural waters.

The EU water framework directive requests a good status of all waters by 2027 (The council of the European Union, 2015). Therefore the limit of discharged total nitrogen

into waterbodies sensitive to eutrophication is set below 15 mg/L for wastewater treatment plants (WWTPs) exceeding 10,000 population equivalents (European Council, 1991). The threshold value for drinking water is currently set at 50 mg/L as Nitrate (11 mg NO_3-N /L) (The council of the European Union, 2015).

Those threshold values can be sometimes problematic. Especially in groundwater, critical nitrate concentrations resulting from excessive agriculture or decentralized wastewater treatment are becoming more and more challenging for drinking water reclamation.

To prevent the release of nitrate into aquifers, this study investigates possible options to integrate an anoxic zone into SMART sand filters. There are several possibilities to introduce electron donors. Continuous dosage of easily degradable organic carbon is a well known technique to induce denitrification, but it promotes biofilm growth and gas clogging when applied in sand beds that cannot be backwashed. Another option is the application of H_2 as inorganic electron donor, but due to its low water solubility of only 1.7 mg/L and additional technical efforts it seems not applicable for removing nitrate concentrations exceeding 16 mg/L in a non-pressurized system.

Fixed bed materials seem to be promising to integrate electron donors into a SMART system since the organic material and biofilm growth could be limited to a defined zone in the sand filter. Furthermore, it allows comparably low operational effort and costs. A broad overview on solid phase denitrification is given in the review paper of Wang and Chu (2002). Different plant-based materials for denitrification were already evaluated in laboratory as well as in pilot studies (Gibert et al. 2008; Warnecke et al. 2011). Schaffer et al. (2015) tested compost in a laboratory set up as denitrifying layer in SAT applications. Besides natural substrates, synthetic but biodegradable polymers such as polycaprolacton (PCL), polylactic acid (PLA), polyhydroxyalkanoate (PHA) and polybutylene succinate (PBS) were investigated as electron and carbon sources for fixed bed denitrification (Boley et al., 2000; Chu and Wang, 2013; Shen and Wang, 2011).

In this study natural as well as synthetic materials are tested as electron donors for in-situ denitrification to be included in a sand filter system. A set of laboratory columns simulates an anoxic filtration zone in SMART.

Material and Methods

Straw, pine woodchips (soft wood), peat, PCL and PLA were tested regarding their potential dissolved organic carbon (DOC) leaching, gas formation and the removal of nitrate and trace organic compounds (TOrCs) under comparably short hydraulic retention times (HRT) of less than ten hours. Sand from a MAR site located at lake Tegel was used as reference filling material. Prior to column tests all materials were inoculated with WWTP effluent. All materials were packed into glass columns (35 mm inner diameter, 200 mm height) which were operated in the dark and under upstream conditions with a mean flow rate of 19.6 ± 0.4 mL/h at temperatures of 22.6 ± 3.6°C. The influent consisted of Berlin tap water containing a non-biodegradable DOC of 5.5 mg/L. It was spiked with sodium nitrate to a mean nitrate concentration of 52.2 ± 15.9 mg/L. In this way the applied test water revealed a low bio-degradable DOC (BDOC) to nitrogen (N) ratio and oxygen concentrations below 2 mg/L adjusted by aeration with nitrogen. The effluent passed a gas capture bottle to quantify released nitrogen. Samples were taken under anoxic conditions and filtrated with 0.45 µm membranes prior to further analyses. Oxygen was quantified in the influent with an OXY-4 mini fiber-optic oxygen meter (PreSens, Precision Sensing GmbH, Germany). Nitrate and nitrite were determined via ion-chromatographic measurements (Dionex, USA). DOC measurements were carried out with a high combustion analyzer (Elementar, Germany). The HRT was determined with KBr as tracer and conductivity measurement. The corresponding breakthough curves were evaluated with the c-peak method (Schudel, 2004).

Results and Discussion

Fixed bed denitrification: Column experiments

Except for the reference sand column and PLA, all tested substrates showed a mean nitrogen removal of 3-15 mgN/L·d. As presented in Table 1, the highest removals were achieved with 30 g rye straw and 153 g PCL. The relative effluent concentrations of nitrate and nitrite shown in Figure 1 revealed an incomplete denitrification to nitrite with PCL. Both substrates released high amounts of DOC. Especially PCL emits low molecular weight compounds for more than 70 days whereas the highest DOC washout from straw occurred within the first 30 days of operation. Zhang et al. (2016) reported TOC release rates for PCL of 0.12 -

0.14 mg/g·d, which would reflect the DOC release during the first 70 days assuming that most of the released TOC is smaller than 0.45 µm.

Table 1: Comparison of applied fixed bed materials

Material/ Applied dry matter (g)	Reference (Sand) 323	Rye straw 30	Soft wood 20	Peat 49	PCL 153	PLA 177
HRT (h)	9.0	7.8	8.8	9.0	2.9	5.3
Mean nitrogen removal (mgN/L·d)	< 1	15±5	5±1	3±1	9±5	< 1
DOC-leaching (mgDOC/g)	< 0.1	16.6	8.3	6.3	8.6	< 0.1
Gas formation (mL)	0	358	109	59	224	0
Mean effluent pH (-)	8.2 ± 0.1	8.1±0.1	8.1±0.1	8.1±0.1	8.1±0.2	8.3±0.1

Although soft wood was described as suitable material for denitrification (Christianson et al., 2016; Saliling et al., 2007), only a minor nitrate removal was observed in the column tests. In most of the studies nutrient rich water was applied, suggesting a possible nutrient limitation when applying groundwater. Furthermore the HRT of 8.8 h might not have been long enough, since in previous studies it was often exceeding 24 h (Cameron and Schipper, 2010; Gibert et al., 2008).

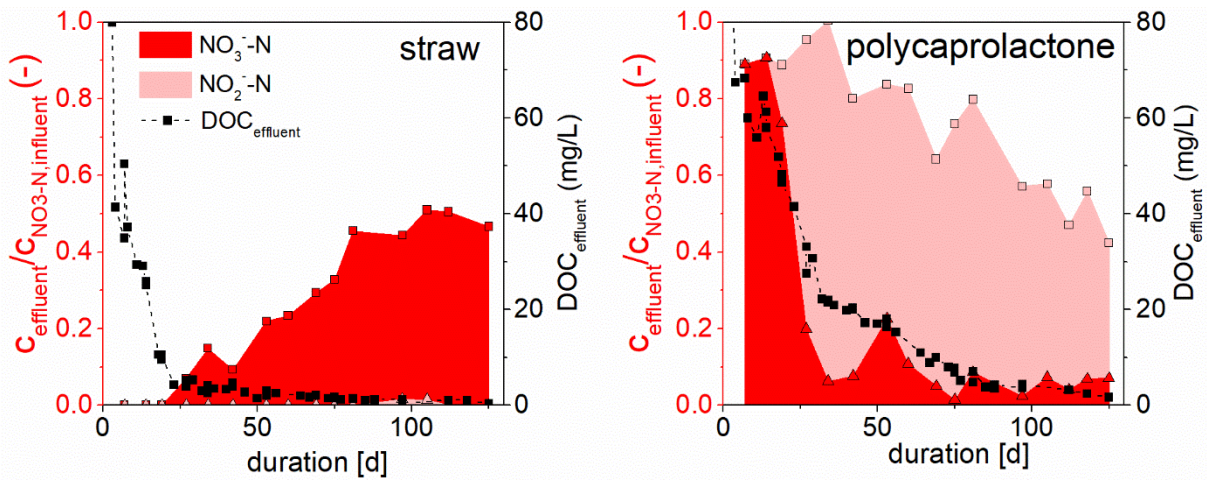


Figure 1: Relative DOC effluent concentration and stacked effluent concentration of NO_3-N and NO_2-N relative to the NO_3-N influent concentration

The reference sand column remained oxic due to its low content of organic matter (0.04 % C) and the low influent BDOC concentration. Therefore no significant nitrate

removal was observed. When applying influent with a higher BDOC/N ratio, denitrification might already occur in the sand layer prior to the re-aeration in SMART systems, were oxygen is consumed and BDOC is partly removed. Although PLA was reported as possible substrate for denitrification (Fan et al., 2012), no nitrate removal was observed. Similar results were reported by Xu et al. (2011). Possibly the organic carbon bound in the PLA polymer was not readily bioavailable and higher temperatures of more than 30°C are required (Fan et al., 2012). The use of PLA/starch blends as reported by Shen et al. (2013) might be also an alternative.

Alternative options for denitrification in SMART

The first part of a MAR system could be implemented as a constructed wetland to achieve advanced nutrient removal as described by Lin et al. (2002) before re-aeration. For a technical sand filter system the mixing and equalization (MAE) tank could be equipped with biofilm carriers and an additional carbon dosage for optional nitrate removal. Another option would be the combination of denitrification with total suspended solid (TSS) removal in the rapid sand filter prior to the technical SMART system. Therefore the rapid sand filter needs to include additional biofilm carriers for the denitrifiers and an optional dosage of easily degradable organic carbon. Treating just a part of the SMART influent as a recirculated side-stream in a separated and controlled denitrification unit could be another possibility to achieve the required threshold values.

Conclusions

To secure process stability and to meet current threshold values, an advanced nitrogen removal might have to be considered in SMART systems. Results from the conducted experiments and from literature indicate a challenging implementation of denitrification into a technical sand filter bed due to high DOC release and nitrite formation as well as limited hydraulic control on clogging caused by gas formation. Instead an integrated denitrification step in a preceding filter system e.g. rapid sand filtration or constructed wetland is suggested. Controlled side-stream denitrification of the SMART influent seems also feasible.

References

Boley, A., Müller, W.-R., Haider, G., 2000. Biodegradable polymers as solid substrate and biofilm carrier for denitrification in recirculated aquaculture systems. Aquacultural Engineering 22 (1-2), 75–85.

Cameron, S.G., Schipper, L.A., 2010. Nitrate removal and hydraulic performance of organic carbon for use in denitrification beds. Ecological Engineering 36 (11), 1588–1595.

Christianson, L.E., Lepine, C., Sharrer, K.L., Summerfelt, S.T., 2016. Denitrifying bioreactor clogging potential during wastewater treatment. Water Research 105, 147–156.

Chu, L., Wang, J., 2013. Denitrification performance and biofilm characteristics using biodegradable polymers PCL as carriers and carbon source. Chemosphere 91 (9), 1310–1316.

European Council, 1991. Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment: UWWT Directive.

Fan, Z., Hu, J., Wang, J., 2012. Biological nitrate removal using wheat straw and PLA as substrate. Environmental technology 33 (19-21), 2369–2374.

Gibert, O., Pomierny, S., Rowe, I., Kalin, R.M., 2008. Selection of organic substrates as potential reactive materials for use in a denitrification permeable reactive barrier (PRB). Bioresource technology 99 (16), 7587–7596.

Hellauer, K., Mergel, D., Ruhl, A., Filter, J., Hübner, U., Jekel, M., Drewes, J., 2017. Advancing Sequential Managed Aquifer Recharge Technology (SMART) Using Different Intermediate Oxidation Processes. Water 9 (3), 221.

Lin, Y.-F., Jing, S.-R., Wang, T.-W., Lee, D.-Y., 2002. Effects of macrophytes and external carbon sources on nitrate removal from groundwater in constructed wetlands. Environmental Pollution 119 (3), 413–420.

Saliling, W.J.B., Westerman, P.W., Losordo, T.M., 2007. Wood chips and wheat straw as alternative biofilter media for denitrification reactors treating aquaculture and other wastewaters with high nitrate concentrations. Aquacultural Engineering 37 (3), 222–233.

Schaffer, M., Kröger, K.F., Nödler, K., Ayora, C., Carrera, J., Hernández, M., Licha, T., 2015. Influence of a compost layer on the attenuation of 28 selected organic micropollutants under realistic soil aquifer treatment conditions: insights from a large scale column experiment. Water Research 74, 110–121.

Schudel, B., 2004. Application of artificial tracers in hydrogeology: Guideline. Bulletin d'hydrogéologie No. 20. P. Lang; Centre d'hydrogéologie, Université, Berne, Neuchâtel.

Shen, Z., Wang, J., 2011. Biological denitrification using cross-linked starch/PCL blends as solid carbon source and biofilm carrier. Bioresource technology 102 (19), 8835–8838.

Shen, Z., Zhou, Y., Wang, J., 2013. Comparison of denitrification performance and microbial diversity using starch/polylactic acid blends and ethanol as electron donor for nitrate removal. Bioresource technology 131, 33–39.

The council of the European Union, 2015. Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption: Drinking Water Directive.

Xu, Y., Qiu, T.-L., Han, M.-L., Li, J., Wang, X.-M., 2011. Heterotrophic Denitrification of Nitrate-Contaminated Water Using Different Solid Carbon Sources. Procedia Environmental Sciences 10, 72–77.

Zhang, Q., Ji, F., Xu, X., 2016. Effects of physicochemical properties of poly-ε-caprolactone on nitrate removal efficiency during solid-phase denitrification. Chemical Engineering Journal 283, 604–613.

Bank filtration at highly polluted rivers

Grischek, T., Sandhu, C., Musche, F., Otter, P., Division of Water Sciences, University of Applied Sciences Dresden, Germany, Boernick, H., Institute for Water Chemistry, TU Dresden, Germany

Bank filtration (BF) has been well-established as a sustainable technique for natural water treatment through highly effective removal of a large number of pollutants at low costs. At many sites worldwide, BF schemes at streams, rivers, lakes, ponds and basins have been successfully operated for several decades. Most of BF schemes in Europe are monitored to ensure optimisation of processes in the river/lake bed and in the aquifer. Some inefficient schemes have been closed due to clogging or water quality concerns. Although in Europe new BF site developments are rare due to decreasing water demand, there is a wide scope for BF technology in the India, South Korea, Egypt, Thailand and other countries even at highly polluted rivers. Currently guidelines do not exist to support engineers in identifying an appropriate site for BF. A complex and comprehensive assessment of hydrological, hydrogeological, hydrochemical aspects together with state-specific regulations, land use, cost and other issues is necessary for optimal BF siting. It is essential to have a clear understanding of how BF will be utilized (e.g., as a means of pre-treatment or as a primary treatment) prior to commencing site location planning studies.

In the case of wastewater-polluted river water, river bank filtration (RBF) offers a natural cost-effective pre-treatment step, achieving the removal of pathogens, a reduction in disinfection by-product formation, better taste of water, and protection against shock loads of chemicals and pathogens resulting from accidents. The authors see a huge potential for wider use of RBF worldwide, especially because the removal of microbial pathogens in drinking water from surface water through RBF would be a crucial factor. Thus, it could serve as an alternative to direct river water abstraction. At a minimum, bank filtration acts as a pre-treatment step in water production for drinking, industrial and agricultural use. Even if treated wastewater contributes to a high percentage to river discharge, RBF may be feasible to improve water quality for further use of the river water.

The future utilisation of RBF requires an integrative assessment of the sustainability of bank filtration under changing boundary conditions, e. g. caused by potential

climate change and wastewater input. Such boundary conditions are mainly the frequency, duration and peak behaviour of floods and droughts affecting the available water quantity, changing river water temperature and concentrations of biodegradable organic matter and redox species resulting in changing biomass production and biological activity and thus influencing the water quality and treatment capacity. To our present knowledge, the potential climate changes do not jeopardise the bank filtration effectiveness, although adaptation strategies have to be developed to account for an increase in extreme events. To cover low flow periods, integrated water resources management becomes of main importance. In the United States and in India, horizontal collector wells have been installed with laterals directly beneath the river bed. Thus, there is sufficient water abstraction during low flow periods, but the pre-treatment effect is limited due to short retention times (several hours to a few days). Furthermore, high abstraction rates cause clogging of the riverbed. Low flow conditions are critical for RBF operation if the extraction rates per unit area of the river bed/ river bank are high. From long-term experiences, an average infiltration rate of less than 0.2 $m^3 m^{-2} day^{-1}$ over the river bed ensures limited clogging and stable infiltration conditions.

Results from a literature survey and field experiments using abstraction wells and observation wells to study the removal efficiency of RBF sites located at rivers heavily polluted by non-treated and treated wastewater in India, Egypt, South Korea and Russia will be summarized. Problems and limitations of RBF related to source water quality will be highlighted. It will be shown that BF could act as a safety measure against spills of contaminants into the river and as a cost effective pre-treatment step. Experiences from existing sites in Europe and Asia will be used as a benchmark for planning new sites setting a focus on feasible surface water quality. Regional differences in source water quality, design and operation of BF schemes will be highlighted. BF as an element of IWRM, coupling of BF with innovative techniques for post-treatment (AquaNES project) as well as proposed steps for wider application and acceptance of BF in Asia will be discussed.

A Novel Measurement of MBR Integrity to Augment Monitoring in Potable Reuse Applications

Stephen Katz P. Eng, SUEZ Water Technologies & Solutions, Oakville, Canada;
Pierre Côté, COTE Membrane Separation, Ltd, Hamilton, Canada;
Joel Citulski, SUEZ Water Technologies & Solutions, Oakville, Canada;
Daniella Mosqueda-Jimenez, SUEZ Water Technologies & Solutions, Oakville, Canada;

There is ample evidence in literature that Membrane Bioreactor (MBR) technology provides advanced removal of pathogens (Katz et al., 2017); this is attributed to a variety of mechanisms related to biological treatment in addition to the physical exclusion of the membrane itself. Despite MBR's capability as a robust barrier to pathogens, in certain jurisdictions the difficulty in monitoring pathogen removal is a gap that has been identified in the adoption of MBR for indirect and direct potable reuse (IPR/DPR) applications. This was recently highlighted as a key research need in the report to the California Legislature on the feasibility of developing water recycling criteria for direct potable reuse. With the purpose of addressing this gap, this paper presents a novel method for the calculation of solids log removal value (LRV) based on the standard method for total suspended solids, with a modification to the sample collection process which allows for orders-of-magnitude more resolution.

Turbidity monitoring is the standard for MBR permeate quality and has also been adopted in various potable water reuse guidance documents, including the WaterVal Membrane Bioreactor Validation Protocol (WaterSecure, 2017) and the World Health Organization's Guidance for Producing Safe Drinking-Water (World Health Organization, 2017). Literature shows that online turbidity measurement was sufficiently responsive to detect membrane damage that resulted in declines in contaminant removal at a turbidity level of 0.2 NTU (Mosqueda-Jimenez et al., 2011); when membranes were damaged to a point where turbidity was elevated above 0.2 NTU significant pathogen removal was still seen; turbidity responded immediately to changes in membrane integrity; and that advances in turbidity monitoring have enhanced the ability to quickly detect breaches (Katz et al., 2017). The sensitivity of permeate turbidity in MBR is also improved relative to direct filtration applications

because the reactor turbidity is much higher (WaterSecure, 2017). The proposed method could be used as a means of supplementing turbidity and augmenting monitoring of MBR systems, providing further assurance of pathogen removal.

The method proposed relies on the widely utilized standard method ASTM D5907-10 for enumeration of total suspended solids (TSS). The resolution of the TSS measurement method for low-solids streams such as MBR permeate is limited by the impractical volume of liquid that must be filtered to accumulate sufficient mass for accurate weighing. In the modified procedure, this limitation is overcome by utilizing an inline filter housing that allows for filtration of up to 1 cubic meter of MBR permeate. The advantage of this adaption is that the resolution for TSS can be extended by 3 orders of magnitude thereby allowing one to measure a high level of removal across the MBR system. The TSS method uses filters with a 1.5 µm pore-size, which is less than the diameter of various pathogens, such as cryptosporidium oocysts (4-6 µm) and giardia cysts (8-14 µm), and less than the 3 µm-defect resolution that the pressure decay approach in drinking water applications is based on. The proposed method offers the ability to calculate a solids LRV across the MBR system which directly measures the removal of particles that, based on the filter size cut-off, would include free bacteria, protozoa, as well as the solid particles and flocs to which they and the viruses present in wastewater can adsorb. Therefore, the solids LRV method accounts for all pathogen removal mechanisms, beyond physical separation of the membrane itself, and is based on a well-established method that is easily carried out without specialized facilities or training.

This paper will detail:

- Background and calculations forming the basis of the method
- Results from the initial validation experiments – which indicated that the Solids-LRV test can be performed daily with simple and low-cost equipment. Eight measurements on a pilot showed that MBR provided a LRV of 5.84 based on the solids in the membrane tank, which was reduced to 3.72 when applying conservative volume concentration factors.
- Review additional experimental data focused on the method’s repeatability and accuracy, and testing response to membrane breaches
- Optimal operating conditions and test setup

A Novel Measurement of MBR Integrity to Augment Monitoring in Potable Reuse Applications

Stephen Katz P. Eng, SUEZ Water Technologies & Solutions, Oakville, Canada; Stephen.Katz@suez.com;
Pierre Côté, COTE Membrane Separation, Ltd, Hamilton, Canada;
Daniella Mosqueda-Jimenez, SUEZ Water Technologies & Solutions, Oakville, Canada;
Joel Citulski, SUEZ Water Technologies & Solutions, Oakville, Canada;

Introduction

There is ample evidence in literature that Membrane Bioreactor (MBR) technology provides advanced removal of pathogens (Katz et al., 2017); this is attributed to a variety of mechanisms related to biological treatment in addition to the physical exclusion of the membrane itself. Despite MBR's capability as a robust barrier to pathogens, in certain jurisdictions the difficulty in monitoring pathogen removal is a gap that has been identified in the adoption of MBR for indirect and direct potable reuse (IPR/DPR) applications. This was recently highlighted as a key research need in the report to the California Legislature on the feasibility of developing water recycling criteria for direct potable reuse. With the purpose of addressing this gap, this presentation presents a novel method for the calculation of solids log removal value (LRV) based on the standard method for total suspended solids, with a modification to the sample collection process which allows for orders-of-magnitude more resolution.

Turbidity monitoring is the standard for MBR permeate quality and has also been adopted in various potable water reuse guidance documents, including the WaterVal Membrane Bioreactor Validation Protocol (WaterSecure, 2017) and the World Health Organization's Guidance for Producing Safe Drinking-Water (World Health Organization, 2017). Literature shows that online turbidity measurement was sufficiently responsive to detect membrane damage that resulted in declines in contaminant removal at a turbidity level of 0.2 NTU (Mosqueda-Jimenez et al., 2011); when membranes were damaged to a point where turbidity was elevated above 0.2

NTU significant pathogen removal was still seen; turbidity responded immediately to changes in membrane integrity; and that advances in turbidity monitoring have enhanced the ability to quickly detect breaches (Katz et al., 2017). The sensitivity of permeate turbidity in MBR is also improved relative to direct filtration applications because the reactor turbidity is much higher (WaterSecure, 2017). The proposed method could be used as a means of supplementing turbidity and augmenting monitoring of MBR systems, providing further assurance of pathogen removal.

Proposed Approach

It is proposed to use total suspended solids (TSS) as a surrogate parameter to estimate the log removal value of pathogens by MBRs; hence, the method is called "Solids-LRV". The Solids-LRV method measures the removal of pathogens including protozoa, bacteria, as well as smaller pathogens such as viruses adsorbed to larger particles or agglomerated into flocs. The Solids-LRV method is based on a well-established standard method that is easily carried out without specialized equipment or training - standard method ASTM D5907-10 for enumeration of total suspended solids (TSS). The resolution of the TSS measurement method for low-solids streams such as MBR permeate is limited by the impractical volume of liquid that must be filtered to accumulate sufficient mass for accurate weighing. In the modified procedure, this limitation is overcome by utilizing an inline filter housing that allows for filtration of up to 1 cubic meter of MBR permeate over a multi-hour period. The advantage of this adaption is that the resolution for TSS can be extended by 3 orders of magnitude thereby allowing one to measure a high level of removal across the MBR system. The TSS method uses filters with a 1.5 µm pore-size, which is less than the diameter of various pathogens, such as cryptosporidium oocysts (4-6 µm) and giardia cysts (8-14 µm), and less than the 3 µm-defect resolution that the pressure decay approach in drinking water applications is based on. The proposed method offers the ability to calculate a solids LRV across the MBR system which directly measures the removal of particles that, based on the filter size cut-off, would include free bacteria, protozoa, as well as the solid particles and flocs to which they and the viruses present in wastewater can adsorb. Therefore, the solids LRV method accounts for all pathogen removal mechanisms, beyond physical separation of the membrane itself.

Figure 1 shows the equipment needed to measure the permeate TSS (in red), by sampling the permeate of the entire plant or of a specific membrane train. Permeate is extracted from the main line (downstream of the plant permeate pump) using a peristaltic pump at a fixed flow rate and passed through the TSS filtration cell. The sampling point should be located as close as possible to the membranes, and upstream of any disinfection. Sample collection is stopped when the membranes are backwashed or relaxed. The sample is collected over a period, targeted to be less than 24 hours, but is stopped if the pressure across the filtration cell reaches a terminal value.

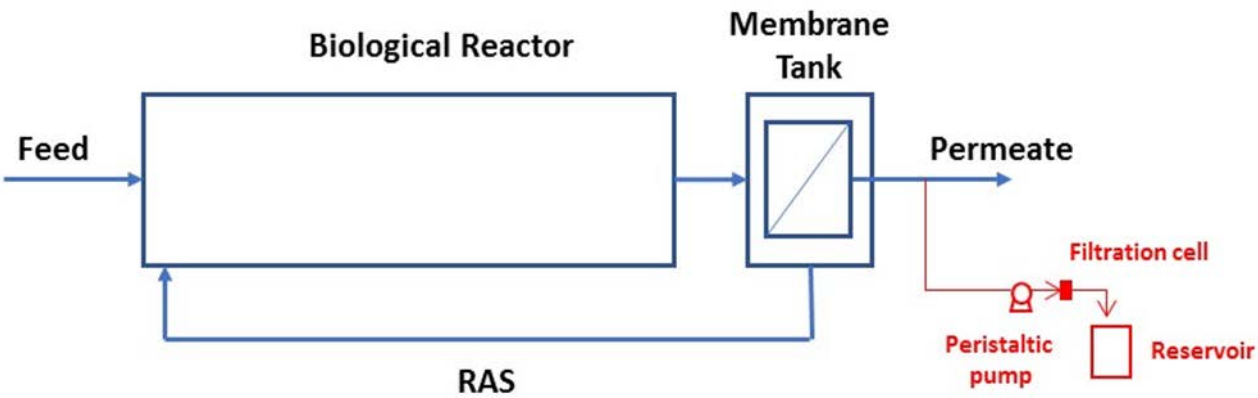


Figure 1 - Equipment needed for determination of permeate solids concentration

The value of overall solids log removal across the system (**LRV_{solids}**) is obtained by correcting the log removal across the membrane with two volumetric concentration factors (VCFs). The formulas to calculate the **LRV_{solids}** are shown in Figure 2 below.

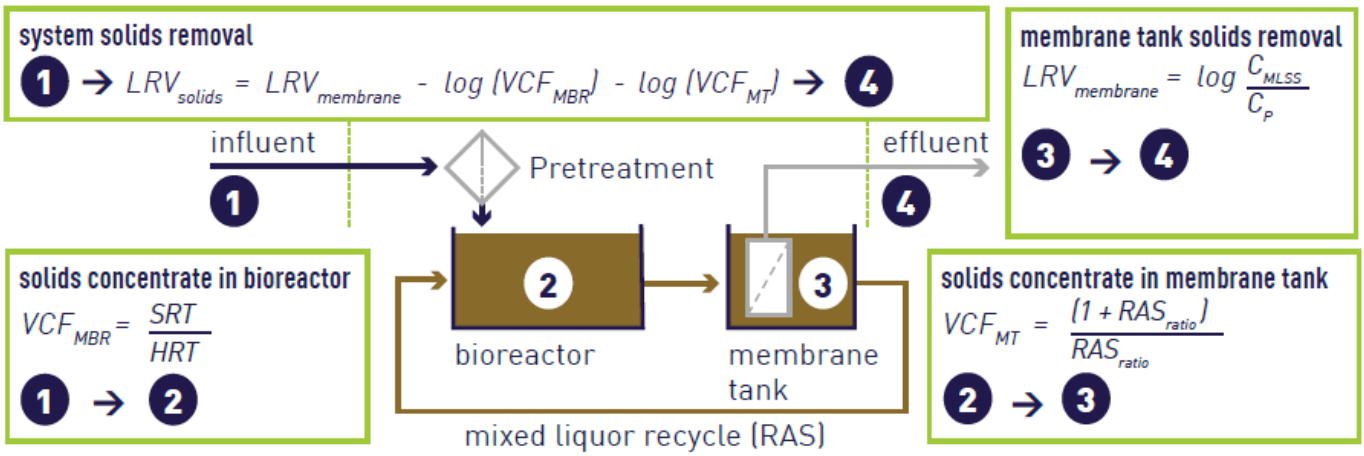


Figure 2 – Solids-LRV Equations

$LRV_{membrane}$ is the logarithmic ratio of the solids concentration applied to the membrane (C_{MLSS}) to the solids concentration in the permeate (C_p)

VCF_{MT} represent the concentration increase due to the fact that the membranes reject and concentrate solids in their vicinity.

VCF_{MBR} represents the solids concentration increase in the bioreactor due to operation at a solids retention time (SRT) longer than the hydraulic retention time (HRT).

Results and Discussion

Results from the initial validation experiments indicated that the Solids-LRV test can be performed daily with simple and low-cost equipment. Eight measurements on a pilot showed that MBR provided a LRV of 5.84 based on the solids in the membrane tank, which was reduced to 3.72 when applying conservative volume concentration factors.

This presentation will review the initial validation data along with additional experimental data focused on the method's repeatability and accuracy, and testing response to membrane breaches. As well, it will explore the optimal operating conditions and test setup.

References

Katz, S., Salveson, A., Fontaine, N., Bucher, B., and Berryhill, J. (2017) Giving Credit where is Due: MBR for Potable Reuse, WEFTEC 2017 Proceeding, 5142- 5157.

Mosqueda-Jimenez, D., Thompson, D., Theodoulou, M., Katz, S. (2011) Monitoring Microbial Removal in MBR. WEFTEC 2011 Proceeding, 6245-6268.

WaterSecure (2017) Membrane bio-reactor, WaterVal validation protocol, Australian WaterSecure Innovations Ltd., Brisbane.

World Health Organization (2017) Potable Reuse: Guidance for producing safe drinking-water, Geneva.

Non RO based treatment trains for reuse – A solution for inland facilities

J. Scheideler* Roshanak Aflaki**

** Xylem Services Gmbh, AOP Manager, Boschstr. 4-13, 32051 Herford, Germany; jens.scheideler@xyleminc.com*
*** City of Los Angeles, Bureau of Sanitation, USA roshanak.aflaki@lacity.org.*

Abstract

The application of membrane based treatment technologies for potable and non-potable reuse has become the gold standard in many countries worldwide especially easy to implement for utilities with the access to ocean outfall for the disposal of the brine. However regions suffering from severe droughts are often located inland challenging the utilities to move towards reuse and dealing with brine from membrane based treatment. Over the last years huge research efforts have been made to investigate alternative treatment trains that do not rely on membranes and at the same time provide a water quality that is aligned with the guidelines enabling even direct potable reuse. This paper will provide insights into three major projects that have focused on or implemented potable reuse without membrane filtration:

- Rio Rancho Pure Project (1 MGD Reuse Facility in New Mexico)
- Water Reuse Research Foundation Project 11-02
- DC Tillmann Pilot Project (City of Los Angeles)

The paper will benchmark the different treatment trains with regards to their efficiency and costs for implementation as well as produced water quality compared to RO based treatment trains

UV Advanced Oxidation Processes for Potable Reuse: Pilot Study at the Largest Recycled Water Treatment Facility in Northern California

Mihaela Stefan, Trojan Technologies, London, ON, Canada; Paolo Baltar, SCVWD, Santa Clara, CA, USA; Zachary Helsley, SCVWD, Santa Clara, CA, USA; Minhwan Kwon, Trojan Technologies, London, ON, Canada; Steve McDermid, Trojan Technologies, London, ON, Canada; Alan Royce, Trojan Technologies, London, ON, Canada

Advanced water purification trains for water reuse typically include microfiltration or ultrafiltration, reverse osmosis (RO) filtration, and an UV-advanced oxidation process (UV-AOP). California water reuse regulations require treatment to less than 10 ng/L NDMA and minimum 0.5-log removal of 1,4-dioxane (or equivalent). In recent years, UV/chlorine (UV/Cl_2) AOP has been investigated as an alternative to the commonly implemented UV/H_2O_2 AOP for water recycling. The UV/Cl_2 process presents practical and economic advantages over the UV/H_2O_2 process, particularly under the low-ammonia and low-pH conditions characteristic to RO permeate (ROP). Free Cl_2 (FC) and ammonia are added to the secondary wastewater effluents to form monochloramine (NH_2Cl) in order to prevent membrane bio-fouling. NH_2Cl and residual free ammonia along with low-molecular weight pollutants such as NDMA and 1,4-dioxane, and inorganic ions are present in the ROP. For the UV/Cl_2 AOP, free chlorine is dosed to the ROP for the UV-oxidation process in the UV reactor. Unlike in the UV/H_2O_2 AOP case, upon FC addition to ROP breakpoint chlorination reactions involving ammonia and chloramines start instantly. The extent of these reactions depends on various factors such as water pH, individual species concentrations, and hydraulic residence time (HRT). Therefore, there will be an instant FC demand, lowering the amount of FC dosed for the AOP process.

NH_2Cl is a much stronger absorber of 254nm radiation than FC and H_2O_2. This impacts the AOP performance through the decrease in the UV transmittance (%*T*) of ROP. On the other hand, NH_2Cl photolyzes inside the UV reactor with *in situ* formation of reactive species and increase of water %*T*. NH_2Cl and its byproducts scavenge OH radicals, affecting both the UV/Cl_2 and the UV/H_2O_2 performance. Understanding and predicting chlorine chemistry in the ROP prior to UV-AOP, photochemistry of NH_2Cl, FC, and H_2O_2 and subsequent reactions inside the UV

reactor are paramount for accurate UV equipment sizing and UV-AOP performance prediction and control in water reuse projects. Furthermore, understanding the complexity of the UV-AOP in the presence of chloramines enables efficient operation of the UV system.

Santa Clara Valley Water District (SCVWD) owns and operates the Silicon Valley Advanced Water Purification Center (AWPC) which is the largest treatment plant of its kind in northern California. This state-of-the art plant treats 8 MGD of recycled water to near drinking water quality using microfiltration, RO and UV disinfection. SCVWD and Trojan Technologies collaborated on a pilot study focused on the abovementioned aspects of UV-AOPs for water reuse projects. In this study the UV/Cl_2 and UV/H_2O_2 processes were compared under similar ROP quality and UV system conditions. A TrojanUVPhox™8AL20 reactor with LPHO UV lamps was operated over a wide electrical energy dose range (EED, 0.33–1.08 kWh/kgal) using a side-stream of ROP from the AWPC. NH_2Cl photochemistry in the absence of oxidant and its impact on 1,4-dioxane and NDMA removal was investigated at ambient (~3mg/L as Cl_2; %*T*~96.5%) and ~5.2mg/L as Cl_2 (93.5%*T*) levels. Despite up to 5%*T* increase across the reactor, 1,4-dioxane removal was poor for the UV/NH_2Cl process (up to 0.34-log) and non-linear with EED and/or NH_2Cl levels, which is explained by the radical scavenging dynamics. NDMA-log removal depended mostly on the EED. Upon FC addition to ROP containing 0.55mg/L NH_3-N and 3mg/L NH_2Cl as Cl_2, NH_2Cl level increased but breakpoint reactions also occurred with HRT-dependent dichloramine formation. 1,4-Dioxane-log removal increased in the presence of either FC (2~7mg/L) or H_2O_2 (2~6mg/L) at each EED. Not all UV-AOP conditions resulted in 0.5-log 1,4-dioxane removal. NDMA removals were high (0.8->2.6log) and did not vary noticeably with the oxidant concentration. The experimental data and molecular and radical chemistry of species involved in the UV-AOPs allowed us to develop a mechanistic kinetic model using MATLAB software. The model predicts well the breakpoint reaction dynamics and its impact on UV/Cl_2 performance, as well as the 1,4-dioxane, NDMA, and oxidant patterns. Changes in water transmittance, NH_2Cl decay and *in-situ* radical scavenger formation were experimentally measured and predicted by the model. Pilot test data and model predictions will be presented and interpreted based on current scientific understanding and from a practical perspective on UV-AOPs for water reuse projects.

Water-Energy Regenerative House

M. Ramezanianpour, Department of Engineering and Architectural Studies, Ara Institute of Canterbury, Christchurch 8011, New Zealand;
M. Sivakumar, School of Civil, Mining and Environmental Engineering, Faculty of Engineering and Information Sciences, University of Wollongong, Wollongong, NSW 2500, Australia;
H. Chen, Department of Engineering and Architectural Studies, Ara Institute of Canterbury, Christchurch 8011, New Zealand;
T. Vessey, Department of Engineering and Architectural Studies, Ara Institute of Canterbury, Christchurch 8011, New Zealand;
matt.pour@ara.ac.nz

Abstract:

Population growth, urbanisation and affluence together with the effects of climate change pose a significant threat to energy and water resources. The close relation between energy and water anticipates exigent situations. This research reflects utilisation of sustainable technologies in a regenerative house to overcome water and energy adversity in future. The main aim is to design integrated water and energy infrastructure through the application of water reuse and renewable energy technologies. A decision support system (DSS) is developed to address the available water or energy sources to the demand points in a household. This project presents the importance of net-positive water and net-positive energy building in conserving natural resources and reducing the impact on environment.

Keywords: Decision support system; Energy infrastructure; Regenerative house; Water infrastructure

Introduction

Building construction has traditionally aimed to provide essential requirements such as wellbeing, function and safety taking into account social and economic aspects. Initial design and construction can require modernising or replacement when circumstances change and this can result in adverse financial and environmental impacts (Olubunmi et al. 2016). Carbon emission, environmental degradation, and lack of attention to global warming are the main reasons for criticism of the construction industry (Wong and Zhou 2015). Net-zero impact on environment is achievable in mimicry of natural processes within the energy, water and waste cycle.

Moving towards green building solution is not only the design and materials, it can be a sustainable design integrated with regeneration of energy, water reuse and waste recycling. Sustainable design requires appropriate design and construction respecting the environment in order to meet green building standards (Banchor 2014). Green buildings are certified through a variety of parameters including energy consumption, living environment, material used, water reuse, emissions, innovation, waste management, etc. It is clear that the life cycle cost is reduced proportionally with water and energy savings. Additionally, innovative building concepts must now improve sustainable design by introducing regenerative houses.

Regenerative buildings support the stability of the ecosystem by utilising sustainable and innovative infrastructure technologies to protect water and energy resources. This is achievable through the application of water saving and energy generation technologies. The concept of water and energy regenerative house is mainly explains that the typical households are able to afford their power and water sources. They can reduce the need to be reliant upon the grid as well as contribute excess energy from on-site power generation back to the community. Although they may connected to the grid in emergency situations they are generally autonomous and not reliant upon the electrical grid or other utility systems to operate (Li et al. 2016).

Water recycling in a sustainable manner is increasingly being practised around the world to protect water resources. Abundantly available brackish water sources suitably treated can be used for recycling purposes. Greywater recycling has been accepted due to the quantity and quality of this source compared to sewage. Water treatment for reuse will not only decrease the rate of fresh water consumption in urban areas but will also reduce the pressure on water and wastewater treatment plants. These substantial improvements are obtainable through the use of appropriate treatment technology in a sustainable and efficient manner.

Water is closely interconnected with energy. Water extraction, treatment, transport and distribution all require energy. Renewable energies offer alternative solutions along with two benefits: reliability and cost. The application of renewable energy is essential in order to convert water treatment units into green technology. The combined water-energy infrastructure system results in zero greenhouse gas emissions and reduction of operational carbon footprint. These approaches can engender a solution to water-energy crises in future too.

Material and Methods

This research demonstrates that DSS is an effective tool for real-time operations of water and energy supply systems based on single and multiple objectives. The DSS tool optimised the design for both water-energy infrastructure in this research. An algorithm prepared in both water and energy section to connect appropriate sources to demand points. DSS is applied in a small scale water management network which has multiple objectives on both sources and demand points. The availability of water or energy sources with acceptable quality level is a condition to address the demands in such scale. In this research the technologies available in the market for water treatment and energy generation were evaluated and the most sustainable unit was selected and used in the infrastructure designed by the DSS tool.

Roof catchment is treated to provide water for drinking. The Ultraviolet Water Purification System is manufactured by Sterilight Cobalt Ltd. This system comprises carbon filtration and Ultraviolet (UV) disinfection that can enhance rainwater quality to the drinking water standard level. It can treat water at the rate of 1.8 to 3 m^3/hr. Greywater is the most important source for recycling. Greywise treatment unit is manufactured by Wisewatersolution that can treat a maximum 1,140 L/d with membrane technology. It is decided to treat storm water with this unit due to its capacity. Biological treatment is required in a black water recycling system. Alternative Treatment Units (ATU) manufactured by Aquarius Ltd comprises a tank to retain solids followed by aeration chamber to reduce BOD and nitrates.

Domestic household energy generation solutions such as: PV solar panels, small-scale wind turbines and biofuel methane digesters will maximise the efficiency of electricity production simultaneously. Monocrystalline PV panels are the most efficient at a recorded 21.5%. Vertical axis turbines are commonly used in turbulent wind. Due to their 360° design, these turbines can generate power from all wind angles. The maximum efficiency of a turbine is approximately 40% at a velocity of 9 m/s. Creating methane gas from household waste and other products via a biofuel digester is a very sustainable way of generating power. The methane is used as a fuel to be burnt, to power cooking apparatus and even in heating a home. The average New Zealand home produces about 80 kg of organic waste per year. A 4 bedroom house with an average 200 m^2 roofing area and 100 m^2 external pavement for four people is assumed in the case study in Christchurch, New Zealand.

Results and Discussion

The water infrastructure layout and details required for the DSS algorithm is presented in Figure 1. The water sources are water main, roof catchment, storm water, treated greywater, and treated black water. This classification is a quality based ranking system on water sources. The demand points are also classified from the highest quality demand to the lowest one. Fresh water is provided by the water distribution system. Rainwater is collected from the roof and treated by filtration and a UV disinfection system. Storm water is directed to the greywater treatment unit along with the discharge from the bathtub, shower, hand basin, washing machine, dishwasher, and kitchen sink. Finally, black water is generated at the toilet and sent to the allocated treatment unit. The overflow from tank 1 is directed to tank 2. The green circles are the valves that control the flow direction. The pipe lines with arrows show the flow direction. The water consumption rate is 227 L/p/d in Christchurch. The roof catchment tank size is calculated to be 220 L assuming 5 days average intervals of raining. The size of the tank for treated greywater is also determined using 160 L/p/d generation rate. A 750 L tank is required to store treated water. The detention time for the black water treatment unit is 2 days. Therefore, a 340 L volume of chamber is required. A series algorithm of the decision support system is provided to show the position of each valve for different situations.

The energy infrastructure layout and details required for the DSS algorithm is presented in Figure 2. The layout consists of five sources including solar, wind, biofuel, main grid power, and evacuated tubes. There are six energy demands including heating, hot water, appliances, fridge, lighting and cooking. A sustainability study is required to decide the usage of the storage unit. The layout utilises 11 switches, controlling the sources and demands. The DSS investigates the availability of renewable energy sources to address the demands. The Bio-digester mainly supports the energy required for cooking and then the hot water tank. Data collected from a typical household energy consumption shows that the design for renewable energy need to fully power to house's daily requirement, 35kWh in summer and portion of 45 kWh in winter. The 500W vertical wind turbine was considered the best fit for Christchurch's residential use. The 1.4 m by 1.2 m model is a practical size to mount on a residential roof. The calculations show the power generated from a wind turbine peaking at around 65 W.

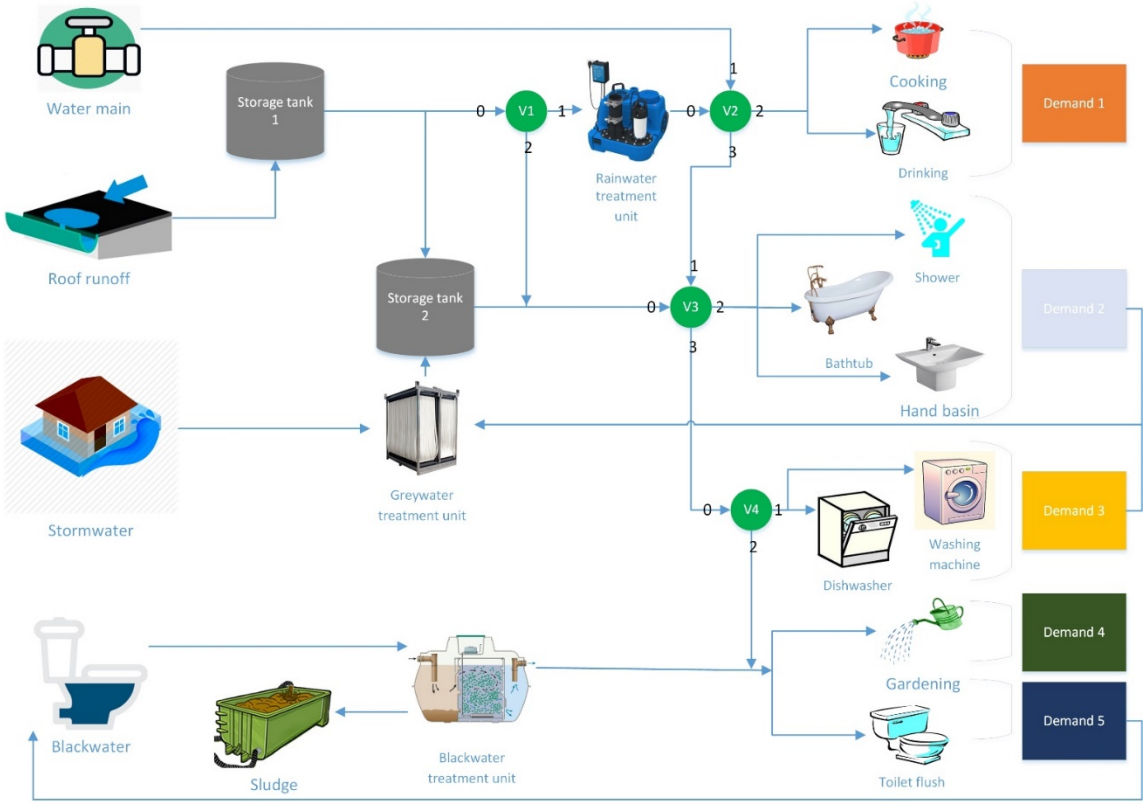


Figure 1 Water infrastructure layout

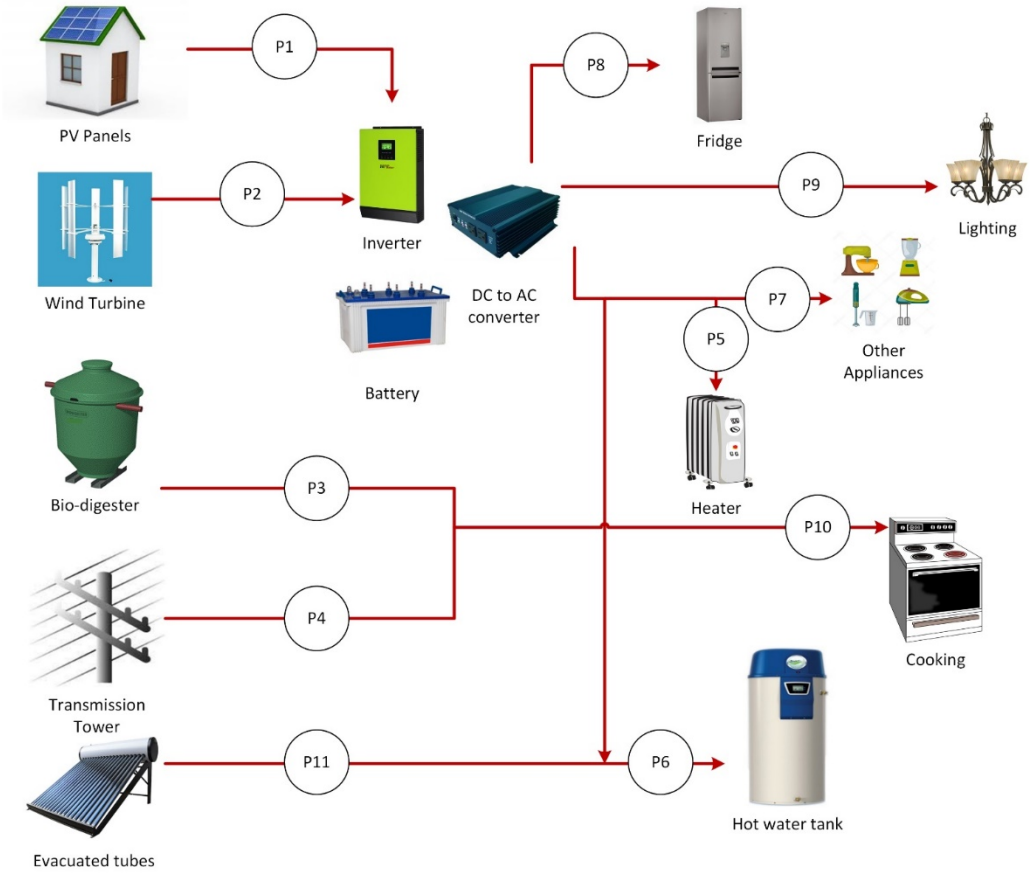


Figure 2 Energy infrastructure layout

Conclusions

This research developed water and energy infrastructure layouts for a regenerative house. The idea of incorporating roof catchment, greywater, storm water and black water treatment units results in regenerating water required in the household and reduces impacts on the environment. The regenerative house will moderate the pressure on water treatment and wastewater treatment plants. The DSS effectively addresses the demands in water infrastructure layout based on the quality and availability of the water sources. In this research, weather analysis, water and energy consumption, source of water and energy and investigations have been undertaken, along with the algorithm and supporting diagram. This research implemented the DSS tool that ultimately control the performance of the system. Functions that will aid in assisting the algorithm with timing, direction and quantity of energy have been developed to aid electrical efficiency within the household. The simulation study showed the regenerative house is able to save water in summer and winter by 90.9% and 100%, respectively. Dependent on the number of solar panels and wind turbines, it was possible to save up to 78% in winter in the case study.

References

Banchor A. (2014) Smart Green Building Materials for Smart Homes. Architecture Update, 8(8), 49.

Li H. X., Gül M., Yu, H., Awad H. and Al-Hussein M. (2016) An energy performance monitoring, analysis and modelling framework for NetZero Energy Homes (NZEHs). Energy & Buildings. 126, 353-364.

Olubunmi O. A., Xia P. B. and Skitmore M. (2016) Green building incentives: A review. Renewable and Sustainable Energy Reviews. 59, 1611-1621.

Wong J. K. W. and Zhou J. (2015) Enhancing environmental sustainability over building life cycles through green BIM: A review. Automation in Construction. 57(Supplement C), 156-165.

Sustainability and success of operation of decentralized, small scale SUWA systems: a case study in central Mexico

L. Benavides[1], T.Avellán[1], A. Müller[1], A. Hahn[1], S. Caucci[1], C. Paillés[2], A.L. Velasco[2], E. Muñoz[2]

This study examines the sustainability and success of a decentralized wastewater treatment system currently operating as part of a citizen-led management strategy in operation in the semi-arid region of Tepeji del Rio, in central Mexico. This strategy was set up as a response to the lack of central, publicly operated wastewater management in the municipality, and the urgency to provide wastewater treatment and reuse solutions. Before the construction of the plants presented in this study case, all domestic wastewater produced in the municipality was discharged without treatment directly into local surface water resources (the Tepeji river and the Requena dam). On the other hand, increasingly scarce water resources are demanded by agricultural production and other irrigation needs. Small scale treatment systems could not only provide an alternative to satisfy this demand, but also help diminish degradation of surface water quality. Decades of experience and research on wastewater and treated wastewater irrigation in the neighboring regions provide additional support for such a project.

Recently, a trust operated by private citizens designed, built and started to operate a series of small scale (~2 l/s) anaerobic plants, seeking to provide treatment for wastewater and an irrigation water source for local farmers. We examined one of twelve plants set up by the trust using a multi-dimensional and multi-scalar framework to understand its degree of sustainability.

The results show that, decentralized SUWA type systems may be an excellent option to treat water in the absence of other treatment facilities and to provide alternatives to farmers and other stakeholders in arid and semi-arid regions. Relative low costs in raw materials and energy consumption as well as comparatively less complicated training and capacity-building needs, along with the opportunity of fostering local stakeholder involvement and awareness are some of the advantages. Nonetheless, certain key factors must be considered to ensure sustainable performance, including acceptance of the system by

users, neighbors and other stakeholders, and the incorporation of such a system into overarching wastewater management strategies (e.g. by government facilities).

This paper briefly described the overall methodology to perform the assessment (the methodology is presented in detail in a separate publication), presents the findings of the case study, identifies successes and opportunities for improvement, and gives detailed recommendations to improve the current situation. Lessons learned may also be of use to other small scale agricultural reuse systems in the Latin American region.

[1] United Nations University, Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES)

[2]Fideicomiso de Infraestructura Ambiental de los Valles de Hidalgo (FIAVHI), México.

Improving water quality and pathogen removal using a low-cost anaerobic wastewater filtration –applicable for small-scale agricultural production in developing countries

Korbinian Kaetzl[1,2], Manfred Lübken[1], Gülkader Uzun[1], Tito Gehring[1], Edith Nettmann[1], Kathrin Stenchly[3] and Marc Wichern[1]

[1]Instiute of Urban Water Management and Environmental Engineering, Ruhr-Universität Bochum, Universitätsstraße 150, 44780 Bochum

[2]Grassland Science and Renewable Plant Resources, Universität Kassel, Steinstraße 19, 37213 Witzenhausen

[3]Organic Plant production and Agroecosystems research in the Tropics and Subtropics, Universität Kassel, Steinstraße 19, 37213 Witzenhausen

Introduction

In many developing countries, as such as in Sub-Saharan Africa (SSA), the agricultural sector accounts for approximately 90% of the freshwater withdrawals, and with only 10% of the generated wastewater that undergoes an appropriate treatment. Thus, there is an urgent need for the development and implementation of a low-cost, simple and efficient wastewater treatment system. For the production of safer irrigation water, a two stage anaerobic wastewater filtration consisting of an anaerobic pre-filter (AF) and followed by downstream anaerobic biofilters (AnBFs) was developed. Rice husk biochar and their unpyrolysed feedstock, as locally available agroresidues, were used and their efficiency as filtration media for AnBF tested and compared with sand as a common reference material.

Material and Methods

In this experiment, raw sewage from a municipal full-scale wastewater treatment plant in Germany pretreated with an AF was used. The AF was operated with a mean organic loading rate of 194±74 $g_{COD}\cdot m^{-3}\cdot d^{-1}$. AnBFs were constructed as normal slow sand filters and contained a filter bed of 55 cm in depth and covered by a 5 cm sand layer to prevent floating of the light materials. Filters were run in triplicates under saturated conditions and fed with the effluent from the AF. Mean OLR of AnBFs was 63±16 $g_{COD}\cdot m^{-3}\cdot d^{-1}$. All filters were operated at 22 °C room temperature with a hydraulic loading rate of 0.05 $m\cdot h^{-1}$ for 400 days. Raw wastewater contained

305±107 mg·chemical oxygen demand (COD) per liter. After treatment, effluent of the biochar filters was used to irrigate lettuce plants, which were tested for reduced FIB contamination in comparison to raw wastewater that is commonly used in urban production systems in SSA countries.

Results and Discussion

The performance of the biochar filters was significantly better than or equal to the tested sand and rice husk filters. FIB (up to 3.9 $\log_{10}$-units; Figure 1), bacteriophages (up to 2.7 $\log_{10}$-units), COD (up to 94%) and turbidity (up to 97%) could be significantly reduced, whereas nitrogen and phosphorous were not affected by the water treatment, which is a positive aspect for irrigation.

The results from the irrigation experiment confirmed furthermore the efficiency of the biochar filters for wastewater treatment as the contamination of the majority of the lettuce plants by FIB was below the detection limit. Since disinfection through ultraviolet (UV) light was minimized in the framework of our greenhouse experiment, an even higher FIB inactivation by solar UV light can be assumed for on-farm conditions, particularly within SSA. The achieved water quality of the effluent is thus suitable for unrestricted irrigation, following the multibarrier approach of the WHO (2006) guidelines.

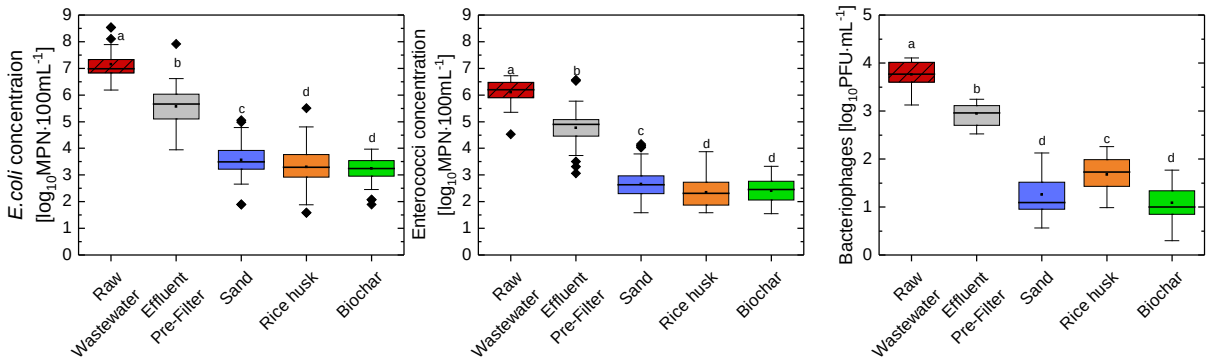


Figure 1. Concentration of FIB and bacteriophages in raw wastewater and the effluent of the anaerobic pre-filter and the AnBFs. Mean values are marked as black squares and whiskers represent 1.5 interquartile range. Different letters indicate significant differences of the mean after post-hoc analysis using $p < 0.05$ as significance threshold.

Assessment of source separated sanitation technologies for sustainable wastewater management

T. Zinati Shoa, Department of urban water management, Technical University of Berlin, Berlin, Germany ; A. Wriege-Bechtold, Technical University of Berlin, Berlin, Germany ; B. Zinati Shoa, Department of management, Technical University of Shahrood, Shahrood, Iran ; M. Lenzen, Technical University of Berlin, Campus El Gouna, Egypt ; M. Barjenbruch, Technical University of Berlin, Berlin, Germany ;

Abstract:

Conventional and source separated urban sanitation systems are compared with regard to their energy demand and emission of CO2. The assessment is carried out using developing new combined energy and material flow analysis model to consider the efficiency of urban sanitation systems. The model equations not only integrate mass and nutrients flow but also the energy balance of the various systems. The material flow model of all relevant processes is set up and evaluated for resource recovery potential. The comparisons showed varying potential of source-separated concepts.

Keywords: Source separated sanitation concept; Material flow analysis; Conventional sanitation system;

Introduction

Within the framework of sustainable development, it is important to find ways of reducing natural resource consumption and to change towards closed-loop management of nutrient, energy and water resources (Meinzinger, 2010). The municipal wastewater sector in urban water management consume high amount of energy to remove nutrient and pollutant and release the treated water to nature. Even though conventional wastewater treatment resolves hygiene and aquatic environment related problems, it does not have control on generated wastewater at the source and does not consider resource recycling (Otterpohl, 2002). As alternative to conventional wastewater, many approaches based on source separated sanitation system have been introduced (Larsen et al., 2009, Otterpohl et al., 2002, Zeeman et al., 2008). Although the technical feasibility of source separated sanitation systems

in different pilot projects (Larsen & Lienert 2007; Peter-Fröhlich et al. 2007) have been successfully proved, nevertheless there is still lack of knowledge to more resource-oriented sanitation system alternative. This study aims to develop an integrated nutrient-energy flow analysis model to compare different developments of source separation systems that could be sustainably more feasible than conventional treatment of wastewater. It focuses on innovative systems and leading-edge technologies that are commercially available and have the potential to improve sustainability criteria in the short or mid-term.

Material and Methods

Conventional and source separated urban sanitation systems are compared in terms of their resource recovery potential including nutrient, energy and water demand in a settlement with 50,000 inhabitants in Germany. The evaluation has been done with sustainability indicators for resource demand and emission to air, water and soil.

A range of required wastewater treatment processes (emphasizing on processes, which lead to nutrient/energy production) is defined. The required parameter is set for each flow (including greywater, blackwater and urine) and corresponding processes.

The material flow model is set up using SIMBA# software and SAmpSONS Simulator tool (Schütze, et al., 2018) a preliminary version for visualization of material flow of new sanitation system. The model is developed by transferring corresponding processes into mathematical equations. The model equations not only integrate mass and nutrients flow but also the sustainability indicator of various systems. The validation and calibration have been completed.

In order to comparatively assess these systems, four different concepts have been set up including conventional system, concept 1 with nutrient recovery from urine storage, concept 2 nutrient recovery from precipitation of separated urine, concept 3 separation of greywater and energy production from undiluted wastewater.

The simulated concepts involve the processing of different wastewater fraction, transport, and energy supply. The resulting substance flow model is evaluated with a set of indicators including nutrient recovery, effluent quality, and energy and water balance in investigated sanitation concepts.

Results and Discussion

Figure 1 and 2 present the energy demand equivalent and CO_2 equivalent emission in different urban sanitation concepts. The conventional system does not provide any potential of nutrient recovery, while the concept 2 with precipitation process from urine show the highest amount of possibility of nutrient recovery for the replacement of mineral fertilizer.

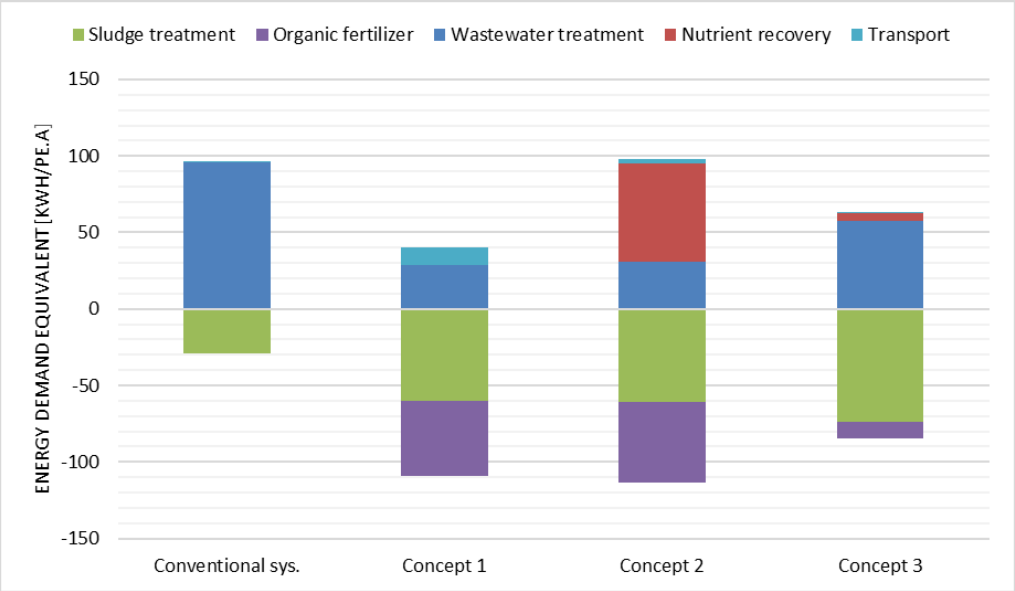


Figure 1. Energy demand of different concepts

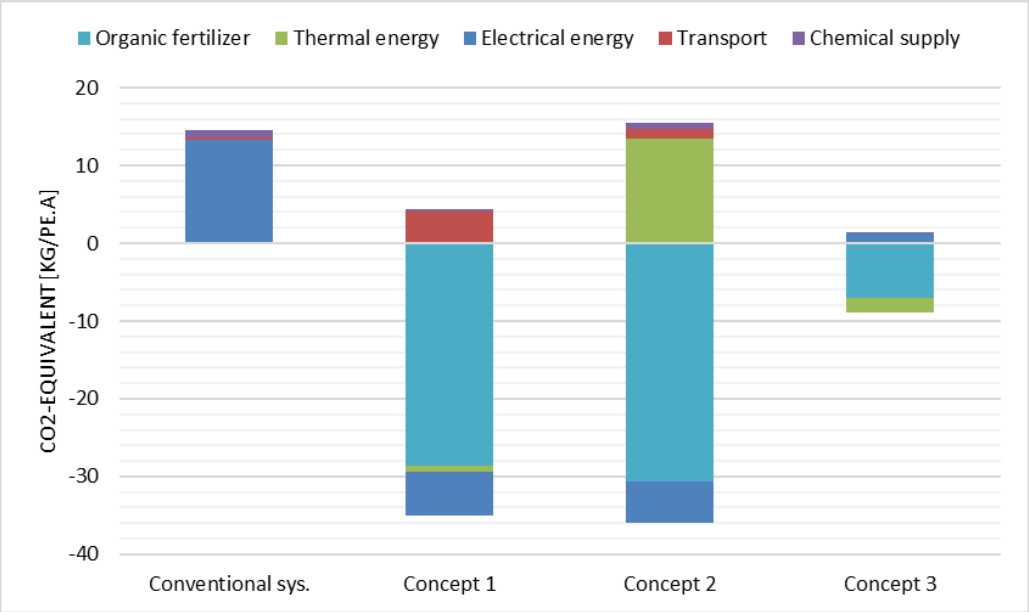


Figure 2. CO_2 equivalent of different concepts

Although source separation concepts are showing high potential for resource recovery and reduction of CO_2 emission, these concepts are still immature and risky in term of application in urban areas. Therefore, the developed model in this study offers the identification of such opportunities and by simulating a more realistic picture of the impact of this improvement before a decision is made.

Conclusions

Using the results of this study, the urban planner and the decision maker will be better prepared to implement successful strategies to increase efficiency of sanitation system. A general assessment of source separated sanitation system is not possible only based on process engineering technology. Although other aspects connected to source separation system may be more difficult to solve. However, it is important to evaluate carefully the new approaches in terms of their sustainability, including environmental, economic and social impacts. Source separating technologies are still considered immature and risky by most wastewater professionals.

References

Meinzinger, F. (2010) Resources efficiency of urban sanitation systems: a comparative assessment using material and energy flow analysis. Ph.D. thesis, Hamburg University of Technology, Institute of Wastewater Management and Water Protection, Hamburg, Germany.

Otterpohl R., 2002. Options for alternative types of sewerage and treatment systems directed to improvement of the overall performance. Water Sci Technol;45(3):149–58.

Peter-Fröhlich A, Pawlowski L, Bonhomme A, Oldenburg M., 2007. EU demonstration project for separate discharge and treatment of urine, faeces and greywater—part I: results. Water Sci Technol; 56(5):239–49.

Peter-Fröhlich, A., Bohomme, A., Oldenburg, M., Gnirss, R. & Lesjean, B. (2007) Sanitation concepts for separate treatment of urine, feces, and greywater (SCST)-results, Kompetenzzentrum Wasser Berlin gGmbH, Berlin, Germany.

Schütze, M., Wriege-Bechtold, A., Zinati Shoa, T., Söbke, H., Wißmann, I., Schulz, M., Veser, S., Londong, J., Barjenbruch, M. & Alex, J. (2018) Simulation and

Visualization of Material Flows in Sanitation Systems for Streamlined Sustainability Assessment, (subm. to Journal Water Science & Technology).

Zinati Shoa, T., Barjenbruch, M. & Wriege-Bechtold, A. (2017) Source separation technologies, opportunities for sustainable wastewater management. Journal European Water 58: 111-117, 2017. ISSN: 1105-7580.

High-integrate membrane bioreactor for wastewater treatment and reclamation in rural areas of China

Qiaoying Wang (presenting author), Tongji University, Shanghai, China; Lili Zang, Shanghai Zizheng Environmental Technology Co., Ltd, Shanghai, China; Zhichao Wu, affiliation3, City3, Country3

In this study, we will present our industrialization achievement---High-integrate membrane bioreactor (HI-MBR) for both wastewater treatment and reclamation. HI-MBR was obtained on the basis of the support of National Science and Technology Support Program in China (project no: 2012BAJ21B05), aiming at the treatment and reclamation of urban wastewater in small-scale/decentralized systems at the capacity range of 1 ~ 500 m^3/d. We have investigated and optimized the core technologies, and integrated with high efficient nitrogen and phosphorus removal technology. At the same time, the modular production and optimal configuration technology of core treatment units, such as low energy consumption self-cleaning membrane module, is developed, and finally the standardized products were formed.

The schematic diagram of HI-MBR process is shown in Figure 1. The HI-MBR process includes the regulation tank, anoxic tank, aerobic MBR tank, membrane sludge thickening digestion (MSTD) tank and equipment room. The advantages of this product lie in the adoption of novel anti-fouling membrane materials, synchronous sludge thickening and digestion by flat-sheet membrane, unique phosphorus removal patent technology, professional design software, Internet of Things management technology, etc. Due to the above mentioned core technology, HI-MBR could obtain high quality effluent for reuse, such as flushing toilets, car washing and watering, etc. The membrane cleaning period could last for 6 to 12 months, and the occupy less than 1 m^2/ton of water. On the basis of the use of Internet of Things management technology, the operation and maintenance of HI-MBR is much simple and efficient, and the labor cost is very low. The investment costs and operating costs of HI-MBR process are at the range of 450-1500 dollar/ton of water, consume 0.40-0.65 kWh/ton of water.

HI-MBR process is suitable for rural decentralized domestic sewage treatment, villa domestic sewage treatment, river point source pollution treatment and other fields. Currently, we have built more than 200 wastewater treatment project with HI-MBR process in the Yangtze delta area. It is expected that the development and widely

application of HI-MBR process could promote the treatment and reclamation of decentralized sewage in rural areas.

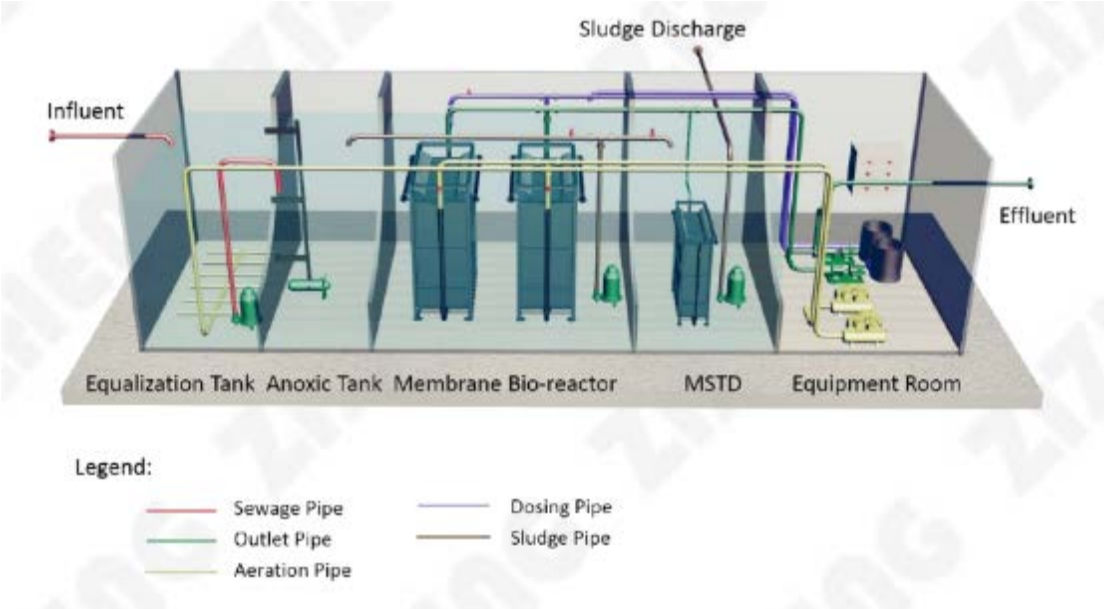


Figure 1 The schematic diagram of HI-MBR process

Systematic determination of the inert COD of industrial wastewaters in the context of COD fractionation

Alicja Yogendran, Maike Beier, Stephan Köster; Institute of Sanitary Engineering and Waste Management (ISAH), Leibniz University Hannover, Germany

Abstract

A still unsolved problem in industrial wastewater treatment is the poor degradability of soluble organic compounds resulting in low performance of the biological treatment. Using modified Zahn-Wellens tests, selected industrial wastewaters were analyzed and complemented with literature data. As a result, an overview of the most important industrial polluters is presented. This information is beneficial to the planners of biological treatment schemes especially in larger industrial sites or parks. Furthermore, it was shown that the chosen F/M ratio strongly influences the outcome of the degradation tests. Lastly, assessment methods of biodegradability regarding planning and operation phase were discussed, suggesting the soluble COD/DOC ratio as on-line parameter during operation.

Keywords: industrial wastewater, biodegradability, COD fractionation, inert COD

Introduction

The COD fractionation is used within the framework of worldwide recognized design approaches in order to provide the relevant input variables (e.g. Activated Sludge Model, German DWA-A 131). However, the COD fractionation is still a patchwork of individual approaches and not sufficiently standardized as a whole (Fig. 1). In addition, several methods to measure the readily, slowly and non-biodegradable fractions are very time-consuming and laborious. A further disadvantage of the biological tests is their dependence on numerous factors – such as the selected Food/Microorganism (F/M) ratio, varying origin of the sludge used and its required adaptation. Furthermore, toxicity in wastewater can have inhibitory effects. Considering these shortcomings, it is difficult to refer to the available literature data for a comparative discussion. Particularly important for industrial wastewater treatment is the in-depth knowledge of the fate and occurrence of inert organic substances. These are often labeled as “inert”, “refractory” or “non-biodegradable” and pass through the biological treatment unchanged. The inert COD fractions are certainly responsible for operational problems in industrial wastewater treatment

plants. Sudden drops in treatment performance resulting in elevated effluent concentrations can originate from a poor biodegradability.

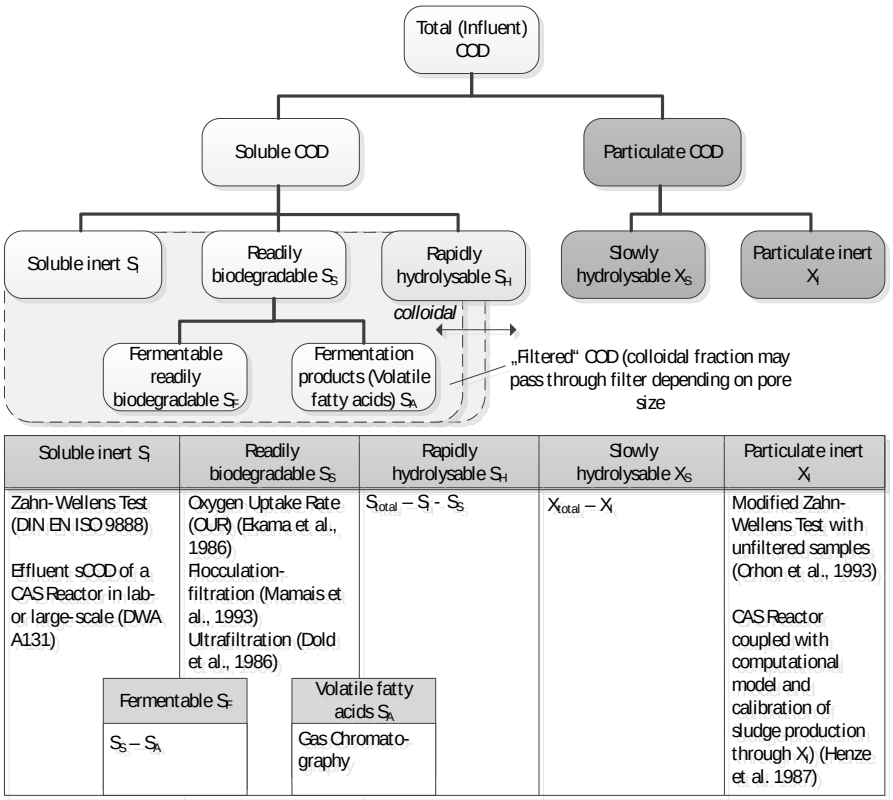


Figure 1: COD fractionation model according to Henze et al. (2000) and possible measurement techniques for determination of the fractions

Since the biodegradability during operation is currently not sufficiently monitored, it is very difficult to implement appropriate countermeasures. Especially, industrial wastewaters from chemical, paper/ pulp, textile and yeast industry show high inert (or at least poorly biodegradable) fractions. The Zahn-Wellens (ZW) test according to DIN EN ISO 9888 or OECD 302b is a recognized method to determine the inert soluble fraction, even if some experts are critical. Marcelino et al. (2015) and Ballasteros et al. (2010) doubt the transferability of the test results to large-scale operation due to different test conditions (i.e. operation mode: batch vs. continuous, HRT: 28 days vs. 1 day). However, Stucki (2000) concludes that, at least regarding the HRT, the gained results can be compared to large-scale continuous operation.

Material & Methods

Industrial wastewater samples from different German production sites (e.g. cellulose (derivates) production, adhesion promoter production) were taken. Furthermore, municipal wastewater from one WWTP at Hannover was also used. As inocula

served – whenever possible – sludge from the industrials sites as well as from the municipal plant. The initial F/M ratio was set to 0.5 gCOD/gTSS. Inherent biodegradability tests were carried out according to DIN EN ISO 9888 (Zahn-Wellens test) with coupled soluble COD (sCOD) and DOC measurements by HACH® cuvette tests. In some cases, DOC samples were measured with high-temperature combustion vario TOC cube analyzer (Elementar®). If necessary, tests were carried out longer than standard 28 days due to the slow degradation rate of the chosen substrates. A special feature of the test was the combined assessment of inert and readily biodegradable COD by incorporating an OUR measurement according to Ekama et al. (1985). Another aspect of the experiments was to assess the influence of parameters to be chosen in the test, such as F/M ratio and used sludge. A systematic batch series was conducted with synthetic substrates representing chemical wastewater (MC and Carboxymethylcellulose (CMC)) and tannery wastewater (tannic acid). Synthetic wastewaters were mixed with distilled water and chemicals from Sigma-Aldrich and Carl Roth (Methocel® A15 LV, CAS No. 9004-67-5; Tannic acid ≥86 %, p.a., ACS, CAS No. 1401-55-4; CMC LV, CAS No. 9004-32-4).

Results & Discussion

The results from the degradation tests can be combined to an extensive and systematic “screening” of the biodegradability of industrial wastewaters (Fig. 2).

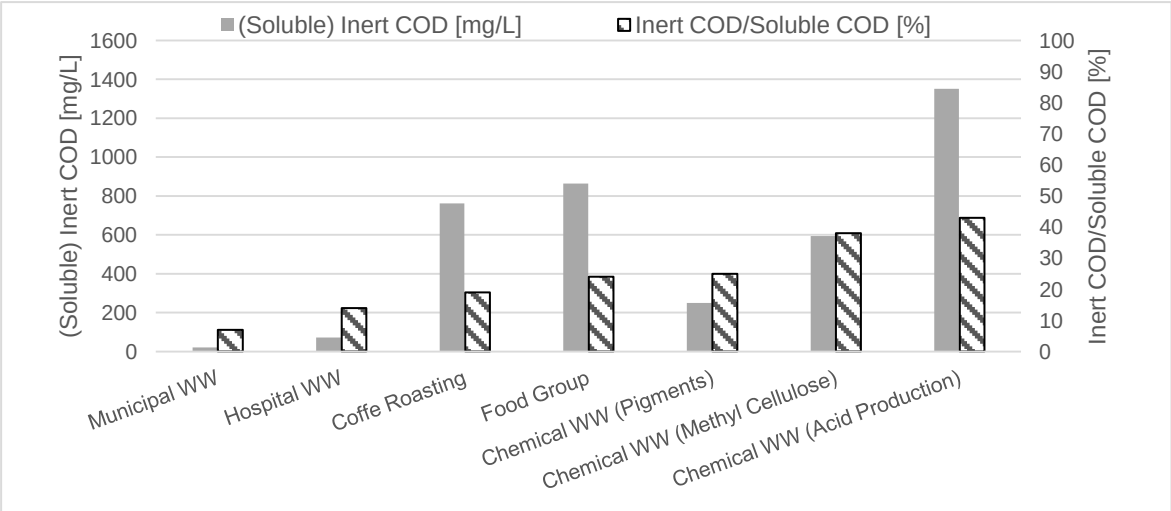


Figure 2: Results of industrial soluble inert COD fractions (excerpt)

The presented test results and the test method itself can be used by planners of biological treatment schemes especially in larger industrials sites and parks for a rough estimation of the (biological) treatment efficiency. It was also found that the

obtained sCOD/DOC ratios are linear functions of the degradation process and are specific for each wastewater/ substance (Fig. 3). This means, the sCOD/DOC ratio decreases with ongoing degradation.

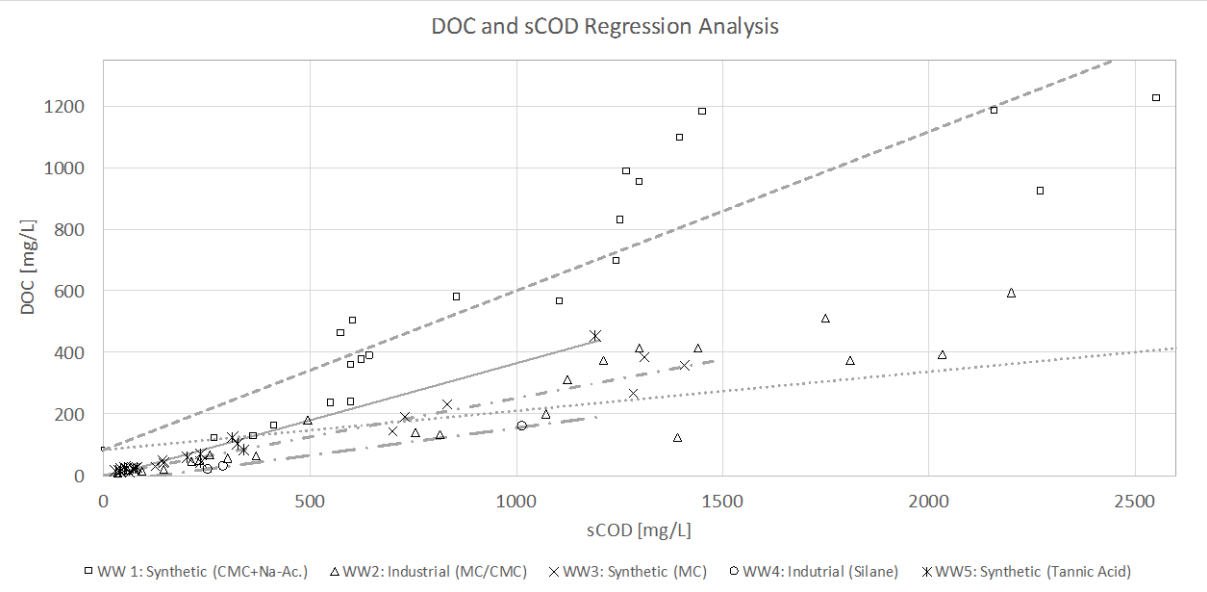


Figure 3: Regression analysis of the parameters sCOD and DOC obtained during ZW tests for different synthetic and real wastewaters

Consequently, the ratio can be used as parameter for on-line monitoring of the influent and the performance of the biological treatment step – provided that incoming wastewater streams are known. The ZW tests for the wastewater "screening" were conducted with same test settings (e.g. F/M ratio = 0.5 gCOD/gTSS) to ensure comparison of the results. According to the guidelines of DIN EN ISO 9888, parameters, such as F/M ratio and concentration of the substrate can be chosen within certain boundaries and therefore should not have an impact on the outcome of the test. Hence, a series of batch test with varying parameters was carried out. Results show a strong influence of the chosen F/M ratio and concentration for tannic acid (Fig. 4). It seems, that with higher concentration and F/M ratio, the degradation rate and relative elimination are higher. Regarding the degradation rate, this coincides with Monod kinetics. The reason for the overall greater elimination with higher F/M ratios is still unsolved. Since this influence of the F/M ratio could not be shown for MC, further tests are necessary. Finally, a comparison between biodegradability batch tests and large-scale operation performance was done. Therefore, data from the municipal plant available for the

year 2014 was used to analyze COD concentration in the effluent downstream the biological treatment (Activated Sludge Tank, SRT = 12,9d).

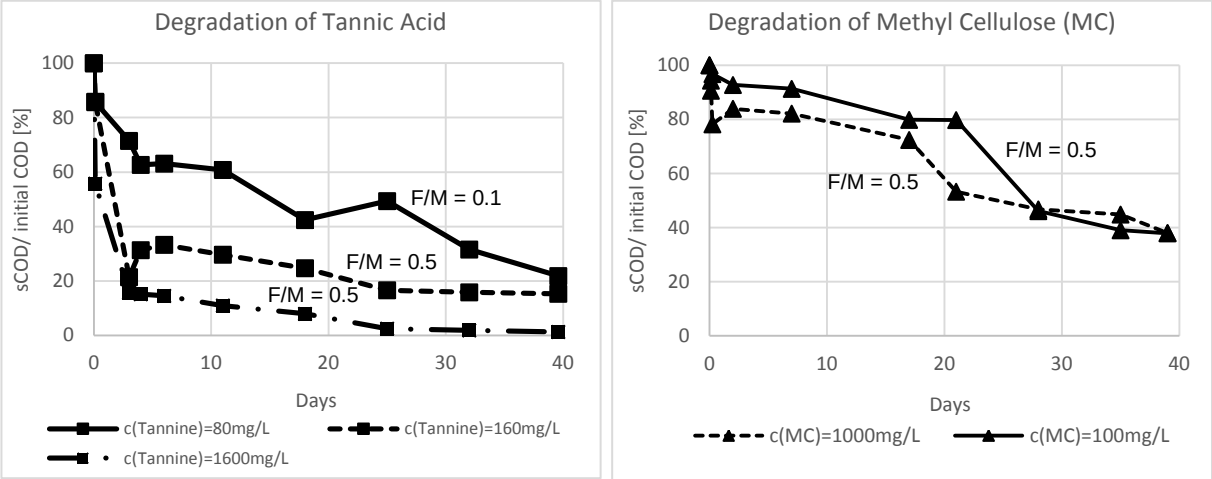


Figure 4: Degradation of (pure) tannic acid and methyl cellulose (MC) for different initial concentrations and F/M ratios

The average COD concentration in the reference year 2014 was 42.5 mg/L. This is nearly two times higher than the concentration obtained in the ZW test in 2017 (23 mg COD/L). The concentrations in the inflow were approximately the same in both years. The most common Activated Sludge Models according to Henze et al. (2000) and DWA A-131 assume that no inert soluble COD is formed during the degradation process. This would mean that the observed difference can only occur due to different elimination rates. As in the test ideal conditions prevail in terms of O_2 concentration, mixture, HRT, temperature and nutrients, all available substrate can be degraded. Thus, the test shows the maximum degradation potential. However, as summarized by Barker & Stuckey (1999), scientific evidence proofs the formation of inert soluble microbial products (SMP) during biomass growth and decay, leading to an effluent soluble concentration higher than the initial inert sCOD.

Conclusions

There is still an urgent need to adequately include the proportion of inert COD in the design of biological treatment stages, in particular with regard to complex industrial effluents containing a high proportion of inert organic compounds, and even more in the implementation of industrial water reuse. One reason for the low use of the inert COD is the laborious analyzation method and the ongoing discussions about

performance and reasonability of the ZW results. This work shows that the degradation test results can help to make profound (investment) decisions if separate or additional treatment steps are required to eliminate inert COD. However, the obtained values cannot be transferred without verifying tests (ZW tests and continuous pilot-scale tests) with the wastewaters on-site. During operation of WWTPs, it is recommended to use the sCOD/DOC ratio in the influent and effluent as additional on-line parameter for monitoring (changes) in biodegradability.

Acknowledgements

This research has been funded by the German Federal Ministry of Education and Research (BMBF) in the project “WaReIp – Water-Reuse in Industrial Parks”.

References

Ballasteros Martín, M.M., López, J., Oller, I., Malato, S, Sánchez Pérez, J.A. (2010). A comparative study of different tests for biodegradability enhancement determination during AOP treatment of recalcitrant toxic aqueous solutions. Ecotoxicology and environmental safety, 73.

Barker, D.J., Stuckey, D.C. (1999). A review of soluble microbial products (SM) in wastewater treatment systems. Water Research, Volume 33, Issue 14

Brito Portela Marcelino, R., Andrade, L., Vieira Martins Starling, M. C., Amorim, C., L. T. Barbosa, M., Lopes, R., Reis, B., Leao, M. (2016). Evaluation of aerobic and anaerobic biodegradability and toxicity assessment of real pharmaceutical wastewater from industrial production of antibiotics. Brazilian Journal of Chemical Engineering, 33, pp. 445-452.

DIN EN ISO 9888:1999-11. (1999). Water quality - Evaluation of ultimate aerobic biodegradability of organic compounds in aqueous medium - Static test (Zahn-Wellens method). German version EN ISO 9888:1999.

Ekama, G., Dold, P., V. R Marais, G. (1986). Procedures for Determining Influent COD Fractions and the Maximum Specific Growth Rate of Heterotrophs in Activated Sludge Systems. Water Science and Technology, 18.

Henze, M., Gujer, W., Mino, T., van Loosdrecht, M. (2000). Activated Sludge Models ASM1, ASM2, ASM2D, ASM3. IWA Publishing, London.

Stucki, G. (2000). Zur Aussagekraft des biologischen Abbautests nach Zahn-Wellens zum Schicksal von chemischen Abwässern in Industriekläranlagen: Erfahrungen aus der chemischen Industrie. GWF, Wasser, Abwasser, 141, 10.

A novel gas diffusion electrode reactor for the treatment of highly concentrated membrane fabrication wastewater.

Garcia-Rodriguez Orlando, Peh Shu Fang Ashley, Olvera-Vargas Hugo, Lefebvre Olivier.

Centre for Water Research, Department of Civil and Environmental Engineering, National University of Singapore

1 Engineering Dr. 2, Singapore 117576, Singapore.

Abstract:

In this study, a 100 cm^2 scaled-up carbon-PTFE GDE reactor with straight zigzag channels and a water chamber with serpentine channels was designed to improve fluid distribution, maximise H_2O_2 generation and subsequent hydroxyl radical ($^{\bullet}OH$) production by electro-Fenton (EF) and anodic oxidation (AO). The design of the reactor was optimized using flow simulations in a CAD software, in order to have uniform gas and liquid distributions, resulting in improved energy efficiency. Degradation of a highly toxic and non-biodegradable (BOD/COD = 0.08) wastewater generated during the process of membrane fabrication was conducted in recirculation mode at different concentrations. The system achieved 53% removal at an initial TOC concentration of 800 mg L^{-1} in 3 hours and still 30% removal at an initial TOC concentration of 80,000 mg L^{-1} in 8 hours. Although, the TOC removal percentage declined with the increasing initial TOC concentration, energy efficiency improved at higher initial concentrations and became as low as 2.58 kWh kg-TOC^{-1} for an initial TOC concentration of 80,000 mg L^{-1}. The combination of EF and AO proved to be a promising solution for the treatment of biorefractory and highly-concentrated wastewater.

Keywords: anodic oxidation; electro-Fenton; gas diffusion electrode; membrane wastewater; reactor design.

Introduction

Membrane technology based on polymeric membranes has proven to be an efficient and sustainable process widely used in the field of wastewater treatment and desalination. Despite its growing popularity and fast expansion, there are challenges in the wastewater management resulting from the actual membrane manufacturing that need to be addressed for it to become a greener technology. Membrane

wastewater (MWW) discharge and disposal is difficult and tedious because it contains highly toxic compounds such as N-N-dimethylformamide (DMF), N-N-dimethylacetamide (DMA), among others. Furthermore, wastewater discharge typically comprises up to 95% of total waste generated during membrane fabrication. In view of the above, electrochemical advanced oxidation processes (EAOPs) offer a feasible solution, relying on the *in-situ* generation of the hydroxyl radical ($^{\bullet}OH$), a strong and non-selective oxidant able to destroy hazardous and bio-refractory pollutants that cannot be removed by conventional biological methods. Among EAOPs, the combination of Electro-Fenton (EF) and anodic oxidation (AO) is promising, making use of (i) anode materials with high O_2 evolution overpotential to generate $^{\bullet}OH$ radicals in the electrode surface (equation 1) and (ii) carbonaceous cathodes for the electrochemical generation of H_2O_2 through oxygen reduction reaction (ORR) via the two-electron pathway (equation 2). The reaction between H_2O_2 and catalytic amounts of ferrous ions generates $^{\bullet}OH$ radicals in the bulk solution (equation 3). The regeneration of Fe^{2+} at the cathode (equation 4), allows a continuous process with virtually no sludge generation.

$$M + H_2O \rightarrow M(^{\bullet}OH) + H^+ + e^- \quad \text{(eq. 1)}$$

$$O_{2(g)} + 2H^+ + 2e^- \rightarrow H_2O_2 \quad \text{(eq. 2)}$$

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + {}^{\bullet}OH + HO^- \quad \text{(eq. 3)}$$

$$Fe^{3+} + e^- \rightarrow Fe^{2+} \quad \text{(eq. 4)}$$

Amidst cathode configurations for EF process, gas diffusion electrodes (GDEs), allowing the percolation of gases through the electrode material, have displayed the highest H_2O_2 generation efficiencies due to the enhanced availability of oxygen during the electrolysis. Although these electrodes have been widely studied and optimized, their area remain small (<10 cm^2). In this context, we propose the design and construction of a GDE with an area of 100 cm^2 to treat wastewater from polymeric membrane fabrication with high organics concentration.

Material and Methods

Wastewater characterization and conditioning.

Effluents derived from the fabrication of flat sheet membranes were provided by a local company and stored in a cold room at 4˚C. The Biological Oxygen Demand

(BOD_5) was measured by a Lovibond® BD 600 BOD meter (Germany). The chemical oxygen demand (COD) using Hach test vials and measured spectrophotometrically with a DR6000 HACH UV-vis spectrophotometer. Total organic carbon (TOC) was monitored in a combustion catalytic oxidation/NDIR TOC-V_{CSH} Shimadzu (Japan). GS-MS analyses were done using a Shimadzu GC-2010 instrument equipped with a GCMS-QP2010 MS with EI ionization. The temperature program was as follows: 35° C held for 5 min, increase to 240° C at 10° min^{-1} and hold for 5 min. For identification, injection was done in split mode. The column was a HP-FFAP 25 m length, 0.32 mm diameter and film thickness of 1.0 μm. Prior to degradation experiments, the wastewater was conditioned at room temperature (25 °C). Wastewater dilutions were made with high-purity water from a Millipore Milli-Q system (resistivity > 18 MΩ cm at 25 °C), pH was adjusted to 3 with concentrated H_2SO_4, high conductivity was achieved by adding K_2SO_4 to have a 0.050 M solution and the Fenton's reaction was promoted by the addition of Iron (II) sulfate heptahydrate (0.2 mM). All chemicals were of analytical grade and purchased from Sigma-Aldrich (Singapore).

Reactor Design and experimental set-up.

The electrochemical reactor consisted of two chambers, one for each fluid: air and wastewater. Stainless-steel mesh and carbon cloth (CC) with hydrophobic treatment (Fuel Cell Earth, USA) were used as current collector and cathode, respectively. The anode was a boron doped diamond (BDD) electrode (Condias GmbH, Germany). Both electrodes had a geometrical area of 100 cm^2. Design optimization was done through flow simulations in SolidWorks® 2017 3D computer-aided design (CAD) software before fabrication. The experimental set-up is displayed in figure 1, consisting of an electrochemical reactor operating in galvanostatic mode at a current density of 7 mA cm^{-2} (R&S® Power SupplyHM7042-5). A recirculation flow was sustained by continuous pumping of 400 mL of wastewater at a flow rate of 42 L h^{-1} using a Cole-Parmer® Master flex L/S® pump. Air flow rate was kept constant at 75 L h^{-1} using a common aquarium pump. Electrolysis was carried out for 3 hours, withdrawing aliquots every 30 minutes for further analysis.

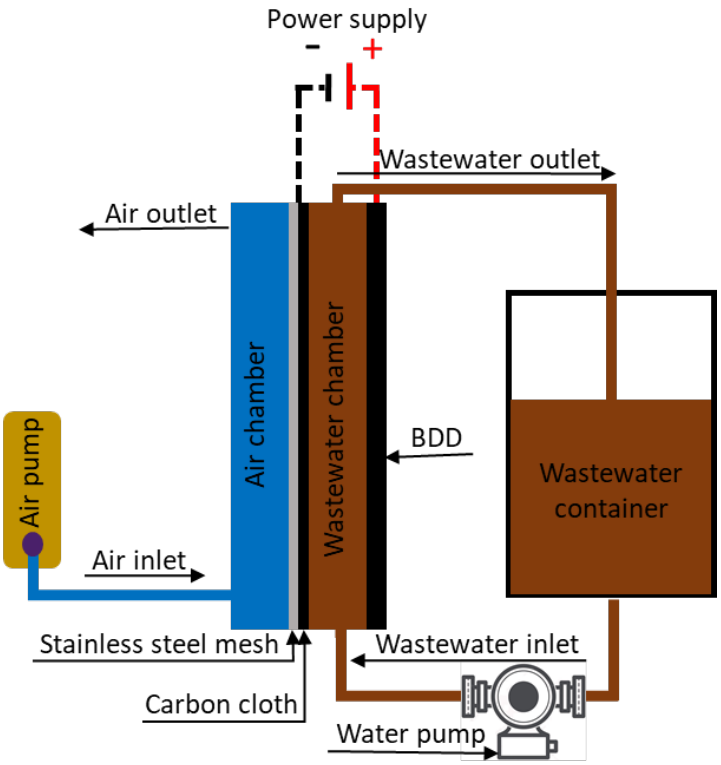


Figure 1. Electrochemical reactor set-up for membrane wastewater treatment.

Results and Discussion

Reactor Design

Optimization of the air and wastewater chamber designs was done by flow simulation in Solidworks® using straight channels, zigzag channels and no channels, with different dimensions, and positions of outlets and inlets. Even air distribution, results in a better use of the entire electrode area and higher oxygen availability for ORR to take place. To contrast the different air distributions according to the design, Figure 2 shows the air flow simulation for three different chamber designs.

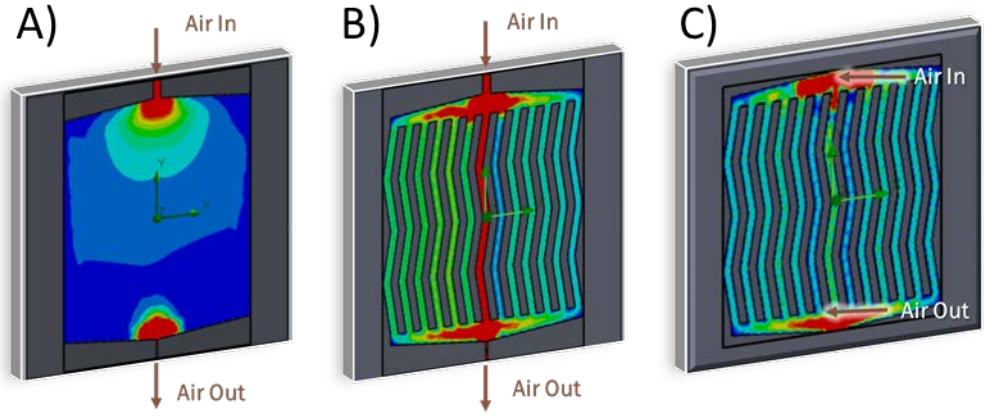


Figure 2. Optimization of the gas diffusion chamber design through flow simulation using SolidWorks®. A) no channel B) zigzag channels with inlet and outlet in the Y axis and C) zigzag channels with inlet and outlet in the Z axis.

The results were compared by analysing the air velocity distribution across the chamber area. It was observed that not having any channels (Fig. 2A) led to poor air distribution due to presence of dead zones, represented by low air velocity regions (in blue) right after air enters the chamber. Furthermore, Fig. 2B and 2C show the importance of the inlet and outlet positions: the zigzag configuration, where the air is inserted in the lateral direction (Z axis), allows better air distribution than the inlet and outlet allocated in the bottom and top of the chamber. In the same way, wastewater chamber was optimized, obtaining a design with serpentine channels (not shown).

Membrane wastewater characterization and treatment.

The characterization of the raw MWW (Table 1), displayed a highly concentrated effluent composed mainly by N-N-dimethylacetamide, N-N-dimethylbutamide, Isopropanol and 1-methyl-2-pyrrolidinone.

Table 1. General wastewater characteristics of the raw wastewater discharge from membrane fabrication process.

TOC (mg L^{-1})	BOD (mg L^{-1})	COD (mg L^{-1})	BOD_5/COD	pH
80, 000	23, 333	285, 278	0.08	8.1

The effectiveness in removing organic pollutants was affected by the initial TOC wastewater concentration. As expected, the highest TOC removal (53 ± 2.7 %) was obtained with the lowest TOC initial concentration of 800 mg L^{-1} (100x dilution) and

the removal percentage decreased with the increase in the initial TOC concentration achieving 30 ± 1.8 % without any dilution. Although, this could be attributed to a lower reaction rate of similar amounts of produced $^{\bullet}OH$ radicals to oxidize greater amounts of organic compounds, the non-proportional decrease in the TOC removal percentage indicates that probably the formation of more persistent products towards hydroxyl radicals oxidation was also a limiting factor. Moreover, despite the lower removal percentage at higher concentrations, the process was more efficient in terms of TOC removal amount (Figure 3), the energy consumption went from 100.56 kWh kg-TOC^{-1} with the lowest initial TOC concentration to 2.58 kWh kg-TOC^{-1} when the non-diluted wastewater was treated. Furthermore, despite the non-complete mineralization, the biodegradability (BOD_5/COD) of all the effluents was improved ranging from 0.25 to 0.6.

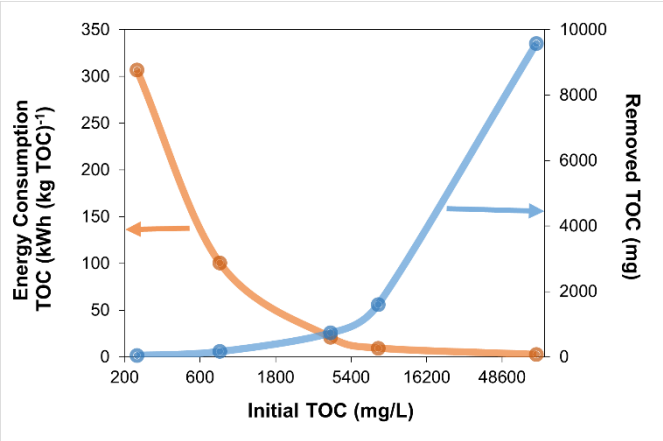


Figure 3. Energy consumption and removed TOC at different initial TOC concentrations.

Conclusions

We conclude that the new scaled-up carbon-PTFE GDE design improved liquid and air distribution to support the treatment of real complex and concentrated wastewater at low cost, with efficiency equivalent to that of 10-fold smaller-scale GDE reactors. The study also displayed how energy consumption and removal rates are dependent on the initial concentration of the wastewater. This research outlined the relevance of EF and AO processes in highly concentrated and biorefractory wastewater treatment, for which there is no gold standard at the moment.

A study of synergistic oxidation between ozone and chlorine on benzalkonium chloride removal for municipal wastewater reclamation RO (mWRRO) concentrate treatment

Nan Huang[1], Wen-Long Wang[1], Zi-bin Xu[1], Qian-Yuan Wu[2], Hong-Ying Hu[1]

[1] School of Environment, Tsinghua University, Beijing, China

[2] Graduate School at Shenzhen, Tsinghua University, Shenzhen, China;

Background

Reverse osmosis (RO) technology plays an increasingly important role in municipal wastewater reclamation. However, non-oxidizing antimicrobials (e.g., benzalkonium chloride and methylisothiazolone) are used excessively to prevent membrane biofouling in mWRRO treatment plants in China. These toxic chemicals are added to the mWRRO system in large quantities and then concentrate in RO concentrates at elevated levels, inducing great difficulty in their safe disposal. It is urgently needed to develop efficient methods for non-oxidizing antimicrobials removal from mWRRO concentrate.

Ozonation processes are widely used in drinking water and wastewater treatment plants. The combinations of H_2O_2, energy input (e.g., UV and ultrasound), and catalysts have been proposed as effective strategies to improve the efficiencies of ozonation by enhancing the production of hydroxyl radicals. However, chlorine, which was widely used for disinfection or pollutant removal,was never considered as potential strategy to improve the removal efficiency of pollutant during ozonation process, because chlorine alone was not capable of activating ozone to produce hydroxyl radicals. In this study, it was found for the first time that the presence of chlorine increased the production of reactive species significantly during ozonation of benzalkonium chloride (DDBAC).

Results and Discussion

The combination of ozone and chlorine showed synergistic effects on the degradation of DDBAC. DDBAC hardly underwent degradation by the chlorination process. The degradation percentage of DDBAC by ozonation after 10 min increased from 22% to 92%, when chlorine dosage increased from 0 to 1.58 mM.

The radical quenching experiments showed that the reactive species that could quenched by tBuOH (e.g. hydroxyl radicals) made the most important contributions to DDBAC degradation by ozone/chlorine oxidation. The pseudo first order rate

constant of DDBAC dropped from 0.55 min^{-1} to 0.012 min^{-1} with the injection of 20 mM tBuOH. It should be noted that the degradation of DDBAC by ozone/chlorine oxidation with 20 mM tBuOH (k = 0.012 min^{-1}) was higher than that by sole ozonation under the same conditions (k = 0.005 min^{-1}). It implies that other reactive species, which could not be effectively quenched by tBuOH, formed during DDBAC degradation by ozone/chlorine oxidation. The contributions of ozone, reactive species that could or could not be quenched by tBuOH were 8%, 78% and 13%, respectively.

pCBA was used as the hydroxyl radical probe to further verify the generation of hydroxyl radical and determine the steady-state hydroxyl radical concentrations. In the mixed system of DDBAC and pCBA, the degradation of both DDBAC and pCBA was greater by ozone/chlorine oxidation than by sole ozonation. The degradation percentage of DDBAC and pCBA after 15 min increased from 31.0% and 13.1% to 53.8% and 28.3% with the presence of chlorine, respectively. Based on the steady-state concentration assumption, the steady-state concentration of ·OH was calculated as $7.5*10^{-14}$ M with the presence of 0.14 mM chlorine, which was 2.3 times higher than that during the sole ozonation process.

Ten main intermediates were identified during the degradation of DDBAC by ozone/chlorine oxidation using HPLC-MS/MS and a possible degradation pathway was proposed. Three degradation mechanisms were observed during ozone/chlorine oxidation of DDBAC: the hydrogen abstraction of the alkyl chain via hydroxyl radical; the cleavage of the benzyl-nitrogen bond of DDBAC; and the addition of hydroxyl on the aromatic ring or the alkyl chain. Hydroxyl radicals plays important roles in DDBAC degradation by ozone/chlorine oxidation, which was consistent with the radical quenching and radical probe experiments. Overall, this study suggest that the combination of ozone and chlorine oxidation might be efficient treatment method for mWRRO concentrate containing benzalkonium chloride.

Layered quorum quenching media for more sustainable biofouling control in membrane bioreactors

Kwang-Ho Choo, Kyungpook National University, Daegu, Korea; Huarong Yu, Harbin Institute of Technology, Harbin, China; Xiaolei Zhang, Kyungpook National University, Daegu, Korea; Kibaek Lee, Kyungpook National University, Daegu, Korea

Abstract

Membrane bioreactors (MBRs) have been successfully developed and demonstrated as one of the key technologies for advanced wastewater reclamation and reuse. A large number of MBRs have been built and under construction in treatment capacity from a few tons per day to a few hundred thousand tons per day. Although the confidence to the technology regarding the quality of effluent is clear, the fouling of membranes is still an issue and agony to be resolved for its further extension. Among various approaches for membrane fouling mitigation, recent technological innovations tackle biofouling induced by microbial communications. It has been understood that microbial communities interact each other using signal molecules and eventually they have group behaviors (e.g., biofilm formation on the membrane surface), known as quorum sensing. Interfering with such microbial signaling (i.e., quorum quenching; QQ) enabled mitigation of membrane fouling in membrane bioreactors using enzymes, bacteria, or fungi. Use of living organisms for biofouling control is more attractive than enzymes because they are economically feasible for real applications. For the application of QQ bacteria to MBRs, they should be enriched and encapsulated in a bio-carrier to prevent their washout from MBRs during continuous wastewater treatment. Several different types of media (e.g., vessel, bead, cylinder, hollow cylinder, sheet) have been prepared and tested for effective QQ strategies in MBRs. Until now, all the media developed have been fabricated in a single layered structure using a mixture of hydrogel polymers and QQ bacteria. With this structural design, the QQ bacteria present inside the media were found to have a limitation in access to nutrients and signal molecules because the majority of them were consumed at the outermost layer of the media. Therefore, this study focused on the development of a new structure of QQ medium with dual layers, where biostimulating agents (e.g., gamma caprolactone) are present in the inner part and QQ bacteria are present in the outer part of it. With this structure, it was

expected that the QQ bacteria in the inner part may survive long and keep its activity along with biostimulation, whereas the QQ bacteria in the outer part can utilize the nutrients and organics present in the mixed liquor. So the whole media should be more active and effective for anti-biofouling efficacy in MBRs. A core-shell structured QQ bead was thus prepared and tested with respect to its QQ activity in a batch reactor and its efficiency in MBRs. It was estimated that the core prepared with 15% polysulfone may have a controlled biostimulant release duration for >760 d. The dual layer QQ bead was most effective in degrading a signal molecule (e.g., octanoyl-L-homoserine lactone) even when it was tested after a week exposure to the supernatant of activated sludge. Indeed, its fouling delay was most significant compared to any other types of bead structures tested while reducing the concentration of signal molecules and biopolymers in MBRs. Confocal laser scanning microscope images revealed that the QQ bacteria present in the inner part of the dual layer bead well survived after long-term use in MBRs, whereas that of the bead with no biostimulant in the core became dead (Fig. 1). The dual layer bead containing biostimulants in the core inhibited biofilm formation most and maintained its efficacy after use, although the bead with no biostimulant lost it. In summary, layered QQ media design, which contains biostimulant in its core and QQ bacteria in its shell, provides enhanced and sustainable QQ capability for biofouling control in MBRs.

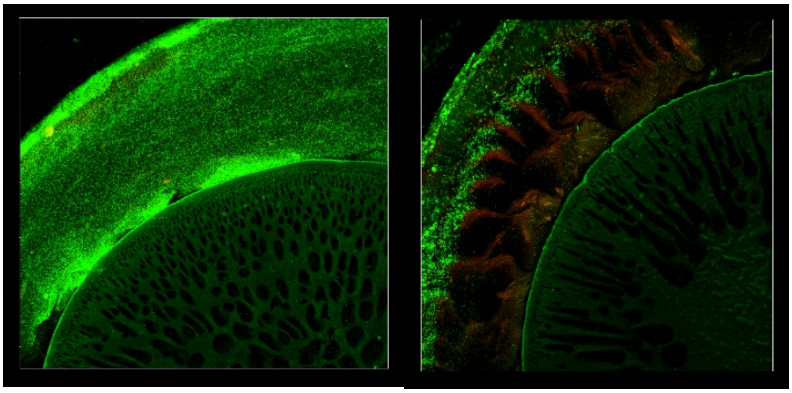


Fig. 1. Confocal laser microscope images of the dual layer beads (left) with and (right) without biostimulants in their core. Red colors on the inner part of the medium on the right hand side indicate that the QQ bacteria on that part were dead.

Adaptation of Marine ANAMMOX Bacterium to Low Salinity and Organics to Simulate Complete Nitrogen Removal Saline Wastewaters

Muhammad Ali, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia; Dario Rangel Shaw, KAUST, Thuwal, Saudi Arabia; and Pascal E. Saikaly, KAUST, Thuwal, Saudi Arabia.

Abstract

As the demand for water increases across the globe due to the increase in population, the per capita availability of fresh water in many regions is likely to decrease. Over 50% of the world's population is residing within 60 km of the coast [1], and seawater can be directly used for toilet flushing to reduce dependence on freshwater resources for non-potable uses. The use of seawater for toilet flushing is already in practice in several coastal cities and nations, mainly including Hong Kong, Avalon, Marshall Islands, and Kiribati [2]. The above practices indicate that the ratio of seawater to freshwater in the saline wastewater (used seawater and freshwater) ranges from approximately 1:2 to 1:1, that is, 33−50% of the saline wastewater is originated from toilet flushing. The presence of high salt content in wastewater could induce salt stress to the microbial species causing inhibition of many enzymes that eventually leads to decrease of cellular activity. Thus, the effect of salinity on microbial activity should be investigated in wastewater treatment bioprocess. Using anaerobic ammonium oxidation (anammox) process [3] to treat saline wastewater can be cost-effective compared to conventional nitrification-denitrification process [4]. However, it is essential to know the proper anammox inoculum to use for the successful application of anammox process for saline wastewater treatment. Previous studies using anammox process to treat saline wastewater used freshwater anammox strains. In contrast, studies using marine anammox strains, which could be advantageous for the treatment of saline wastewaters, are lacking. Furthermore, the impact of organics on anammox process for saline wastewater treatment was not evaluated before. Therefore, this study was designed to evaluate the nitrogen removal performance of anammox reactor operated at different saline conditions with and without organic addition. Initially, two anammox bacterial strains, *Candidatus Brocadia sinica* (predominantly found in freshwater ecosystems) and *Ca. Scalindua sp.* (found in hypersaline ecosystems), were evaluated

in batch incubation experiments at different saline conditions **(Fig. 1)**. These batch experiments revealed that *Ca. Scalindua. sp.* performed better (specific anammox activity: 40–60 nmol-N mg-pro^{-1} min^{-1}) under various salinity concentrations. Subsequently, a membrane bioreactor (MBR) containing an enriched culture of *Ca. Scalindua. sp.* was gradually synchronized (nitrogen removal rate, NRR: ~0.3 kg-N m^{-3} d^{-1}) to synthetic organic wastewater containing only 35% of real seawater **(Fig. 2)**. The contribution of N removal by anammox, denitrification and respiratory ammonification pathways was determined in batch incubation experiments fed with various ^{15}N-labelled substrates **(Fig. 3)**. Interestingly, results revealed that anammox was the primary contributor for nitrogen removal even under organic-rich environment. Additionally, results indicated that anammox bacteria were mainly mediating dissimilatory nitrate reduction to ammonium (DNRA) process. Finally, we confirmed our findings with combined metagenomic and metatranscriptomic approach to establish genome-resolve transcription activities under different conditions **(Fig. 4)**. Our omics results underpinned anammox bacterium as a major contributor to nitrogen removal in the reactor under different operating conditions. Our study demonstrated, for the first time, the use of marine anammox bacterium (*Ca. Scalindua. sp.*) for the treatment of N-rich saline wastewater containing organics. This research could facilitate the treatment of saline wastewater produced via use of seawater toilet flushing.

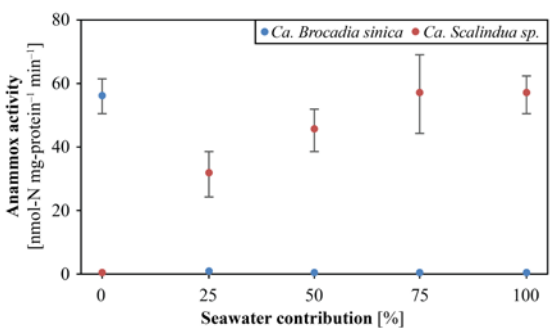
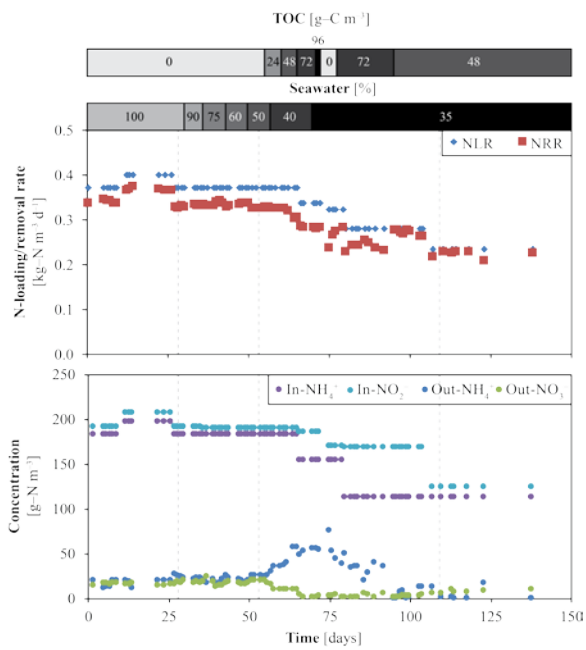


Fig. 1: Salinity tolerance of *Ca. Brocadia sinica* and *Ca. Scalindua sp.* Red sea water was mixed with deionized water at different ratios. Anammox activity was determined as $^{29}N_2$ gas production rate. Error bars represent the standard deviations from triplicate vials.



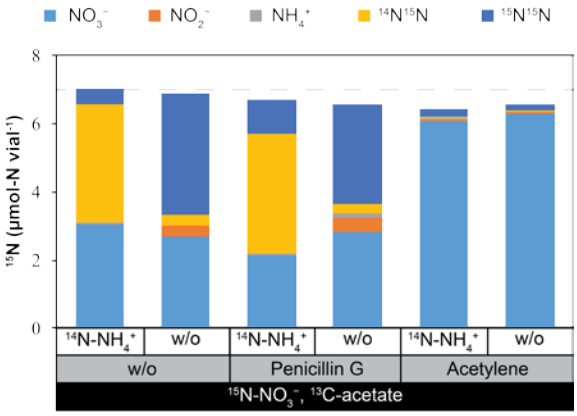


Fig. 3: Nitrate reduction to ammonium via nitrite by respiratory ammonification: The 3.5-mL cell suspension was dispensed into 10-mL glass vials and incubated for 8 h after adding 2 mM $^{15}NO_3^-$and 4 mM $^{13}CH_3COOH$. The $^{14}NH_4^+$(2 mM) was also supplemented as a pooled substrate, which would be preferentially utilized and promote accumulation of $^{15}NH_4^+$. As a control, the same incubation was repeated in the absence of pooled substrates, which is designated as 'w/o'. The heights of the bars represent the mean values of triplicate batch tests. These incubations were repeated with specific inhibitors Penicillin G and Acetylene to selectively inhibit heterotrophic denitrification and anammox processes, respectively. The results indicate that anammox is mainly responsible for driving DNRA process as low activity was observed with addition of acetylene which selectively inhibit anammox process.

Fig. 2: Performance of reactor under different phases. Phase 1 (0-28 days): reactor was operated with fresh Red Sea water containing NH_4^+ and NO_2^-; Phase 2 (28-53 days): freshwater was mixed with Red Sea water at different ratios; Phase 3 (54-150 days): the reactor was operated with organic addition. Dashed lines represent sampling events for metagenome (DNA) and metatranscriptomic (RNA).

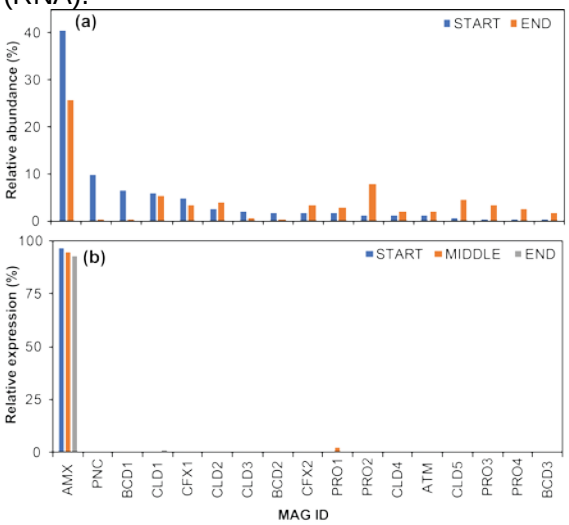


Fig. 4: Abundance and gene expression of the organisms represented by the metagenome-assembled genomes (MAGs) recovered from the anammox bioreactor. Abundance **(a)** and gene expression **(b)** were based on transcription per million (TPM) values of metagenomic reads and transcripts that mapped to each MAG, respectively. Seventeen MAGs were recovered from metagenomic sequencing effort and these MAGs were presented here by their identifiers showing their affiliated phylum, *e.g.* Anammox (AMX), Armatimonadetes (ATM), Bacteroidetes (BCD), Calditrichaeota (CLD), Chloroflexi (CFX), Planctomycetes (PNC) and Proteobacteria (PRO).

Reference.

1. Polunin NVC. AQUATIC ECOSYSTEMS: TRENDS AND GLOBAL PROSPECTS. 2008. Cambridge University Press, Cambridge.
2. Tang S., Yue DP., Ku DC. Engineering and Costs of Dual Water Supply Systems. 2007. IWA Publishing.
3. Kartal B, Kuenen JG, van Loosdrecht MCM. Sewage treatment with anammox. *Science* 2010; **328**: 702–703.
4. Ali M, Okabe S. Anammox-based technologies for nitrogen removal: Advances in process start-up and remaining issues. *Chemosphere* 2015; **141**: 144–153.

Microalgae cultivation in a ceramic membrane photobioreactor for nutrients removal from secondary effluent of WWTP and microalgal biomass production

Qiulong Zhang, Guangdong Provincial Engineering Research Center for Urban Water Recycling and Environmental Safety, Graduate School at Shenzhen Tsinghua University, Shenzhen 518055, China;

Canwei Zhou, Guangdong Provincial Engineering Research Center for Urban Water Recycling and Environmental Safety，Graduate School at Shenzhen Tsinghua University, Shenzhen 518055, China;

Yi Tao, Guangdong Provincial Engineering Research Center for Urban Water Recycling and Environmental Safety, Graduate School at Shenzhen Tsinghua University, Shenzhen 518055, China;*

**Corresponding author: E-mail: tao.yi@sz.tsinghua.edu.cn, Tel: +86 75526033067.,*

Abstract:

High concentration of the nitrogen and phosphorous in the reclaimed water caused harmful algal blooms, which has been one of the biggest obstacles for the reuse of reclaimed water for landscape water resource. Microalgae cultivation in membrane photobioreactors (MPBRs) is capable of providing an alternative method for further nutrients removal from municipal secondary effluent. To enhance microalgae growth rate as well as nutrients removal efficiency is a critical concern for the development of MPBR. In this study, the removal efficiency of nitrogen and phosphorus, microalgae biomass productivity and membrane fouling were investigated within a ceramic membrane photobioreactor (CMPBR). In the CMPBR, a consortium of wild algae (Chlorella vulgaris based) was continuously cultivated with secondary effluent of the NS WWTP at Shenzhen, China. The CMPBR was operated at HRT of 12 h and SRT of 24 h, with aeration of 1% CO_2. The results showed that the nutrients were effectively removed with average removal efficiency of 87% and 95% for TN and TP respectively. The average TN and TP concentrations in the effluent from the CMPBR were 1.12 $mg \cdot L^{-1}$ and 0.06 $mg \cdot L^{-1}$ respectively. The concentration of microalgae biomass in the MPBR remained at around 317 $mg \cdot L^{-1} \cdot d^{-1}$, a high level for more than 3 times of previous reports, since day 3. During the initial 14 days, the transmembrane pressure (TMP) had gradually increased from 3.0 kPa to 14.8 kPa. After brushing with Milli-Q water, the TMP decreased to 3.2 kPa. It suggested that

the membrane fouling of the CMPBR was reversible. The results indicated that nutrients removal and microalgae biomass production were achieved simultaneously in a CMPBR. It has the potential to be developed as a sustainable and cost-effective technology for treatment of secondary effluent from WWTP.

Keywords: Microalgae cultivation; water reuse; membrane photobioreactor; nutrient removal

Introduction

The utilization of reclaimed water is very important to alleviate the contradiction between water supply and demand, However, high concentration of the nitrogen and phosphorous in the reclaimed water caused harmful algal blooms, which has been one of the biggest obstacles for the reuse of reclaimed water for landscape water resource. Microalgae cultivation in membrane photobioreactors (MPBRs) is capable of providing an alternative method for further nutrients removal from municipal secondary effluent (Hultberg et al., 2016). The utilization of membrane module could sperate the HRT and SRT of microalgae, which could enhance the biomass productivity and nutrient removal efficiency. Membrane fouling is an important problem we should concern in reactor operation.

To enhance microalgae growth rate as well as nutrients removal efficiency is a critical concern for the development of MPBR. In this study, the removal efficiency of nitrogen and phosphorus, microalgae biomass production rate and membrane fouling were investigated within a ceramic membrane photobioreactor (CMPBR).

Material and Methods

All experiments were carried out in a Plexiglas photo-bioreactor as shown in Figure 1. The photo-bioreactor was 0.034 m in thickness, 0.35 m in width, 0.50 m in height and 4 L in volume. A ceramic membrane with an effective area of 375 cm^2 was placed right above the aeration bar, making the bubble of aeration could scour the membrane surface evenly. With a pair of peristaltic pump and digital pressure gage installed on effluent pipeline, the trans-membrane pressure (TMP) of ceramic membrane and the effluent flow was real-time recorded. Two peristaltic pumps ensured the influent and effluent were steady to ensure the CMPBR was operated at HRT of 12 h and SRT of 24 h, while the SRT of CMPBR were controlled through adjust the continuous overflowing rate. The CMPBR was fed with the NS WWTP (Shenzhen, China) secondary settling tank effluent. The concentration of NH_4^+-N,

NO_2^--N, NO_3^--N, TN and TP in the effluent was 0.45 mg·L^{-1}, 0.14 mg·L^{-1}, 7.79 mg·L^{-1}, 8.65 mg·L^{-1} and 0.10 mg·L^{-1}, respectively. 1.2 mg·L^{-1} of PO_4^{3-}-P was added to the reactor to balance the N, P proportion.

The photo-bioreactor was inoculated with a consortium of wild algae (Chlorella vulgaris based), and the temperature of the reactor was kept at 25 ℃. Eight fluorescent lamps, providing light intensity of 11000 Lux, were applied to illuminate the reactor. 1.2 L·min^{-1} (0.3 v/v) of 1% CO_2 was injected into the reactor through a sparging tube. The pH of the reactor during the operation was between 7-9.

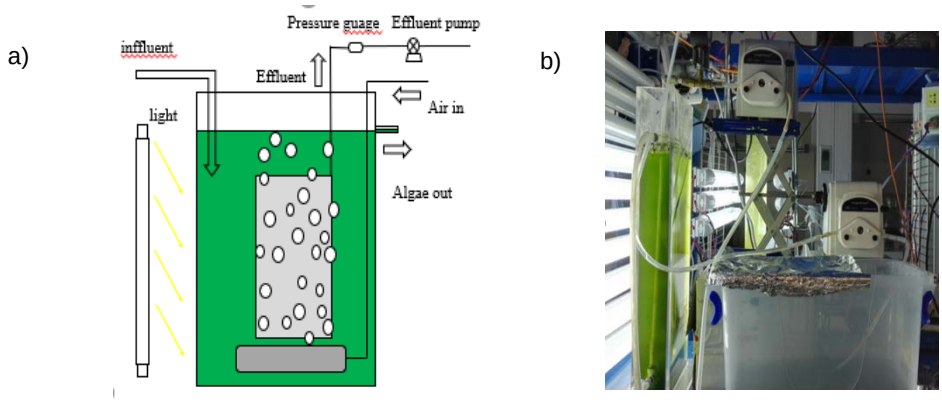


Figure 1 Schematic diagram of the CMPBR (a) structure diagram (b) experimental setup

Results and Discussion

Microalgae biomass production

The CMPBR showed a good performance in continuous microalgae biomass production. The biomass production of the CMPBR was shown in Figure 4. The biomass concentration rapidly increased during the initial 2 days and became steady afterwards. The dominant species of microalgae changed from chlorella into a new species. The microalgae biomass concentration of the CMPBR maintained at a stable level with an average of 317 mg·L^{-1}. As the CMPBR was operated at HRT of 12 h and SRT of 24 h in a continuous mode, the microalgae biomass productivity could be considered as 317 mg·L^{-1}·d^{-1}, which is much more than pervious researches that biomass productivity was below 100 mg·L^{-1}·d^{-1} (Gao et al.,2018; Xu et al.,2016; Honda et al.,2017), this difference can partly contribute to the difference on algae species, another aspect was the high light density.

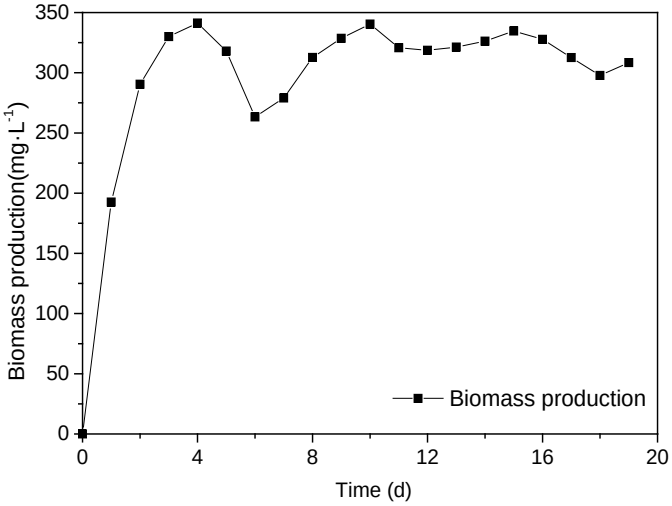


Figure 2 Biomass production in day 0-20

Nutrient removal in the CMPBR

Meanwhile, the removal of nitrogen and phosphorus from wastewater in CMPBR was investigated. As shown in Figure. 2, During the initial 2 days, the concentration of NO_3^--N, TN and TP dropped significantly. The average concentration of NO_3^--N, TN and TP in day 3-20 was 0.62 mg·L^{-1}, 1.12 mg·L^{-1} and 0.06 mg·L^{-1}, respectively. The content of NH_4^+-N and NO_2^--N was below 0.2 mg·L^{-1} since day3. The TN was mainly composed of NO_3^--N. The removal efficiency of NO_3^--N, TN and TP became steady after day3 (Figure. 3). The average concentration of NO_3^--N, TN and TP in day 3-20 was 0.62 mg·L^{-1}, 1.12 mg·L^{-1} and 0.06 mg·L^{-1}, respectively. The average removal rate of NO_3^--N, TN and TP was 92%, 87% and 95%, while the highest was 99%, 94% and 99%, respectively. The nutrient removal processes in the photobioreactor mainly include microalgae assimilation and chemical processes (Gao et al.,2018), based on the microalgae productivity and the common nitrogen and phosphorus content of microalgae, microalgae uptake could be considered the main way to remove nutrients from the secondary effluent.

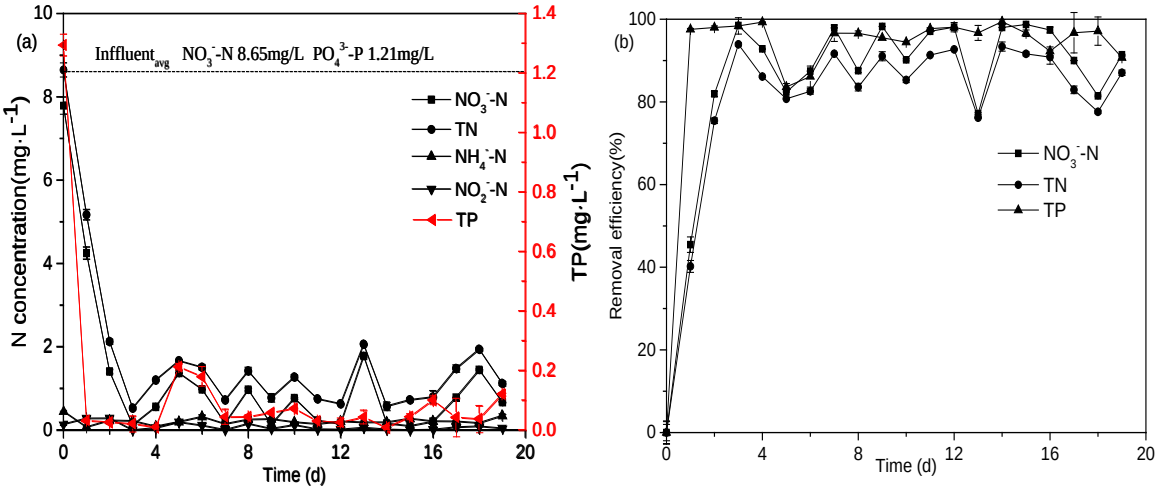


Figure 3 (a) N,P concentration of the reactor in day 0-20 (b) Removal efficiency of N,P in day 0-9

TMP changes in the CMPBR operation

During the operation period, the flux of the membrane module submerged in the reactor was maintained stably at 10 L·m^{-2}·h^{-1}. Figure. 5 showed the TMP varies with time over the CMPBR operation. During the initial 14 days, the TMP gradually increased to 14.8 kPa from 3.0 kPa with an increase rate for 0.84 kPa·d^{-1}. After brushing with Milli-Q water, the TMP decreased to 3.2 kPa. It suggested that the membrane fouling of the CMPBR can be effectively controlled through aeration. The membrane fouling characteristics need further research.

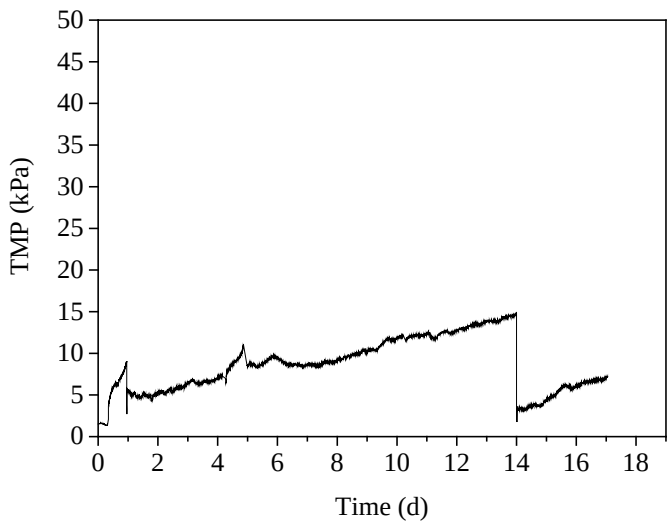


Figure 4 TMP build up in day 0-18

Conclusions

This study indicated that nutrients removal and microalgae biomass production were achieved simultaneously in a CMPBR. It has the potential to be developed as a sustainable and cost-effective technology for treatment of secondary effluent from WWTP. A new species of algae has been found more suitable for treating secondary effluents. High growth rate was maintained under low extracellular nitrogen and phosphorus concentration. The microalgae biomass productivity of the CMPBR could reach at a stable level with an average of 317 $mg \cdot L^{-1} \cdot d^{-1}$. The average TN and TP concentrations in the effluent from the CMPBR were 1.12 $mg \cdot L^{-1}$ and 0.06 $mg \cdot L^{-1}$ respectively and the membrane fouling of the CMPBR was reversible.

References

Malin Hultberg, Lars-Erik Olsson, Goran Birgersson, Susanne Gustafsson, Bertil Sievertsson. (2016). Microalgal growth in municipal wastewater treated in an anaerobic moving bed biofilm reactor, Bioresource Technology. 207: 19-23.

F. Gao, Y. Peng, C. Li, C. Li, W. Cui, Z. Yang and G. Zeng. (2018). Coupled nutrient removal from secondary effluent and algal biomass production in membrane photobioreactor (MPBR): Effect of HRT and long-term operation. Chemical Engineering Journal, 335: 169-175.

M. Xu, P. Li, T. Tang, Z. Hu. (2015). Roles of SRT and HRT of an algal membrane bioreactor system with a tanks-in-series configuration for secondary wastewater effluent polishing, Ecol. Eng. 85: 257–264.

R Honda, J Boonnorat, C Chiemchaisri. (2012). Carbon dioxide capture and nutrients removal utilizing treated sewage by concentrated microalgae cultivation in a membrane photobioreactor. Bioresource Technology, 125: 59-64.

awaregio - Modular wastewater treatment processes for the reuse of wastewater, nutrients and energy

Dr.-Ing. Henry Riße, Research Institute for Water and Waste Management at RWTH Aachen (FiW) e. V., Aachen, Germany; M.Sc. Thomas Breuer, (FiW); Julius Kieseler, LINEG; Dr. Sabrina. Schiwy, RWTH Aachen; Dr. Sabine Lautenschläger, Universität Leipzig; John Reiter, EvU GmbH

Key words: innovative treatment technologies and applications, water, food and energy nexus in reuse, energy and nutrient recovery, concentrate treatment

Introduction

Extended dry periods also in Europe can lead to water use conflicts. Wherever human settlements exist, an alternative water source is ubiquitous: wastewater. The challenge lies in developing flexible, adaptable solutions for the synchronization of treatment systems and reuse options. The pilot project awaregio is funded by the BMBF. In the joint effort of German research institutes, small and medium sized enterprises (SMEs) and a regional water entity, a modular pilot plant with downstream aquaponic system has been developed and implemented and is now driven for patricianly almost one year.

The pilot project awaregio aims at the development of innovative, modular wastewater treatment methods fostering **the reuse of water, nutrients contained in the wastewater and** the exploitation of **energetic potentials**. To monitor the efficiency of the treatment steps, applicable methods for water quality analytics are being tested. The parameters in focus are pesticides, biocides, pharmaceutical compounds and industrial chemicals frequently found in wastewater.

The pilot plant

The multi-stage treatment scheme consists of a primary treatment followed by a number of secondary treatment approaches evaluated in parallel (figure 1). The aim is to reuse until 90% of the treated wastewater. Additionally, the reuse of nutrients and (partial) desalination are focal points of the research effort.

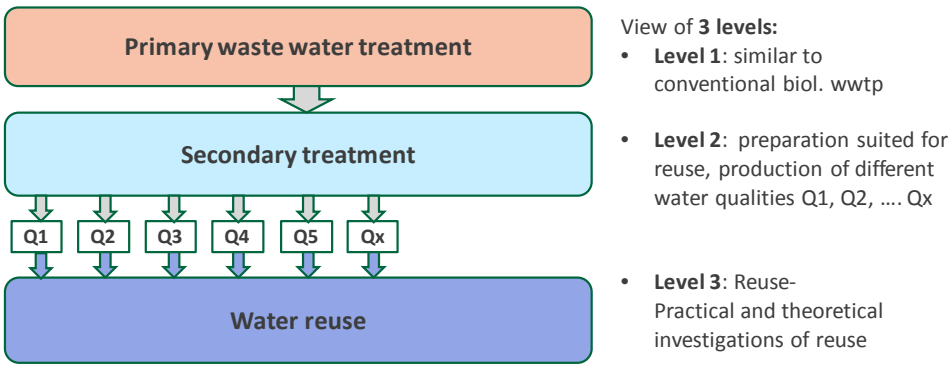


Figure 1: Levels of treatment und reuse

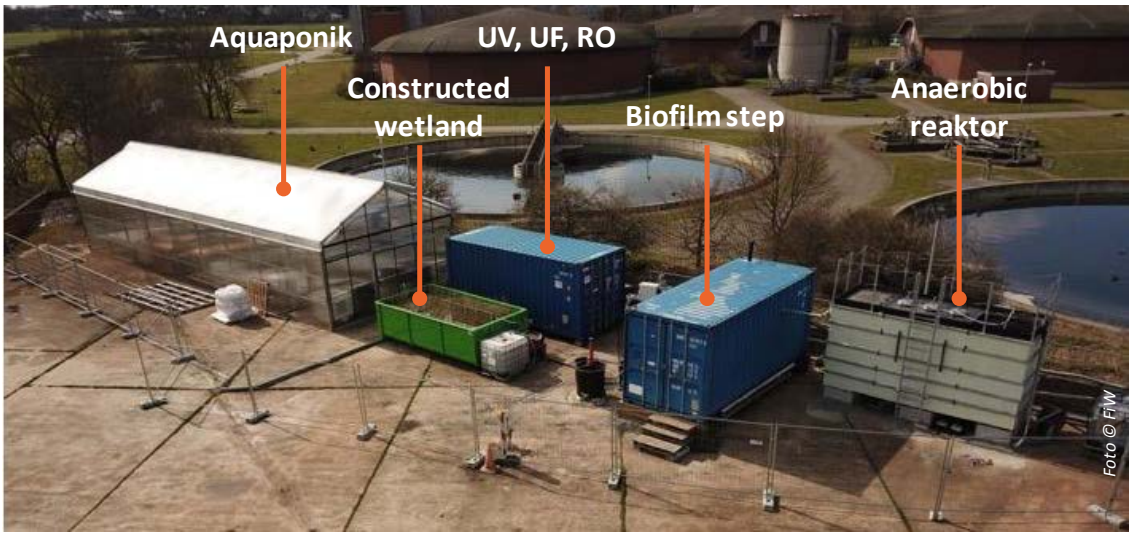


Figure 2: View to the pilot plant

Primary treatment

The combination of an improved anaerobic Reactor (ABR + AF) with an anoxic Moving Bed Biofilm Reactor (MBBR) and an improved Trickling Filter (TF) ensures an energy and cost-efficient as well as low-maintenance primary treatment of the pilot plant.

Secondary Treatment

A range of secondary treatment modules producing different effluent qualities (Q) are being evaluated. An operationally simple approach (Q1) is a Constructed Wetland (CW). As an alternative approach (Q2), the operability of an UV disinfection unit is assessed. More sophisticated secondary treatment options producing higher effluent qualities (Q3 and Q4, respectively) are an Ultrafiltration (UF) and a downstream Low Pressure Reverse Osmosis (RO) module. Additionally, nitrogen- and phosphorous-recovery for agricultural fertilizer application is obtained in a physicochemical post-treatment of the RO-concentrate.

Greenhouse with Aquaponics

In aquaponic systems, nutrient-rich water from pisciculture (fish: African catfish) is used to fertilize plants in a hydroponics system (plant production: vegetables, herbs and flowers). In the greenhouse of the awaregio pilot plant site four separate aquaponic systems are operated utilizing the process water Q1, Q2, Q3 and well water as a reference.

First Results

The improved Anaerobic Reactor allows COD reduction from >1000 mg/l in the inlet to approx. 250 to 300 mg/l mg/l in the effluent of this reactor at ambient temperatures (15…20°C). A small amount of biogas is measured at waste water temperatures >15°C additionally especially in the AF-part (approx. 9 l/PE*d). That means that

approx. 75% of the organic load of concentrated municipal waste water can be reduced with a very low input of energy, machinery and maintenance.

The aerobic post treatment includes an improved trickling filter for nitrification and a MBBR system for partly denitrification. The improved trickling filter is characterized by a plastic biomass carrier material with >500 m²/m³ surface with a filling height of only 1 m and the possibility of backwashing. The MBBR-denitrification allows the operation of an anoxic step in combination with a trickling filter without intermediate clarifier. Both together - the improved trickling filter and the MBBR-denitrification enable a total nitrogen removal between 50 and 60% with low energy input and in relatively small reactors. In spring 2019 were obtained an increased number of red worms which reduces the biomass content in the system.

For the secondary treatment in behalf of the energy and maintenance saving the constructed wetland is the favorable system. The effluent COD-concentration approximate 20 mg/l (see figure 3) and the nitrogen oscillates around the level of 20 mg/l by a TN-inlet of 25 to 45 mg/l. The constructed wetland shows a good elimination of pathogens (approx. 2 … 3 log steps). All this good results are possible with a very low energy consumption only for the small feeding pump.

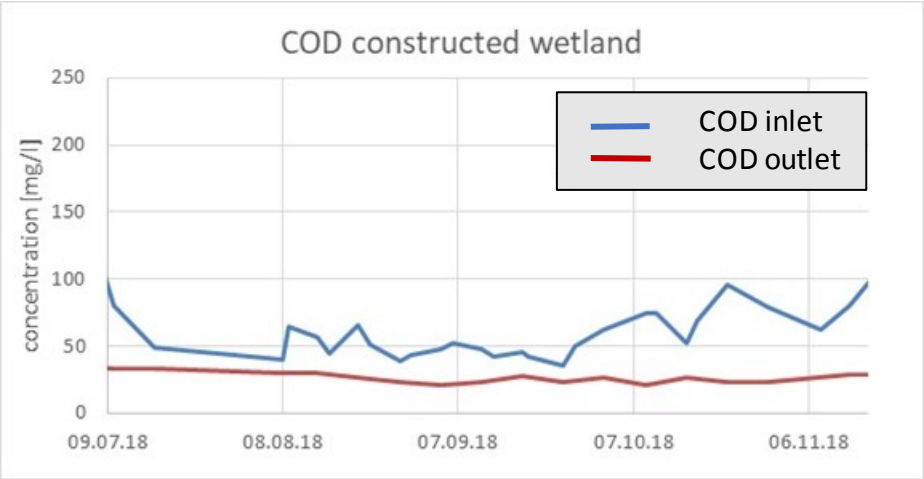


Figure 3: COD effluent of the constructed wetland for post treatment at the pilot plant

The low pressure RO works at 8 bar pressure compare to 60 bar for sea water desalination. The RO- membrane performance was nearly constant during the pilot trials but a more or less prophylactic chemical cleaning was performed latest after three months. In the backwash solution were obtained increased concentrations of alkali ions and Phosphates – a signal for lightly tendency of precipitation.

All produced reuse water qualities (constructed wetland, UF, UV) are principal suited as source in the aquaponics system. The tested crops grew very fast. The African catfish grew also well in this water, their weight increased from approx. 120 g to approx. ¾ kg until 3 months.

In addition, the removal of trace substances is evaluated as well as ecological and hygiene investigations are taking place. Some trace substances like Bisphenol A.

Carbamazepine and Nonylphenol can be reduced in the biological treatment steps between 30 to 90%. The UF was able to reduce this substances and Metoprolol furthermore. A 100% Elimination of this substances was only possible by RO-filtration. Some investigations about toxicity showed that the produced reuse qualities had a very low toxicity potential. A small level of endocrine effect was obtained at the catfishes which has to be investigated furthermore.

A suited treatment of the concentrate (brine) to recover phosphorus respectively the elimination of organics by advanced oxidation are in progress. First results showed that the combination of UV + H_2O_2 allows a further significant reduction of the COD in the concentrate of RO also a reduction of trace substances. The precipitation of Phosphorous in the concentrate was possible. The products investigated until April 2019 contained different Ca-phosphate compounds.

Emerging micropollutants removal by combined persulfate oxidation – membrane distillation process for wastewater reuse

Muhammad B. Asif, William E. Price, Faisal I. Hai

Strategic Water Infrastructure Laboratory, University of Wollongong, Wollongong, Australia

Introduction

Global trends such as population growth, urbanization and climate change highlight the need for new water sources. Following appropriate treatment, wastewater can be used as an alternative water source for diverse end-user applications [1]. The removal of micropollutants is possibly one of the most challenging aspects of wastewater reuse. Biological wastewater treatment processes such as conventional activated sludge process and membrane bioreactors (MBR) were not specifically designed for effective micropollutant removal [2, 3]. As a result, it is necessary to complement a biological treatment process with an additional treatment process to produce water suitable for reuse.

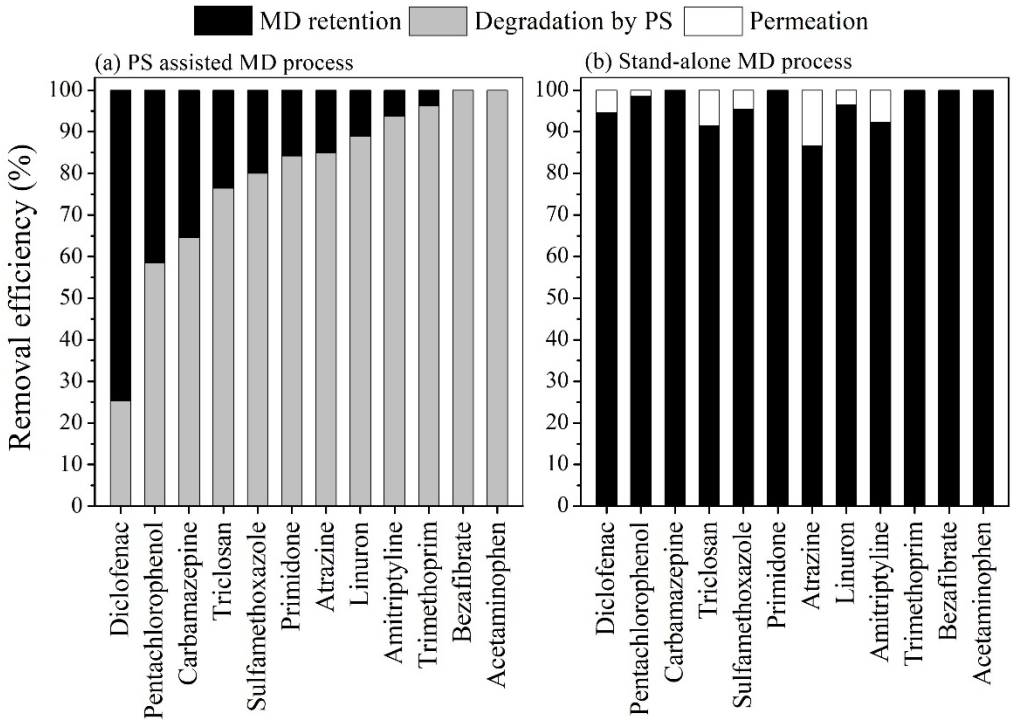
Membrane distillation (MD) is a thermally driven separation process emerging as a wastewater reuse technology. The MD process can theoretically achieve complete retention of non-volatile organics [2, 4]. Thus, it can potentially be used for the effective removal of micropollutants from secondary wastewater [5]. In this study, persulfate (PS) oxidation process was integrated with the MD process for the first time for effective degradation of 12 recalcitrant micropollutants from secondary wastewater.

Materials and methods

For this study, a set of 12 micropollutants (seven pharmaceuticals and 5 pesticides) were selected based on their ubiquitous occurrence in municipal wastewater [6]. Reagent grade potassium persulfate ($K_2S_2O_8$) was purchased from Sigma Aldrich (Australia), and was studied at a concentration of 1 mM. A laboratory scale PS-MD system was used [7]. The MD system with and without PS addition was operated separately for 10 days in continuous-flow mode under following conditions: feed temperature = 40 ± 1.5 °C; distillate temperature = 20 ± 0.5 °C; micropollutant concentration = 5 µg/L; feed and distillate flow rate = 1 L/min.

Results

Depending on the hydrophobicity and volatility of the investigated micropollutants [8], the stand-alone MD system achieved 85-100% retention of the micropollutants from secondary wastewater (Figure 1). Contaminants retained by a membrane needs to be safely disposed. To simplify this concentrate disposal, we combined persulfate (PS) oxidation with the MD process. PS addition led to 25 to 100% degradation of the retained micropollutants (Figure 1). At the operating temperature (40 ^{o}C) of the MD system, PS possibly absorbs heat energy and generates two sulfate radicals through scission of the peroxide bond. The sulfate radicals can directly degrade organic matters including micropollutants [9]. Along with micropollutants, PS degraded up to 70% of the bulk organics present in MD feed. As evident from a more stable flux in case of the integrated PS-MD system, addition of PS also helped mitigate membrane fouling. Notably, the chemical degradation products can be more toxic than the parent compounds. However, toxicity analysis revealed that the treated effluent (i.e., MD permeate) was non-toxic. This is the first study that shows the performance of persulfate oxidation process in a continuous MD system for micropollutant retention



and degradation for safe reclaimed wastewater reuse.

Figure 1. Fate of micropollutants in PS assisted MD and stand-alone MD process.

Keywords: advanced oxidation process, membrane distillation, membrane fouling control, micropollutants; persulfate

References

[1] Current Opinion in Environmental Science & Health. 2018; [2] Bioresource technology. 2014;167:539-46; [3] Environmental Science and Pollution Research. 2018:1-16; [4] Desalination. 2012;287:2-18; [5] Science of The Total Environment. 2018;628-629:358-65; [6] Science of the Total Environment. 2014;473:619-41; [7] Bioresource technology. 2018;247:528-36; [8] Journal of Membrane Science. 2014;453:636-42; [9] Chemosphere. 2016;151:178-88.

Electrospun nanofiber membranes incorporating PDMS-aerogel superhydrophobic coating with enhanced flux and improved selectively for membrane distillation

Bhaskar Jyoti Deka, *School of Energy and Environment City University of Hong Kong, Hong Kong SAR, China*; *Eui-Jong Lee, Department of Environmental Engineering, Daegu University, 201 Daegudae-ro, Jillyang, Gyeongsan-si, Gyeongbuk, Republic of Korea; Jiaxin Guo, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China; Alicia K.J. An, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China*

Introduction

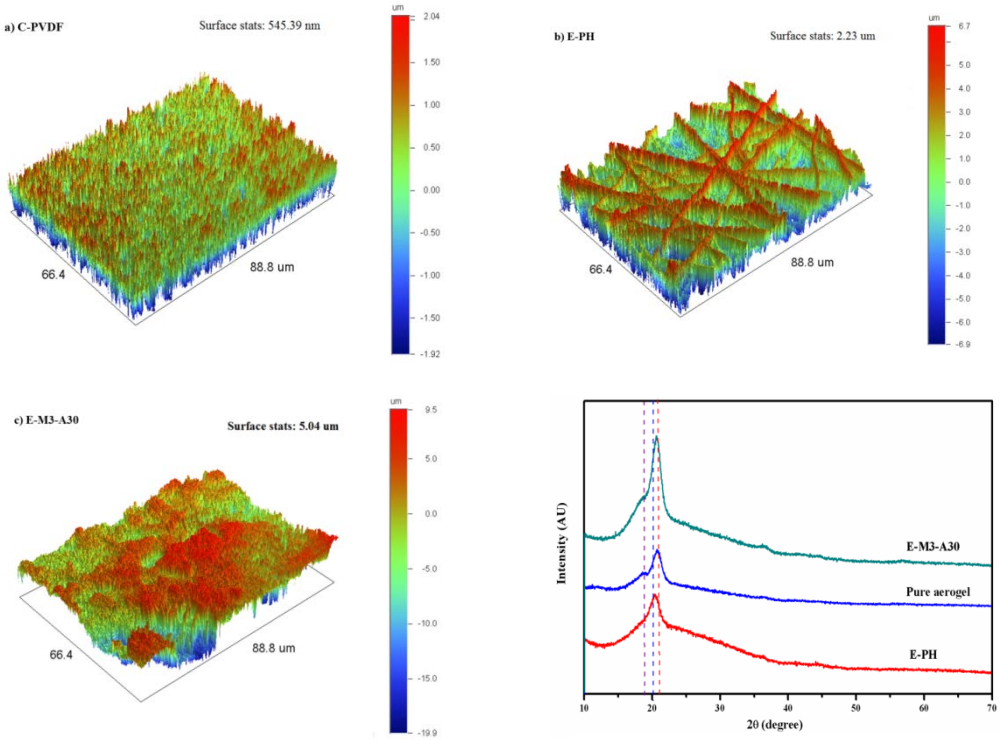
Electrospun nanofiber membranes (ENMs) have continued to gain recognition and are of great interest due to their high void volume fraction and hydrophobicity, in particular for its application for Membrane distillation (MD).[1] However, still MD technology has limitations in transforming from labscale to service plant application mainly due to low permeate flux and contamination over time at permeate side due to membrane wetting, predominantly during treatment of feed consisting of low surface tension compounds such as surfactant. Herein, we report a high flux and anti-wettability property of hybrid dual layer electrospun nanofibrous membranes (ENMs) by PDMS-aerogel spray-coating on the PVDF-HFP (E-PH) membrane. The fabricated ENM with 30% aerogel (E-M3-A30) exhibited superhydrophobicity with a water contact angle (CA) of 170˚ and high anti-wetting treating in harsh saline water (3.5% of NaCl) consisting 0.5 mM sodium dodecyl sulfate (SDS), and synthetic algal organic matter (AOM) comprised of sodium alginate (SA), humic acid (HA), and bovine serum albumin (BSA) over MD operation. Meanwhile, the same E-M3-A30 membrane presented significant performance in 48 hours DCMD operation mainly due to its superior advantages in terms of liquid entry pressure (LEP) of 129.5 ± 3.4 kPa, average pore size (µm) of 0.47 ± 0.05, porosity of 85.8 ± 0.28 %, vibrant short water droplet bouncing performance (11.6 ms), and higher surface roughness (Ra) value of 5.05 um.

Materials and Methods

The dope solution for electrospinning was prepared with polyvinylidene fluoride-co-hexafluoropropylene (PVDF-HFP, Mw = 455,000 g mol^{-1}, Sigma-Aldrich) which referred as PH and its solvents, N,N-Dimetylformamide (DMF, certified ACS grade, >99.9%, Sigma-Aldrich) and acetone (certified ACS grade, >99.7%, Sigma-Aldrich). To prepare the polymeric dope solution for the electrospraying processes, polyvinylidene fluoride (PVDF, Mw = 530,000 g mol^{-1}, Sigma-Aldrich) mixed with solvents N-dimethylformamide (DMF, anhydrous, >99.8%, Sigma-Aldrich) and tetrahydrofuran (THF, anhydrous, > 99.9%, Sigma-Aldrich), and in presence of silica aerogel (Enova Aerogel IC3100, particle size and density 2-40 µm, 120-150 kg m^{-3}). PDMS (Sylgard 184) that is composed of a silicon elastomer base (Pt catalyst and prepolymer dimethylsiloxane with vinyl groups mixture) and curing set (prepolymer dimethylsiloxane with vinyl groups and Si-H groups) (10:1 wt/wt), another polymer for electrospraying, was purchased from Dow Corning Corporation. Sodium dodecyl sulfate (SDS, ACS reagent, ≥ 99.0%,) was used to control the surface tension of feedwater. A commercial PVDF (hereafter, C-PVDF) membrane (0.45 µm, HVHP) from Millipore Company was used as a reference membrane in the assessment of the MD performance.

Results and Discussion

The superhydrophobic characteristics of electrospun membranes in this study can be attributed to their surface roughness (Ra) values as recorded highest for E-M3-A30 (5.05 um) membrane as compared to C-PVDF (0.55 um) and E-PH (2.23 um) membranes as computed by optical profiler images are shown in Fig. The XRD patterns for pure aerogel, E-PH and E-M3-A30 membranes are presented in Fig. The peculiar peak for pure aerogel at 18.6° was not observed in case of E-PH membrane, however, after the electrospray with aerogel, the same peak was observed at same angle for E-M3-A30 electrospray membrane. It illustrates clearly the attachment of both layers leading to increase in surface roughness and highest achieved CA.



Conclusion

In this study, superhydrophobic dual layer electrospun membranes were fabricated through the combination of electrospinning E-PH membrane and electrospraying PDMS/PVDF/aerogel solutions. The optimized PDMS/PVDF/aerogel (E-M3-A30) and operational condition lead to fabrication of a superhydrophobic membrane with water CA of 170˚. The labmade E-M3-A30 membrane was recorded as having an LEP of 129.5 ± 3.4 kPa, and average pore size of 0.47 ± 0.05, and porosity of 85.8 ± 0.28 %, which were found to be significant improvements to these characteristics. Further the same electrospun membrane showed best performance in treatment with synthetic saline water for 48 hours, demonstrating long-term viability and greater applicability for desalination operations.

References

(1) Lee, M. W.; An, S.; Latthe, S. S.; Lee, C.; Hong, S.; Yoon, S. S. Electrospun Polystyrene Nanofiber Membrane with Superhydrophobicity and Superoleophilicity for Selective Separation of Water and Low Viscous Oil. ACS Appl. Mater. Interfaces 2013, 5 (21), 10597–10604.

A real seawater membrane distillation system development by reproducible superhydrophobic TiO2 electrospun membrane with anti-fouling and anti-wetting function

Jiaxin Guo, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China; Bhaskar Jyoti Deka, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China; Kyung-Jo Kim, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China, Alicia K.J. An, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China

Introduction

Here we show an easy way to control the membrane fouling during seawater desalination via application of reproducible superhydrophobic TiO2 electrospun membrane coupled with coagulation/oxidation/dissolved air floatation (DAF) (COD) system. The characteristics of fabricated membrane, effect of pretreatment, membrane performance and fouling mitigation were investigated. TiO2 nanoparticles were well coated on the electrospun poly(vinylidene fluoride-co-hexafluoropropene) (PVDF-HFP) (E-PH) membrane using electrospraying. The fabricated membrane (E-TiO2) showed improved seawater desalination performance and strong reproducibility after 30 mins of simple water flushing of fouled E-TiO2 membrane (contract angle: from 131.4°±2.2° to 151.3°±1.2°). Compared with commercial PVDF membrane, this E-TiO2 membrane had increased anti-fouling and anti-wetting properties that could efficiently be recovered by simple physical water flushing. Additionally, the combination of NaOCl with Fe(III) was able to enhance the removal of DOC and mitigation of membrane fouling due to the formation of robust oxidizing agent (ferrate)[1]. This reproducible superhydrophobic E-TiO2 membrane coupled with COD system has proven its potential to be applied in removal of

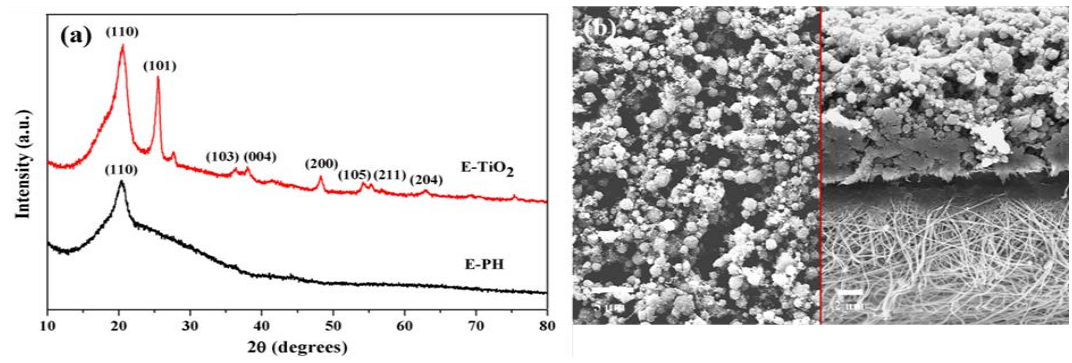
algal organic matter (AOM) and membrane fouling mitigation and has shown its performance as a novel technology for seawater desalination.

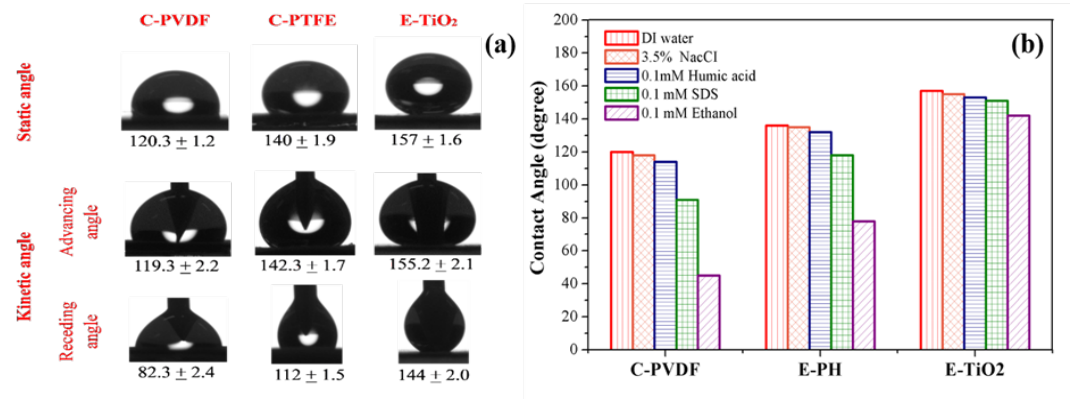
Materials and Methods

The base supporting layer of the nanofiber electrospun (hereafter, E-PH) membranes were first obtained through the charged (16 kV) accumulation of nanofibers on a collector (15 cm from the nozzle) at a flow rate of 0.7 mL/h. The E-PH membrane without the coating was fabricated by separating the fabricated membrane from the collector and drying it in an oven at 60 °C for more than 1 day. Then, the bottom E-PH membrane was coated with F-TiO2 nanoparticles by electrospraying at a high voltage of 18 kV employed on a 0.8-mm diameter nozzle with a dope solution injection rate of 1 mL/h and the coating layer collected 15-cm apart on a rotating collector.

Results and Discussion

The TiO_2 particle was mixed with PVDF-co-HFP at the ratio of 2:1 and then distributed uniformly on the support layer (E-PH membrane). The SEM image of the TiO_2 membrane surface clearly shows TiO_2 nanoparticle on the coating layer with even covering, while the cross-sectional SEM image exhibits clearly the TiO_2 membrane's dual layer structure. The water contact angle was much improved in the E-TiO_2 membrane in comparison to C-PVDF and E-PH membrane. The water contact angle of the E-TiO_2 membrane is 157 °, indicating superhydrophobicity.





Conclusion

In this work, reproducible superhydrophobic TiO2 electrospun membrane (E-TiO2) was fabricated by electrospinning and electrospraying technique. E-TiO2 membrane could successfully mitigate the membrane fouling and improve desalination productivity in MD system. In comparison to the C-PVDF and E-PH membrane performance without pretreatment, water flux of E-TiO2 membrane was maintained between 75% and 80%, which significantly enhanced desalination productivity and mitigated membrane fouling. E-TiO2 membrane with COD pretreatment was also able to achieve a great desalination performance and mitigate the membrane fouling by AOM (salt rejection 100% and DOC removal 100%). After water flushing of fouled membranes, contact angle of E-TiO2 was recovered from 100° to 147° and was recovered to 151° with COD pretreatment. These results mean that irreversible fouling on the TiO2 membrane did not occurr during the seawater desalination in MD and this hybrid system considerably mitigated membrane fouling. TiO2

hybrid material also protected membrane from rapid initial fouling.Additionally, this study of seawater desalination with reproducible hydrophobic E-TiO2 membrane on long-term operation is proven to confirm the sustainability of the process.

References

[1] B.J. Deka, S. Jeong, S.A. Alizadeh Tabatabai, A.K. An, Mitigation of algal organic matter released from Chaetoceros affinis and Hymenomonas by in situ generated ferrate, Chemosphere. 206 (2018) 718–726. doi:10.1016/j.chemosphere.2018.05.052.

A strategical planning and assessment framework to design municipal wastewater treatment plants from a resource recovery perspective

Philipp Kehrein, TU Delft, Delft, Netherlands;
Jo Dewulf, Ghent University, Ghent, Belgium;
Patricia Osseweijer, TU Delft, Delft, Netherlands;
Mark van Loosdrecht, TU Delft, Delft, Netherlands;
Marianna Garfi, UPC Barcelona, Barcelona, Spain;
John Posada Duque, TU Delft, Delft, Netherlands

Abstract:

The objective of this planning and assessment framework is to design a WWTP from a resource recovery perspective. It combines methodologies from wastewater treatment plant design, resource recovery, industrial engineering, project management, and market analysis and uses criteria to assess the treatment performance, sustainability impact, and resource recovery potential of innovative WWTP. It solves the multi-criteria design problem in a holistic approach that structures both the process related and non-process related design space. Following the management principle “to begin with the end in mind” this framework covers a wide range of factors to design a WWTP that meets highest treatment standards, allows the recovery of marketable resources, and is designed in accordance to its environment.

Keywords: WWTP process design; resource recovery; techno-economic assessment; sustainability impact assessment; strategical planning

Introduction

Domestic wastewater cannot any longer be considered as “waste”, because it is a resource full of clean water, energy, and valuable materials including nutrients (Wan et al. 2016). Academia has widely recognized that a sustainable wastewater treatment plant (WWTP) focusses instead of contaminant removal on resource recovery and feeds into the circular economy (several refs). This can mean a complete reimaging of the treatment process, or in some plants just slight

modifications in the process design (Puyol et al. 2017). From a resource recovery perspective wastewater treatment is a fascinating concept that promises to partially tackle the multiple challenges of resource depletion, environmental pollution, and green energy (Li et al. 2013).

Due to increasing available treatment technologies, conventional WWTP design already becomes more complex and the multi-criteria retrofitting problem of designing an optimal treatment process has been tackled by mathematical programming (Bozkurt et al. 2016) or computational environmental decision support systems (Castillo et al. 2017). The overall objective of existing WWTP process design methodologies is to find the process design among numerous alternatives that optimally treats a given influent (Hamouda et al. 2009). These methodologies mostly consider technical and economic decision criteria in the design and decision making process. (Hamouda et al. 2009; Bozkurt et al. 2017).

Despite these outstanding WWTP design methodologies, little attention has yet been given to how to plan and assess a WWTP from a resource recovery perspective instead of merely focusing on treatment related criteria (Wang et al. 2015). Although considerable interest in the planning, design, and implementation of resource recovery technologies into WWTPs exists, resource recovery is not yet a major objective in WWTP design methodologies. If next generation WWTPs want to feed into a future circular economy, resource recovery technology integration needs to be reflected from the earliest stage in the process design phase and considered as equally important as treatment performance and economic feasibility. Since resource recovery technology integration into WWTPs may alter the treatment performance as well as the economic feasibility of WWTPs, a holistic design approach is required to make the implementation of resource-oriented WWTPs realistic.

As for wastewater treatment technologies, a key characteristic of the emerging wastewater resource recovery field is a broad range of technical options (Batstone et al. 2015) which increases the complexity of conceptual WWTP design even further if it is fully considered in the process design phase. Although it is difficult to meet all sustainability criteria with one WWTP (Li et al. 2013), the objective of this planning and assessment framework is to design the optimal WWTP among numerous alternatives by considering criteria for classic WWTP assessment, sustainability impact assessment, and specifically, resource recovery potential assessment. Its

novelty is that it solves the multi-criteria design problem of next generation WWTPs in a step wise and holistic approach that structures both the process related and non-process related design space.

The framework introduces a production system perspective into the design space of future WWTPs since resource recovery essentially implies the production of marketable goods. Implementing resource recovery solutions into WWTP requires a careful reflection of multi-dimensional circumstances. The early stage design of innovative processes means that data may be limited and hence, uncertainties may be high.

However, the presented early stage WWTP design and assessment framework is based on extensive literature research of related fields, like for example process engineering decision support systems, and benefitted from the multidisciplinary experiences of the authors.

Material and Methods

The presented framework is based on analysis of secondary data, where “secondary data can include any data that are examined to answer a research question other than the question(s) for which the data were initially collected” (Vartanian 2011). It combines existing methodologies from wastewater treatment plant design, resource recovery, industrial process engineering, project management, and market analysis. Moreover, it uses quantitative and qualitative assessment criteria to design a process that fits real circumstances and meets not only the required treatment performance, but also shows a high resource recovery potential and low sustainability impact. In addition to criteria to assess the impact in the three sustainability pillars (environment, economy, and society), the framework includes technical key performance indicators (KPIs), criteria for successful resource recovery implementation, and a risk analysis approach. Information and methods incorporated into this framework stem from a careful analysis of the mentioned research fields to identify and extract ideas and procedures that are useful for designing WWTPs from a resource recovery perspective. Therefore, this framework has been developed by reflecting the multidimensional and multidisciplinary requirements for implementing next generation WWTPs.

Results and Discussion

The process design and assessment framework is a prescriptive approach following five planning, assessment, and design steps that may lead to a WWTP designed according to carefully defined objectives (figure 1). It structures the decision making process during the early stage process design phase in a way that the final process meets sustainable development goals (SDGs), case specific requirements, and a wide variety of criteria. The framework shall be understood as a holistic and flexible instruction manual in the sense that proposed assessment criteria can be selected according to their usefulness in a specific WWTP design project. Moreover, it is assumed that the starting point of the planning process is an existing WWTP that treats a given wastewater stream but does not fulfill modern sustainability and circular economy criteria and therefore is intended to be renewed.

Conclusions

The framework helps water utilities to design a WWTP that may successfully recover resources and consequently can support decision making for investments into next generation WWTPs that contribute to a future circular economy. It follows the project management principle “begin with the end in mind” (Leach 2005) and covers a wide range of factors to design a WWTP that simultaneously meets highest treatment standards, allows the recovery of marketable resources, and is designed in accordance with the specific circumstances of its environment.

References

Batstone DJ, Hülsen T, Mehta CM, Keller J (2015) Platforms for energy and nutrient recovery from domestic wastewater: A review. Chemosphere 140:2–11. doi: 10.1016/j.chemosphere.2014.10.021

Bozkurt H, Gernaey KV, Sin G (2017) Superstructure-based optimization tool for plant design and retrofitting. In: Innovative Wastewater Treatment & Resource Recovery Technologies. IWA Publishing, pp 581–597

Bozkurt H, van Loosdrecht MCM, Gernaey KV, Sin G (2016) Optimal WWTP process selection for treatment of domestic wastewater – A realistic full-scale retrofitting study. Chem Eng J 286:447–458. doi: 10.1016/j.cej.2015.10.088

Castillo A, Comas J, Garrido-Baserba M, et al (2017) Environmental decision support systems. In: Lema JM, Suarez S (eds) Innovative Wastewater Treatment & Resource Recovery Technologies: Impacts on Energy, Economy and Environment. International Water Association, pp 555–580

Hamouda MA, Anderson WB, Huck PM (2009) Decision support systems in water and wastewater treatment process selection and design: a review. Water Sci Technol 60:1757–1770. doi: 10.2166/wst.2009.538

Leach LP (2005) Critical chain project management, 2nd ed. Artech House, Boston

Li W-W, Yu H-Q, He Z (2013) Towards sustainable wastewater treatment by using microbial fuel cells-centered technologies. Energy Env Sci 7:911–924. doi: 10.1039/C3EE43106A

Puyol D, Batstone DJ, Hülsen T, et al (2017) Resource Recovery from Wastewater by Biological Technologies: Opportunities, Challenges, and Prospects. Front Microbiol 7:. doi: 10.3389/fmicb.2016.02106

Vartanian TP (2011) Secondary data analysis. Oxford University Press, New York

Wan J, Gu J, Zhao Q, Liu Y (2016) COD capture: a feasible option towards energy self-sufficient domestic wastewater treatment. Sci Rep 6:. doi: 10.1038/srep25054

Wang X, McCarty PL, Liu J, et al (2015) Probabilistic evaluation of integrating resource recovery into wastewater treatment to improve environmental sustainability. Proc Natl Acad Sci 112:1630–1635. doi: 10.1073/pnas.1410715112

Start-up and Nitrogen Removal Performance of SNAD Process in a Pilot-scale Oxidation Ditch

Xinying Zhang, Fuzhou University, Fuzhou, PR China; Xiaolong Li, Fuzhou University, Fuzhou, PR China; Yang Liu, Fuzhou University, Fuzhou, PR China; Jian Zhang, Fujian Provincial Academy of Environmental Science, Fuzhou, PR China.

Abstract:

In this study, the completely autotrophic nitrogen removal over nitrite (CANON) process was started successfully in a pilot-scale oxidation ditch. The influent ammonia nitrogen (NH_4^+-N) concentration was about 40 mg/L, while the effluent NH_4^+-N and total nitrogen (TN) concentrations were 2.81 mg/L and 7.80 mg/L, respectively. The average removal rate of TN was 82.17%. After the employment of CANON to deal with actual domestic wastewater, a simultaneous partial nitrification, anaerobic ammonium oxidation (ANAMMOX), and denitrification (SNAD) process was gradually started. During operation of the reactor, both hydraulic retention time (HRT) and aeration / non-aeration time were important parameters for the biological treatment effect and effluent quality of the SNAD process. An HRT of 15 h, and an aeration / non-aeration time of 3 h / 1 h was recommended as the optimal operating parameters in the SNAD process. Sludge activity and high-throughput sequencing analyses showed that the carriers provided a suitable environment for the attachment and growth of anaerobic ammonia-oxidizing bacteria, thus ensuring the reaction of ANAMMOX. This study can provide a deeper understanding on the application of SNAD treatment of domestic wastewater in an oxidation ditch-type continuous flow reactor.

Keywords: CANON; SNAD; Pilot-scale; Oxidation ditch; Domestic wastewater

Introduction

Recently, simultaneous partial nitrification, ANAMMOX and denitrification in a same reactor (SNAD) is mainly used to treat wastewater with low C/N and high NH_4^+-N, such as swine wastewater, landfill leachate. However, there are few reports on such municipal wastewater (low C/N and low NH_4^+-N) treatment with SNAD process. In particular, it is still not clear what effect of operating parameters on nitrogen removal function of SNAD in oxidation ditch-type continuous flow reactor, such as aeration methods, aeration amount and hydraulic retention time (HRT) and so on. In

this study, a pilot scale oxidation ditch was used for developing a SNAD process, a new operating parameter—aeration time/ non-aeration time ratio was proposed as a key operating parameter for controlling SNAD process, and the startup and operation of SNAD process were enhanced by the addition of packing. The research include (1)Start-up and operating characteristics of CANON process; (2)Start-up and operating characteristics of SNAD process; (3)Effect of aeration time/ non-aeration time ratio and HRT on SNAD; (4) Microorganism population structure analysis of suspended sludge and biofilm by high-throughput sequencing methods and the sludge activity tests.

Material and methods

A typical Carrousel 2000 oxidation ditch(OD) was adopted to in this study (Fig. 1).

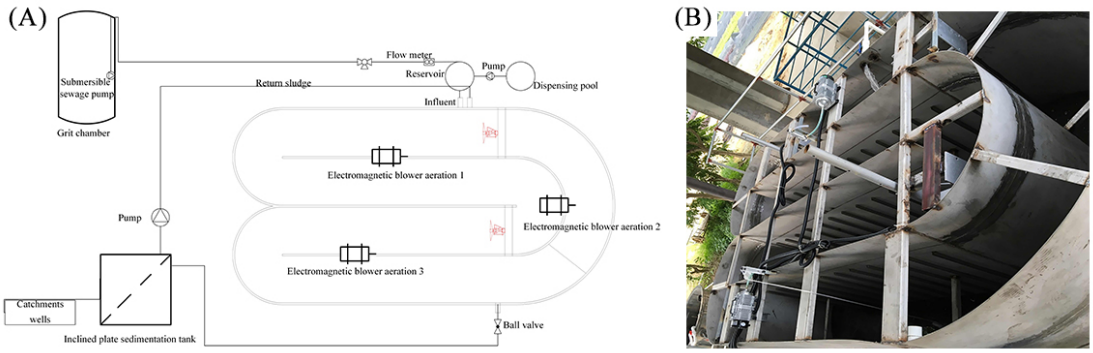


Fig.1 Schematic diagram and photograph of the pilot-scale Oxidation Ditch (A) Schematic diagram of reactor; (B) photograph of reactor

The concentrations of NH_4^+-N, NO_2^--N, NO_3^--N, total suspended solids (TSS) and volatile suspended solids (VSS) (Nepa, 2012),size distribution , specific anammox activity (SAA) (Tang et al., 2009b), hydrazine-oxidizing enzyme (HZO) activity (McGrath et al., 2000), content of Heme c (Berry and Trumpower, 1987) of the anammox granules were also analyzed.

Results and discussion

The pilot-scale OD was operated to treat real synthetic wastewater and actual domestic wastewater. Nitrogen removal was investigated under both CANON and SNAD processes throughout the experimental period. Fig. 2 shows the concentration profiles of various forms of nitrogen and their respective removal efficiencies. The removal effect of pollutant is shown in Fig. 2. Prior to the treatment periods, the first phase (about 12 days) is the groping phase of the operating parameters. The initial

operating conditions were aeration / non-aeration time of 1h/ 1h, aeration rate of 0.6 m^3/h, and a relatively high influent NH_4^+-N concentration of about 70 mg/L. This ensured that AnAOB could better adapt to the environment and protected the AnAOB from any adverse effects of aeration. After the start-up, stable operation of the CANON process was successfully achieved in the pilot-scale OD under batch operation conditions. The influent of the reactor was then directly converted to a continuous flow of actual domestic wastewater, and the CANON coupled denitrification process was constructed by using the COD from the actual domestic wastewater. As shown in Fig. 2, the operational period of the SNAD process contained phases Ⅴ-Ⅻ.

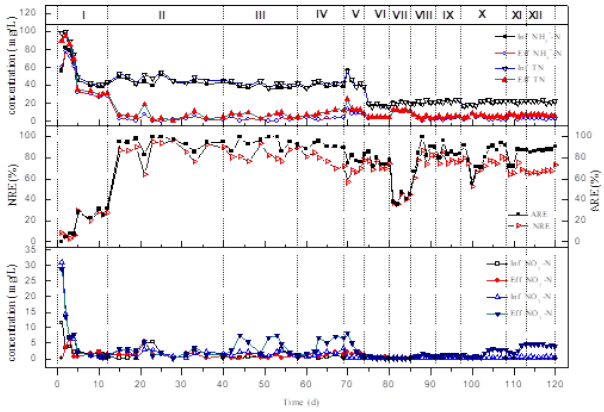


Fig.2 Nitrogen removal performance of the CANON and SNAD processes

In the CANON process, it was found that the NRL of AnAOB in biofilm sludge on packing was 0.110 g/gVSS·d, while the NRL of the suspended sludge was 0.018 g/gVSS·d. The AnAOB activity of the biofilm sludge was more than six times that of the suspended sludge in the reactor, due to the presence of an anaerobic inner zone formed in the packing, which provides a suitable attachment carrier for the AnAOB, thereby ensuring the nitrogen removal reaction of the CANON process. At the end of phase Ⅱ, the reactor achieved an average ARE of 93.9% and an average NRE of 86.8% (Fig.2); and the effluent quality had initially met the first level A emission standard; and the CANON process had started up successfully. From the above, the presence of a packing-formed anaerobic inner zone, which was conducive to AnAOB adhesion growth, also helped inhibit the activity of NOB.

As shown in Fig. 3， the effluent TN was 4.61 mg/L and the maximum NRE reached was 76.1% (Fig.3). Since only a small amount of nitrate was produced in the reactor system, it appears that the nitrate formed by ANAMMOX was used by the denitrifying bacteria and that the biological activity of the denitrifying bacteria has been greatly improved. In general, a combined system of AOB, AnAOB, and denitrifying bacteria responsible for partial nitrification, ammonia oxidation, and denitrification was established. It can be considered that the SNAD process started successfully. In the present study, if aerobic heterotrophic bacteria and denitrifying bacteria were multiplied in large numbers, the DO concentration in the reactor would have been reduced, and the substrate required for ANAMMOX and short-cut nitrification would have been dramatically reduced, resulting in both AOB and AnAOB being simultaneously inhibited. Therefore, the average ARE and NRE in this stage is lower than those in the previous CANON process.

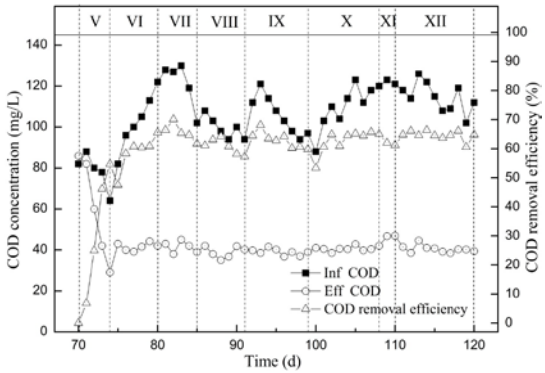


Fig.3 Variations of COD concentration and COD removal efficiencies of the SNAD process

The composition and relative abundance of suspended sludge and biofilm sludge samples at the genus level are shown in Fig.4. The species of microorganisms in the suspended sludge and the biofilm sludge on packing were very similar, but the proportions differed. At the genus level, the composition and relative abundance of the major microflora to nitrogen removal for suspended sludge and biofilm sludge are shown in Table 1. The main microbial components associated with nitrogen removal in the SNAD process were approximately the same as those in the CANON process. Two genera related to partial nitrification were detected, *Nitrosomonas* and *Nitrosospira*, there were four ANAMMOX-related genera in suspended sludge, *Candidatus_Kuenenia, Candidatus Hydrogenedens, Candidatus ANAMMOXoglobus,* and *Candidatus Koribacter*, and there were two genera related to nitrification, *Nitrospira* and *Nitrospirillum*. There were also seven denitrification-

related genera: *Terrimonas, Denitratisoma, Thauera, Hyphomicrobium, Acinetobacter, Pseudolabrys,* and *Pseudoxanthomonas.*

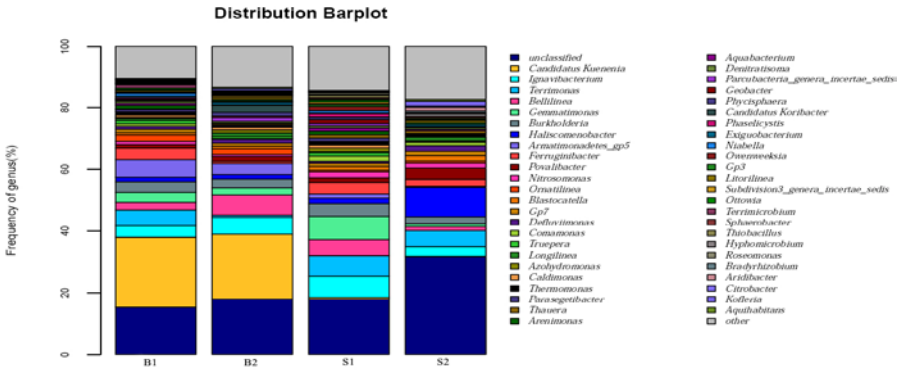


Fig.4 Bacteria composition and relative abundance of suspended sludge and biofilm sludge from the CANON and SNAD processes, identified to genus level. B1: biofilm on packing in CANON; B2: biofilm on packing in SNAD; S1: suspended sludge in CANON; S2: suspended sludge in SNAD.

Table 1 Changes in the microbial components during different stages

Table 3 Changes in the microbial components during different stages

Biological reaction	Genus	CANON system		SNAD system	
		S1	B1	S2	B2
Partial nitrification	*Nitrosomonas*	1.87	1.03	1.60	0.61
	Nitrosospira	0.01	0.02	0.01	0.03
ANAMMOX	*Candidatus Kuenenia*	0.63	22.74	0.10	21.01
	Candidatus Hydrogenedens	0.05	0.08	0.19	0.27
	Candidatus ANAMMOXoglobus	0.12	0	0	0.01
	Candidatus Koribacter	0.06	0.03	0.06	2.29
Nitrification	*Nitrospira*	0.23	0.11	0.25	0.04
	Nitrospirillum	0.01	0.01	0.11	0.02
Denitrification	*Terrimonas*	6.8	5.57	0.66	5.18
	Denitratisoma	0.67	0.7	0.59	1.61
	Thauera	0.17	0.02	0.46	0.91
	Hyphomicrobium	0.18	0.09	0.26	0.88
	Acinetobacter	0.11	0.18	0.3	0.43
	Pseudolabrys	0.02	0.03	0.02	0.04
	Pseudoxanthomonas	0.01	0.02	0.14	0.25

During the SNAD process, Nitrosomonas accounted for 1.60% and 0.61% of the suspended sludge and biofilm sludge, respectively (Table 1), and nitrification-related bacteria Nitrospira accounted for 0.25% and 0.04%, respectively. Therefore, the proportion of AOB and NOB bacteria from suspended sludge in the reactor was higher than that of biofilm sludge, as was seen in the CANON process. However, the study also found that there were fewer bacteria associated with partial nitrification and more bacteria associated with nitrification than seen in the CANON process, likely due to the increased aeration intensity during parameter control and the fact that reactor had a long-term low ammonia concentration, so there was little inhibition of NOB. In addition, the proportion of AnAOB in the suspended sludge was low: the total percentage of bacteria associated with ANAMMOX was 0.35%. The dominant AnAOB in the biofilm was again Candidatus Kuenenia, with a relative content of

21.01%, indicating that the packing provided a suitable environment for the attachment and growth of AnAOB.

Conclusion

The CANON process was successfully started in the Pilot-scale OD after 40d (phase Ⅱ) domestication and operation. Then actual domestic wastewater was directly introduced into the oxidation ditch the start of SNAD process was completed, and the ammonia nitrogen, total nitrogen and COD removal efficiency reached 85.6%, 76.1% and 65.6% respectively. The HRT was 15 h, and the aeration/non-aeration time ratio of 3 h/1 h was the optimal operating parameters in SNAD process.The proportion and biological activity of AnAOB and denitrifying bacteria on the biofilm were significantly higher than the suspended sludge, and AOB and NOB would be slightly less than the suspended sludge, and the carriers provide a suitable environment for the attachment and growth of AnAOB, to ensure that the reaction of ANAMMOX.

References

Berry, E. A., & Trumpower, B. L., 1987. Simultaneous determination of hemes a, b, and c from pyridine hemochrome spectra. Anal. Biochem. 161(1), 1-15.

Nepa, C.,2002. Water and wastewater monitoring methods. Beijing: Chinese Environmental Science Publishing House.

McGrath, J. W., & Quinn, J. P.,2000. Intracellular accumulation of polyphosphate by the yeast Candida humicola G-1 in response to acid pH. Appl. Environ. Microbial. 66(9), 4068-4073.

Tang, C.J., Zheng, P.,Mahmood, Q., Chen, J.W., 2009b. Start-up andinhibition analysis of the Anammox process seeded with anaerobicgranular sludge. J. Ind. Microbiol. Biotechnol. 36, 1093-1100.

Membrane Bioreactors (MBR) in municipal WWTPs as turning point in wide-ranging water reuse?

Klara Westling; Christian Baresel (presenting author); Sofia Lovisa Andersson; Mayumi Narongin

IVL Swedish Environmental Research Institute, Stockholm, Sweden

Highlight

The paper focus on the aspect on the potential of the current trend of converting conventional activated sludge (CAS) processes at municipal wastewater treatment plants (WWTPS) to Membrane Bioreactors (MBR) to facilitate an increase reuse of water in society.

Introduction and objectives

The well-known MBR technology has during recent years experienced an internationally lift with a number of new installation planned around the world. Several municipal WWTPs in Sweden are facing both an increased load due to a growing population as well as more stringent effluent quality requirements. The latter mainly regarding nutrients due to Sweden‘s commitment to the Baltic Sea Action Plan and the implementation of the European water framework directive (WFD). In addition, removal of emerging substances such as pharmaceutical residues, micro plastics and antibiotic resistance are gaining more attention since WWTP effluents are the most or one of the most significant sources of such loads to the environment. Even so, MBRs cannot achieve an efficient removal of micropollutants, the overall effluent quality is significantly better compared to CAS and a subsequent polishing become more resource-efficient.

Methodology approach

Results from several years of pilot-scale trials with membrane biological treatment of municipal wastewater show that MBRs can be a turning point for a wide-ranging water reuse implementation. The test have been carried out by IVL Swedish Environmental Research Institute at the R&D facility Hammarby Sjöstadsverk, in Stockholm, Sweden, and are based on the conversion of Stockholm’s WWTP

Henriksdal from CAS to a MBR to reach a capacity increase, and a higher level of both purification and operational stability.

Our studies show that a proper sewage treatment by MBRs can be achieved for a number of pollutants that could facilitate a reuse of the MBR-effluent for less demanding purposes such as urban reuse including landscape irrigation. Results from a number of test with complementary treatments of the MBR-effluent including for example ozonation, biofilter with active carbon as filter material, UV, reverse osmosis (RO), etc. show that by using the right combinations of technologies, wastewater can be recycled both cost-effectively and to such quality that it can be returned to groundwater fir indirect potable reuse or direct potable reuse.

However, the strategy of reusing treated wastewater as a natural part of water resource management is relatively new, and is still regarded by many countries, including Sweden, as a solution that is some way off in the future and that requires special treatment technologies. By the implementation of MBRs in municipal WWTPs this is changed and the base for a future increase in water reuse is created.

Conclusions and recommendation

By overcoming the limits of traditional sewage treatment, MBRs can be a turning point for a wide-ranging water reuse implementation. This because the particle free MBR-effluent can already without further treatment be utilized for various reuse purposes. With additional treatment of the effluent for removal of micropollutants, both non-potable, indirect and direct potable water reuse can be accomplished in a resource- and cost-efficient way. The large water quantities treated by municipal WWTPs further provides an excellent starting point for implementing a variety of reuse schemes.

Integrated use of real-time sensors and process modelling to optimize wastewater disinfection by peracetic acid

Jacopo Foschi, Matteo Cascio, Andrea Turolla, Manuela Antonelli

Politecnico di Milano, Dep. of Civil and Environmental Engineering, Milano, Italy

Introduction

Disinfection plays a key role in complying with microbiological quality standards in case of wastewater reuse. Among chemical disinfectants, peracetic acid (PAA) is a valid alternative to the commonly-used chlorine, thanks to its high spectrum of biocidal activity, the absence of halogenated disinfection by-product (DBPs) and the easy retrofitting of existing structures [1]. Anyway, it is affected by strong decay during the disinfection contact time which significantly depends on water quality [2]. The presence of suspended solids (SS) has proved to influence PAA disinfection in different ways: (i) enhancing PAA decay rate and (ii) promoting protection mechanism to bacteria [3]. The quantification of SS and microbiological enumeration by laboratory procedures requires many hours, consequently the development of real-time monitoring sensors is spreading in wastewater treatment plant (WWTP).

In the present research, a modelling framework for describing involved phenomena (PAA decay, bacterial inactivation) and accounting for system uncertainty by stochastic tools is developed and adapted to process real-time water quality monitoring data. The final goal is to assess the efficacy of recently developed sensors to evaluate the effect of SS on PAA decay and, consequently, on the overall performance of PAA on *E. coli* inactivation, in the view of real-time control.

Materials and methods

The study is focused on a pilot-scale disinfection reactor which was fed with the secondary effluent of a WWTP (500,000 PE) located in the area of Milan (Italy). Before the inlet section of the reactor, wastewater was analysed by a particle counter instrument (Grundfos Bacmon) which classifies particles as bacteria or abiotic particles [4]. The hydrodynamic behaviour of the disinfection reactor was characterized by tracer tests and the disinfection process was modelled using the Integrated Disinfection Design Framework [5]. The model for the influence of SS on PAA decay rate and the dose-response model were derived from a previous work [3]. A Monte Carlo approach was used to propagate uncertainty related to parameters.

Results and discussion

The elements of the modelling framework were developed using experimental data and an existing WWTP database. The particle count data showed a weak but statistically significant correlation with SS content and *E. coli* enumeration. Moreover, it is worth noticing that peaks of particles occurred in combination with high flow rate (Figure 1a), mostly due to rainy events. The hydrodynamic behaviour was successfully modelled as a combination of conceptual reactor models (plug-flow and continuously-stirred tanks), and residence time distribution was obtained at the outlet section. The elaboration of particle count data within the modelling tool allowed to calculate the optimal PAA dosage necessary to achieve the required bacterial inactivation as a function of the actual water quality characteristics. The main modelling result was the probability of non-compliance (PONC) from the estimation of the probability density function (PDF) of the model output, as shown in Figure 1b.

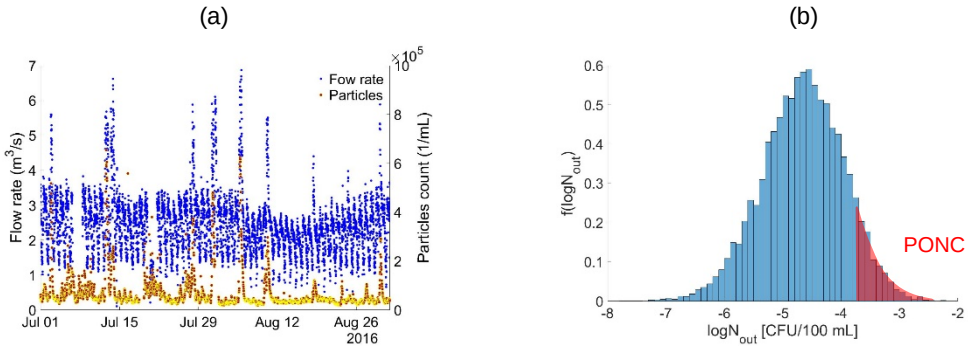


Figure 1 (a) Particle count and wastewater flow rate at the inlet section of the reactor; (b) example of PDF of bacterial inactivation resulting from Monte Carlo simulations and estimated PONC.

Conclusions

A modelling framework based on real-time monitoring data was developed to control disinfectant dosage to assure bacterial inactivation required to wastewater reuse even in case of unexpected changes in water quality, possibly related to rainy events. In particular, the effective integration of innovative on-line sensors was evidenced.

References

[1] M. Kitis, Disinfection of wastewater with peracetic acid: A review, Environment International 30 (2004) 47 – 55.

[2] Domìnguez Henao L., Delli Compagni R., Turolla A., Antonelli M., Influence of inorganic and organico compounds on the decay of peracetic acid in wastewater disinfection, Chemical Engineering Journal 337 (2018) 133-142.

[3] Domìnguez Henao L., Cascio M., Turolla A., Antonelli M., Effect of suspended solids on peracetic acid decay and bacterial inactivation kinetics: Experimental assessment and definiition of predictive models. Science of the Total Environment 643 (2018) 936-954.

[4] B. Højris, S. C. B. Christensen, H. J. Albrechtsen, C. Smith, and M. Dahlqvist, A novel, optical, on-line bacteria sensor for monitoring drinking water quality, Scientific Reports 6 (2016) 1–10.

[5] Bellamy W.D., Finch G.R., Haas C.N., Integrated disinfection design framework, AWWA Research Foundation and American Water Works Ass., 1998.

Graphene oxide cross-linking polydopamine reverse osmosis (GO-PDA-RO) membrane for desalination and water reclamation

Noman Khalid Khanzada, School of Energy and Environment, City University of Hong Kong, Hong Kong, SAR China; Alicia Kyoungjin An, School of Energy and Environment, City University of Hong Kong, Hong Kong, SAR China

Abstract

Increasing population, rapid urban sprawl, industrialization, and climatic variation are resulting in an increasing fresh water demand. This ever-increasing concern has created a burden on the community and influenced to bargain with the alternate resources. Following this trend, many countries are supplementing their water supply via desalination and water reclamation using reverse osmosis (RO). However, the occurrence of domestically generated micropollutants in the treated effluent subsequent to their inappropriate removal through the membrane have been gaining high attention.

Therefore, membrane fouling consequence to flux decline and permeate quality deterioration has now become the platform for many researchers from the last few decades. To cope these challenges, surface modification is considering as a promising method, however, the permeability of the membrane is being compromised to achieve high removal performance or vice versa. Furthermore, the poor dispersion and disintegration of functionalized group is also challenging in a pressurized system.

Herein, graphene oxide cross-linking polydopamine (GO-PDA) is found encouraging for polyamide RO membrane surface modification to confront with these limitations. In this study, we aimed to obtain ultra-high flux with superior permeate quality from the commercial BW4040AFR (LG Chem's NanoH_2O, Korea) RO membrane (GO-PDA-RO) treating pharmaceuticals and endocrine disruptive compounds (i.e. erythromycin, cefalexin, ofloxacin, hormone, bisphenol A, pentadecafluorooctanoic acid). The morphological detail and uniform coating layer distribution were validated by scanning electron microscopy (SEM) of virgin membrane samples. X-ray photoelectron spectroscopy (XPS) and fourier-transform infrared spectroscopy (FTIR) were also performed to observe chemical composition and percent amount of oxygen-containing functional groups over the coated surface. In addition, the

performance of the modified and pristine RO membrane were examined using synthetic feed followed by real seawater as a representative of complex feed solution matrix.

Adding the to transmembrane pressure, permeate flux, and conductivity values, the permeate samples analyzed by liquid chromatography – electrospray ionization – tandem mass spectrometer (HPLC-ESI-MS/MS) showed promising results with high micropollutants rejection (>99%) from the modified membrane. The narrow layer spacing of GO structure and hydrophilic characteristics of PDA worked synergistically to inhibit fouling layer formation by avoiding hydrophobic interaction of the pollutants at the membrane surface. Owing to high surface charge, antimicrobial characteristics, and stable coating layer formation, GO-PDA-RO membrane outperformed for brackish as well as for seawater desalination with less fouling propensity and low operating pressure conditions.

Material and Methodology

A custome made container was utilized for the surface modification of commercial membrane (22 inch^2) [2]. SEPA CF II cell (Sterlitech, USA) was used to performed all filtration experiments and the quality of the permeate was monitored through Ultramerer II (6PFCE, Myron L, USA) meter. For micropollutant detection, the collected permeate sample (prefiltered with 0.22 µm filter) was analyzed through HPLC-ESI-MS/MS [3].

Result and Disscussion

Size exclusion was observed as a dominant mechanism for both membranes. However, the modified (GO-PDA-RO) membrane showed high rejection for low molecular weight (bisphenol A) and nonionic (erythromycine and hormones) compounds and exhibited enhanced flux for synthetic and real feed conditions. This was presumably due to the collegial effects of antifouling and hydrophilic characterisitics.

Reference

[1] H. Guo, Y. Deng, Z. Yao, Z. Yang, J. Wang, C. Lin, T. Zhang, B. Zhu, C.Y. Tang, A highly selective surface coating for enhanced membrane rejection of endocrine disrupting compounds: Mechanistic insights and implications, Water

Res. 121 (2017) 197–203.

[2] H.W. Leung, T.B. Minh, M.B. Murphy, J.C.W. Lam, M.K. So, M. Martin, P.K.S. Lam, B.J. Richardson, Distribution , fate and risk assessment of antibiotics in sewage treatment plants in Hong Kong , South China, 42 (2012) 1–9.

Electrochemical treatment of typical micropollutants from secondary effluent using a three-dimensional electrode reactor with BDD anode and SnO_2-SbO_2 doped granular activated carbon as particle electrode

*Bo SHEN and Xianghua Wen**

School of Environment, Tsinghua University, Beijing 100084, China

Email: shenb12@mails.tsinghua.edu.cn

1. Introduction

The emergence of micropollutants into our aquatic resources is regarded as a serious issue, threatening the safety of reused water quality and increasing environmental concern. Secondary effluent, originating from municipal wastewater treatment plants has been identified as a major source of micropollutants into the aquatic environment[1]. Therefore, it is of great importance to conduct researches on innovative and effective technologies to remove micropollutants from secondary effluent. Electrochemical technologies based on three-dimensional electrode reactor(TDER) have been attracting much attention due to its large time-space ratio, high efficiency of degrading organics and low energy consumption[2]. Although TDER shows great potential for low concentration pollutants, there are few literatures published related to micropollutants, especially those in secondary effluent. In this study, we investigated for the first time the applicability of TDER as an advanced treatment process of secondary effluent containing several typical micropollutants using Boron-Doped Diamond (BDD) anode as working electrode, which is supposed to be one of the most effective anode up to date. What's more, we modified traditional granular activated carbon(GAC) with SnO_2 and SbO_2 to improve its electrocatalytic activity. By using BDD anode and SnO_2-SbO_2 doped GAC as particle electrodes, we studied extensively the efficiency and feasibility of TDER to remove micropollutants from secondary effluent.

2. Experimental set-up and procedures

The TDER consists of a BDD anode(5×10cm), a stainless steel cathode(5×10cm) and SnO_2-SbO_2 doped GAC as particle electrodes. Secondary effluent containing 1000μg/L micropollutants with Na_2SO_4 as electrolytes was pumped into TDER. DC power was turned on when the adsorption of particles had reached an equilibrium. UPLC/MS/MS and HPLC-FLD were used for concentration determination of

micropollutants. Targeted pollutants include 5EDCs (E1, E2, E3, EE2 and BPA) and 3 quinolones (ciprofloxacin, ofloxacin and norfloxacin).

3. Results and Conclusions

3.1 Modification of GAC. Impregnation was used to modify GAC with SnO_2 and SbO_2. SEM, XRD and XPS were used to do physical characterization of the surface morphology of modified GAC. As shown in Fig. 1, Sn and Sb were well-doped on to GAC, occurring as white crystalline pellets.

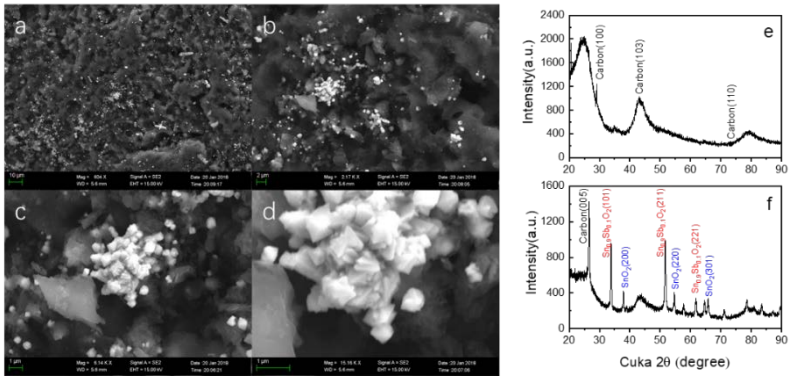


Fig. 1 SEM images (a-d) and XRD diagrams(e,f) of GAC and GAC-SbO_2SnO_2

3.2 Effects of operating and influencing parameters. The effects of particle electrode composition (volume ratio of GAC and glass beads), hydraulic retention time (HRT), current and aeration density were studied in light of micropollutants removal, specific energy consumption (Es) and instantaneous current efficiency (ICE). The best performance of TDER was obtained with 100% GAC, an HRT of 20minutes, a current density of 40A/cm^2 and with aeration added.

3.3 Degradation mechanisms of TDER.

As shown in Fig. 2, when a uniform potential which is larger than the threshold potential of ·OH production, after a certain mount time, the generated ·OH in 3D-GAC-SnSb process was much more than that in 3D-GAC. The results indicated that ·OH played an important role during the degradation of micropollutants in TDER processes.

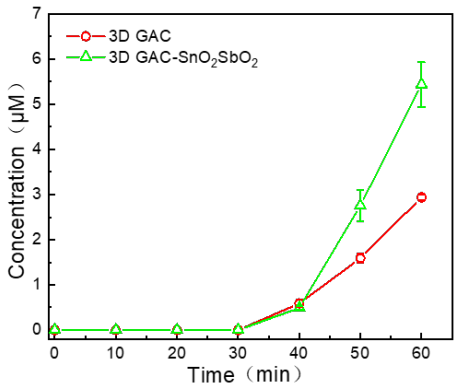


Fig. 2 ·OH generation in different processes

4. References

1. M. Bourgin, B. Beck, M. Boehler, et al., *Water Research*, 2018, **129**, 486-498.

2. A. Ansari and D. Nematollahi, *Water Research*, 2018, **144**, 462-473.

Agricultural reuse of treated municipal wastewater and the transfer of contaminants of concern into food

Hilke Maas, Monika Moeder, Christina Riemenschneider, Bettina Seiwert, Thorsten Reemtsma,

Helmholtz Centre for Environmental Research - UFZ,

Department of Analytical Chemistry, Leipzig, Germany

The increasing need to use treated municipal wastewater (TMW) for growing crops is evident. Also the European Union fosters agricultural reuse as a component of a circular economy. But the EU's recent proposal for quality standards of TMW for agricultural reuse does consider microbiological risks but not pollutants of emerging concern (PECs) [1].

We have performed a range of studies from pot experiments over hydroponic systems to studies on farm land, accompanied by extensive analytical work on the uptake, translocation and transformation of PECs into agricultural plants upon irrigation with TMW. The outcome of these studies will be summarized with a focus on consequences for irrigation water quality and treatment.

Wide variety of PEC

A wide variety of wastewater-borne contaminants were determined in the plants and its edible parts upon irrigation with TMW, from pharmaceuticals to artificial sweeteners and corrosion inhibitors [2]. Carbamazepine is still the most widely found contaminant [3]. The effects of molecular properties are not sufficiently understood to allow for a reliable prediction of internal concentrations of PECs in irrigated crops.

Different reuse scenarios

The scenarios of agricultural reuse of TMW for irrigation differ widely, which greatly influences the concentrations of PECs found in irrigated plants. Irrigation with river water influenced by WWTP discharges is, likely, the least critical situation. Vegetable in hydroponic systems fed with treated wastewater of a housing complex was at the other end of the scale, with orders of magnitude higher concentrations of PECs. Obviously, treatment requirements should differ for these different reuse situations.

Plant species, plant organs and metabolism

The extent of uptake of polar organic contaminants differs for different crops. Besides uptake also the translocation in plants is important for the concentration eventually

found in the edible parts. Generally the concentrations of PECs was found to decrease in the order of root > leaf > shoot > fruit [2]. Consequently, highest concentrations in edible parts are found for leafy vegetables and lettuce [2; 3]. Thus, with respect to food contamination, quality requirements may differ for different crops with leafy vegetables being most demanding.

Plants do also biotransform PEC after uptake through their metabolism. We have identified larger numbers of phase-I and phase-II metabolites of different PECs formed in exposed plants [4 - 6]. However, plant metabolism is rarely considered in studies on irrigation with TMW. This has several consequences: a) the extent of uptake of the parent PECs is underestimated, leading to false conclusion as to the transfer of PECs from the irrigation water [2, 4]; b) the consumer exposure to PECs via agricultural produce may be underestimated as the parent PECs may be liberated from the phase-II metabolite upon ingestion of the food [4]; c) the diversity of exposure of the consumer is underestimated as metabolites add to it.

Assessment of health risks

Possible health risks connected to the occurrence of PECs in produce were usually assessed by the threshold of toxicological concern (TTC) approach [2, 3]. Though in most situations no health risk was recognized for irrigation with TMW, our knowledge on the extent of uptake of wastewater-borne PECs by irrigation with TMW is far from complete. Some of the more critical scenarios (see above) have not been explicitly studied. Moreover, the occurrence of wastewater-born pharmaceuticals and industrial chemicals in food may well affect the public acceptance of this reuse practice and of the produce grown with it.

Therefore, treatment strategies for PEC removal adapted to the different scenarios of agricultural reuse should be developed and implemented.

References

[1] Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse. Brussels, 28.5.2018, COM (2018) 337 final; [2] Riemenschneider et al. (2016) J. Agric. Food Chem. 64, 5784 – 5792. [3] Malchi et al. (2014) Environ. Sci. Technol. 48, 9325 – 9333. [4] Macherius et al. (2012) Environ. Sci. Technol. 46, 10797-10804. [5] Macherius et al. (2014) J. Agric. Food Chem. 62, 1001 – 1009. [6] Riemenschneider et al. (2017) Environ. Sci. Technol. 51, 6100-6109.

The reuse of untreated wastewater in a small town in India
A case study from Vijayapura, Karnataka

S. Vishwanath, Biome Environmental Trust

Avinash Krishnamurthy, Biome Environmental Trust

Abstract: Vijayapura, is a small town with a population of 34,866 (Census of India 2011) close to the city of Bengaluru, Karnataka. The area of the town is 16 sq.km. with about 9329 households. The town has an underground sewerage system serving about 6000 households. The sewerage system was to be linked to a waste-water treatment plant which was however not built because of problems in land acquisition. The collected waste-water in the sewerage network flows out of the town in two major drains.

Reuse:

Farmers adjacent to the drains pick up the waste-water in small ponds and reuse it for cultivation. In an area which is semi-arid and with a rainfall of 600 mm or less, where groundwater tables have collapsed to depths of 400 metres and below, waste-water has become the only reliable source of water for farming.

In conjunction with the users, a modified Sanitation Safety Plan as developed by WHO was attempted in the catchment area. Farmers were persuaded to grow non-edible crops such as flowers and mulberry. The cultivation of mulberry in particular is for the leaves to be fed to silk worms is a popular crop. Some farmers shifted to mulberry and a higher yield has been reported by the farmers with the application of wastewater as compared to cultivation with groundwater.

Farmers developed simple systems to manage wastewater such as creating a small shallow settling pond for an initial holding and disinfection. Furrow farming which has no opportunity of direct contact with wastewater for farm workers has been developed by the farmers. Drip irrigation system is also being tried for mulberry.

Judicious application of wastewater avoids groundwater pollution and soil pollution. Simple precautions such as footwear use can prevent worm infestation in farm workers. A regular dosage of deworming tablets is also recommended for farm workers.

The mulberry leaves report a quicker growth, wider leaves and are much in demand. The silk worms too show no negative impacts in consuming the mulberry leaves.

Farmers have now evolved a system of sharing waste-water and have progressed financially. One farmer in particular has been able to become the head of the milk dairy unit in the town from working as a labourer in the fields of other farmers.

A simplified sanitation safety plan, simple communication with farmers and linking farming to crops with a market demand for produce can lead to waste-water reuse for productive purpose and close the nutrient loop.

The town of Vijayapura does not need a sewage treatment plant with farmers fields acting as the consumer of all wastewater generated from the town.

This case study offers a possible solution for small towns in semi-arid India to be able to reuse wastewater in farmers' fields until they can afford to build sewage treatment plants. The case is shown here https://www.bbc.com/news/av/science-environment-45133277/the-farmers-using-sewage-to-make-saris

Introduction: The Sustainable Development Goal 6 is on Clean water and sanitation . It states specifically to - Ensure availability and sustainable water mangement for all."

Specifically India looks to - By 2030, improve water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally." Also - Support and strengthen the participation of local communities in improving water and sanitation management.- (Source: http://in.one.un.org/page/sustainable-development-goals/sdg-6/)

In India as a whole most towns lack wastewater treatment plants (WWTP'S) and of the total wastewater generated only a small percentage is treated by these WWTPs. According to a report by the Central Pollution Control Board , in the 908 Class I and Class II towns in India , 38,254 million litres of wastewater was being generated of which only 11,587 million litres of wastewater was being treated. (Status of water supply , wastewater generation and treatment in Class I and Class ii towns of India – CPCB-2009)

The policy for urban wastewater reuse as adopted by the Government of Karnataka,India in December 2017 indicates that 23.60 million population live in urban areas and that by the year 2030 this is expected to go up to 36 million people. In Karnataka state alone in the Class i and Class ii towns (excluding Bengaluru) , the

CPCB report states that 2023 million litres of wastewater is being generated but only 65.50 million litres is being treated (CPCB-2009)

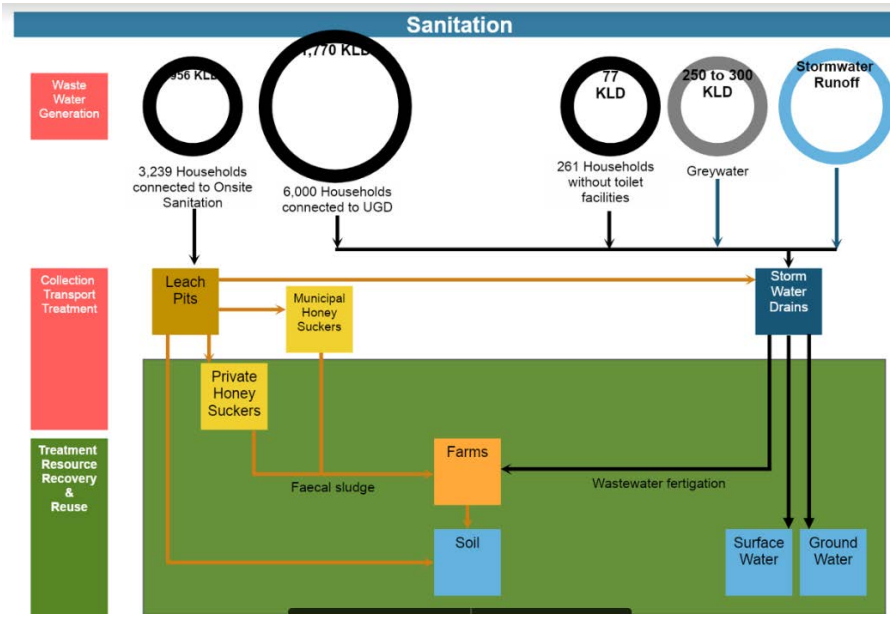
The sanitation and sewerage system was examined for one town in the state of Karnataka, namely Vijayapura. The town of Vijayapura, Bengaluru (Rural) District , Karnataka is located about 50 km to the North of the state capital Bengaluru. According to the census of 2011 the town has a population of 34,866 with 7136 households in an administrative area of 16 sq.km. By 2019 the housholds had gone upto 9239 households. The town has a sewerage system but not a sewage treatment plant. As part of the study, it was estimated that about 6000 Households were connected to the sewerage network and 3239 Households were connected to on site systems , mainly a pit with a pour flush latrine. It was estimated that about 1770 Kilio-litres per day of wasewater flowed in the sewerage lines. The sewerage network ended in 2 separate and distinct channels , flowing outside the town towards a lake.

Vijayapura Town – with drainage channels carrying raw wastewater

Materials and methods :

Preliminary surveys were undertaken to determine the water usage in the town. The water supply was estimated at 3306 kilo-litres per day with a substantial 51 % coming from private sources. All the water supply was groundwater based from deep borewells.

Wastewater and sludge from pit toilets and the route taken was then established. Wastewater flows out in two drainage channels and is entirely reused by farmers for cultivation of various crops including millets, corn , mulberry , flowers , beet root and fodder grass.



Water, wastewater and sludge flow in Vijayapura

With the assistance of maps and a field survey the approximate area under irrigation with wastewater was established. On field discussions with farmers were undertaken to understand the crop choice that they were making and then to start to nudge them towards non edible crops such as mulberry leaves which are used to feed the silk worm.

A leading farmer was identified as being influential and having social capital to persuade others on better practices with the reuse of wastewater . The farmer had taken to the use of wastewater as his well had run dry and the borewell that he had dug had failed to yield water even at 300 metres depth.

Over time, he had developed a good system of drawing wastewater from the adjacent drain to a small pond on his field. He then segregated the solids in the wastewater with the help of a small grill. The wastewater was allowed to settle for a few hours and then pumped up the land to irrigate it in furrows. The entire 6 Hectares of land is irrigated using the furrow method moving away from the flood method . This was because the farmer had observed that flood irrigation with wastewater leads to sewage sickness of the soil as well as crop losses due to high nutrient value in the wastewater.

Mulberry was grown since in the local geographical region the entire silk industry is in operation. Farmers grow mulberry for the leaves. The leaves are used as feed for the silk worm. Cocoons are raised , threads drawn and silk weaved for different cloth in the same area by different set of actors.

The mulberry plants in the farmers field grew much faster , had broader leaves and was much in demand by the silk worm rearers who paid a premium price for these leaves. The silk worms , which are very sensitive to food, consumed the leaves and no problem was reported. The cocoons established well and the yarn drawn was also strong . This higher demand for the mulberry leaves has resulted in more farmers shifting to the cultivation of mulberry using the wastewater. A cooperative of farmers has been formed and the wastewater is shared by rotation for each field , with a fixed time for its access by each farmer.

Risks: The major reasons why wastewater needs to be managed is the health risk they cause as well as environmental risks posed.

For **health** risks , the Sanitation Safety Plan (SSP) as designed by WHO provides a management tool and technique. A simplified SSP was used to understand and establish the risks with wastewater and sludge flow in the town of Vijayapura. Flows were traced from households , through the storm drains to the point of use on the farms.

Table A2-1 Summary of microbial health risks associated with the use of wastewater for irrigation

Group exposed	Bacterial/virus infections	Protozoan infections	Helminth infections
Farm workers and their families	Increased risk of diarrhoeal disease in children with wastewater contact, if water quality exceeds 10^4 faecal coliforms /100 ml; elevated risk of *Salmonella* infection in children exposed to untreated wastewater; elevated sero-response to norovirus in adults exposed to partially treated wastewater.	Risk of *Giardia intestinalis* infection significant for contact with both untreated and treated wastewater; One study in Pakistan has estimated a threefold increase in risk of *Giardia* infection for farmers using raw wastewater as compared to fresh water; increased risk of amoebiasis observed with contact with untreated wastewater.	Significant risk of helminth infection of adults and children for untreated wastewater; increased risk of hookworm infections for workers without shoes; risk remains, for children, but not for adults, even when wastewater is treated to < 1 helminth egg/l.
Populations living within or near wastewater irrigation sites	Poor water quality sprinkler irrigation with (10^6–10^8 total coliforms /100 ml) and high aerosol exposure associated with increased infections; use of partially treated water (10^4–10^5 faecal coliforms /100 ml or less) in sprinkler irrigation not associated with increased viral infection rates.	No data on transmission of protozoan infections during sprinkler irrigation with wastewater.	Transmission of helminth infection not studied for sprinkler irrigation, but same as above for flood or furrow irrigation with heavy contact.
Consumers of wastewater irrigated produce	Cholera, typhoid and shigellosis outbreaks reported from the use of untreated wastewater, sero-positive responses for *Helicobacter pylori* (untreated); increase in non-specific diarrhoea when water quality exceeds 10^4 faecal coliform/100 ml.	Evidence of parasitic protozoa found on wastewater irrigated vegetable surfaces but no direct evidence of disease transmission.	Significant risk of helminth infection for both adults and children with untreated wastewater.

Source: Stenström et al. 2011: 92. Refer to Stenström et al. 2011 page 91–92 for additional comments related to the health risk evidence.

Four categories of people were posited at being at particular health risks

Farmers and farm workers in farms were wastewater was used for irrigation, sanitation workers responsible for keeping the drains clean , consumers of food produce from the farms using wastewater and citizens close to the pathway and point of use of wastewater.

Farmers, their family and Farm labourers. These are the farmers either staying in the farm or everybody who is working together in the farm
Sanitary workers of the municipality. These are involved in cleaning and smooth functioning of UGD lines and storm water drains.
Residential Community. The Vijayapura population who stay next to these farms, or visit the farms or interact with farmers.
Consumers. People who buy and consume produce grown by farmers

Hazard/Hazardous Event	Exposure Route	Existing control measures	Risk Assessment				
			Exposure Group	Likelihood	Severity	Score	Risk rating
Operations at and Cleaning of stormwater drain after UGD has opened out into the drain near the jackwell to divert wastewater into the jackwell : (a) Exposure to bacteria, Viruses, (b) Helminth (c) Lead/Chromium (Heavy metals)	Dermal contact and ingestion through cuts and injuries	No significant control measure	S	4	4	16	High
		No significant control measure	F	4	8	32	High
		No significant control measure	R	1	4	4	Low
	Accidental ingestion	Washing and bathing after work before consumption of food or drink	S	3	4	12	Medium
		Washing and bathing after work before consumption of food or drink	F	3	4	12	Medium
		No significant control measure	R	1	4	4	Low
	Ingestion through the Respiratory system	Does not have any control measures	S	4	1	4	Low
		Does not have any control measures	F	4	1	4	Low
		Does not have any control measures	R	1	4	4	Low
	Vector borne - through mosquito bites	Use of available solutions like Odomos, mosquito coil, mosquito net etc.,	S	4	2	8	Medium
			F	4	2	8	Medium
			R	3	2	6	Low
Installation/maintenance of irrigation pump and jackwell : (a) Exposure to bacteria, Viruses, (b) Helminth (c) Lead/Chromium (Heavy metals)	Dermal contact and ingestion through cuts and injuries	Does not have any control measures	F	4	4	16	High
	Accidental ingestion	Washing and bathing after work before consumption of food or drink	F	2	4	8	Medium
	Ingestion through the Respiratory system	Does not have any control measures	F	4	1	4	Low
	Vector borne - through mosquito bites	Uses available solutions like Odomos, mosquito coil, mosquito net etc.,	F	4	2	8	Medium
Making of furrows and standing in irrigation water during farming. (a) Exposure to bacteria, viruses (b) Helminth (c) Heavy metals	Dermal contact and ingestion through cuts and injuries	Does not have any control measures	F	3	2	6	Low
	Accidental ingestion	Washing and bathing after work before consumption of food or drink	F	2	2	4	Low
	Ingestion through the Respiratory system	Does not have any control measures	F	2	1	2	Low
	Vector borne - through mosquito bites	Uses available solutions like Odomos, mosquito coil, mosquito net etc.,	F	4	2	8	Medium
Consuming the farm produce - exposure (a) Exposure to bacteria, viruses, Helminth and heavy metals	Ingestion	Risk is mitigated in 3 levels. 1) Farmer mostly grows non edible crops 2) The farm support system washes the produce before sending to market 3) The consumer washes the produce again, peels the skin and consumes the cooked food	S	2	2	4	Low
			F	2	2	4	Low
			R	2	2	4	Low
			C	2	2	4	Low

Health Risk Matrix using simplified SSP for Vijayapura wastewater reuse

Environmental Risks were mainly anitcipated for groundwater contamination , surface water contamination and soil contamination**.** Since groundwater table was below 300 metres no evidence of groundwater contamination emerged. Surface water contamination did not occur because wastewater was entirely consumed before it could reach the lake. Soil contamination , especially sewage sickness , was observed only when flood irrigation was undertaken but farmers had broadly shifted to furrow irrigation in most fields.

Results and discussions : Wastewater and its reuse is as much a social construct as it is a technical construct. In semi arid parts of India , in rural areas surrounding towns , wastewater is used by farmers , since groundwater has run out. To manage health risks the Sanitation Safety Plan provides a useful technique in the absence of

other specific directives especially in towns which do not have WWTP's. Environmental risks are to be included as part of a modified SSP.

The significant risks observed were to sanitation workers handling solid waste , bio-medical waste and raw sewage in the cleaning of drains. Practices emerging on ground for reuse of wastewater using farmers innate skills of managing soils could be significantly improved by shifting to non-edible crops.

Since significant investments are needed for putting in place a sewage management sytem or even a sludge management system for all towns in India , the Sanitation Safety Plan approach provides an immediate risk mitigating strategy and should be used in conjunction with the reuse of wastewater , especially in towns in semi-arid India where groundwater tables have fallen significantly.

References:

1. Census of India 2011 –
2. World Health Organisation. (2016). Sanitation Safety Planning: Manual for Safe Use and Disposal of Wastewater, Greywater and Excreta.
3. Status of water supply , wastewater generation and treatment in Class I and Class ii towns of India – CPCB-2009

Distribution of selected pharmaceuticals between soil and plants when irrigated by treated municipal wastewater

Ing. Radka Vesecká, University of chemistry and technology Prague, Czech Republic

prof. Ing. Jiří Wanner, DrSc, University of chemistry and technology Prague, Czech Republic

prof. Ing. Radka Kodešová, CSc., Czech University of Life Sciences Prague, Czech Republic

Ing. Aleš Klement, Ph.D. , Czech University of Life Sciences Prague, Czech Republic

Abstract:

The described bioaccumulation test was focused on pharmaceutical substances. The monitored plant, radish seed (Raphanus sativus), was irrigated with secondary effluent from treatment plant that naturally contained the residues of the medicinal substances. After 28 days from seed sowing, the plants were harvested and subjected to drug analyzes. The results have shown that medicinal substances can penetrate into different parts of plant biomass and accumulate here. However, concentrations in plant biomass in most cases did not exceed 10 µg/kg dry matter. Bioaccumulation tests will play an important role in risk assessment of wastewater reuse for irrigation purposes. The results also confirm the need of further tertiary treatment of municipal effluents before their direct or indirect use in agriculture irrigation.

Keywords: wastewater; secondary effluent; pharmaceuticals; green plants; irrigation; bioaccumulation

Introduction

As a result of climatic changes, irrigation of arable land is becoming very often the only option how to keep agricultural production with existing intensity. In this respect, effluents from municipal wastewater treatment plants are being considered as an important alternative water resource both for direct water reuse or for the application of river water, which is in fact a mixture of natural surface water and effluents from municipal wastewater treatment plants (indirect use). The fraction of municipal

effluents in river water is especially important in dry summer periods when the use of irrigation is critical for agriculture production. This situation in many EU member states resulted in the issue of draft Proposal of EU regulation on minimum requirements for water reuse in agriculture (2018). According to this regulation, the permission for water reuse for agricultural purpose must be accompanied by risk assessment covering both environmental risks and risks to human and animal health. This study is focused on risks connected with the presence of pharmaceuticals in municipal effluents.

Material and Methods

The essence of the project was a repeated bioaccumulation test. The concentrations of pharmaceutical substances that penetrated into plant biomass were monitored. Figure 1 schematically illustrates how the experiment was conducted. The test was repeated once to compare two sets of results. The arrangement of both tests was the same. The methodology of the work is not based on any validated standard method, but was based on findings of similar studies published in the literature (Anastasis, 2017) (Al-Farsia, 2018) (Kodešová, 2018).

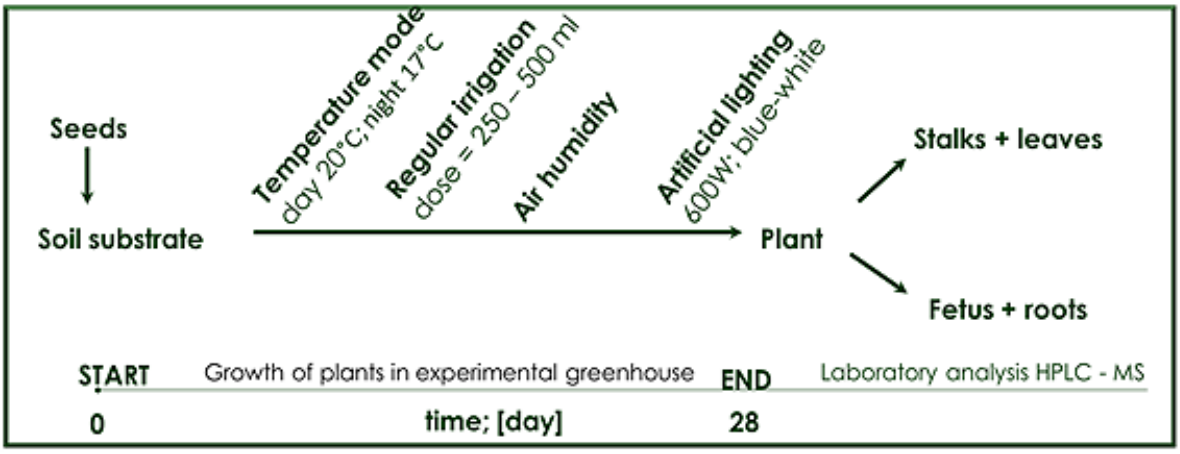


Figure 1: Bioaccumulation test scheme

Radish was selected as a model plant. Radish was grown for 28 days in a conventional horticultural substrate. Canna Terra Seed Mix was used for seeds growing. This is a certified natural soil with a homogeneous structure and high water retention capacity. Increased water retention is caused by fine coconut fibers contained in the substrate. During the experiment radish plants were exposed to the pharmaceutical substances regularly present in irrigation water.

Plants were grown in plastic containers (1 container = 22 separate boxes). Two seeds were placed in each of the boxes. Three experimental containers of plants were observed for comparison. The control container included plants which were irrigated with water with no pharmaceutical substance. Growth conditions were the same for all cultivation tests. Plants were grown in experimental greenhouse environment with controlled temperature regime (8h-17h, 20 °C; 17h-8h, 17 °C), maintained humidity and artificial illumination with a lamp suitable for plant growth (blue-white light, 600 W, power 50,000 lm).

The start of the experiment was given by the moment of sowing radish seeds, i.e., with the application of the first irrigation dose. Secondary effluent from a municipal wastewater treatment plant with a capacity of over 1,000,000 PE was used for irrigation. This water naturally contains the pharmaceutical substances because the plant does not have the tertiary treatment technology to remove those compounds. All irrigation water was taken from the wastewater treatment plant at once. The total amount was divided into 500 ml plastic bottles, which were then frozen to -18 °C. The water dose was thawed before each irrigation. Irrigation doses were applied regularly to the radish plants. The amount of water was based on the actual need. It was approximately 250 ml of irrigation water per container in the first two weeks of the experiment. Subsequently, the water dose was increased to 500 ml of water in each container.

The bioaccumulation test was terminated on the 28th day of the experiment. The green above-ground parts of the plants were cut, washed with deionized water and then frozen. Roots of plants were removed from the soil substrate, washed thoroughly, eventually mechanically cleared of soil residues and quickly frozen. Furthermore, the soil substrate in which the plants were growing was frozen. Then all solid samples were lyophilized. The lyophilization process took place for at least 72 hours. Finally, the perfectly dried samples were ground on a ball mill to a fine powder which was subsequently analyzed.

The analyzes were carried out in the laboratory of the state enterprise Povodí Vltavy s.p. The purpose of the analysis was to determine the concentrations of pharmaceutical substances. 43 pharmaceutical substances were monitored and, for some of them, also selected metabolic products, too.

Irrigation water, plant biomass and soil were analyzed. Particularly above-ground green parts of plants, i.e., stems and leaves, especially roots and fetus, were tested. The purpose of this breakdown was to find out which active substances are capable of transporting to higher parts of the plants. Another reason was the effort to prove the possibility of sorption of active substances on soil particles.

The analysis was carried out in a liquid chromatography system with triple quadrupole triple spectrometer detection according to EPA Method 1694: Pharmaceuticals and Personal Care Products in Water, Soil, Sediment, and Biosolids by HPLC / MS / MS.

The analysis of pharmaceuticals content in solid samples was preceded by double extraction. The amount of solid material (lyophilized and ground) for the extraction was 0.25 g (five decimal places). The first extraction was in an acetonitrile solution for 30 minutes in an ultrasonic bath. This was followed by centrifugation for 10 minutes in a centrifuge at 3500 rpm. The extract obtained was pipetted off. The second extractant was diluted formic acid. The course of the second extraction coincides with the first extraction. The extracts obtained were pooled, re-centrifuged and diluted so that the expected result was within the calibration range, i.e., up to 3000 ng/L. The amount of sample thus prepared, which was injected into a liquid chromatograph column, was 500 µl. A mixture of water and methanol was used as the mobile phase in liquid chromatography. Substance identification was performed in a mass spectrophotometer where the ion source was an electrospray and a triple quadrupole ion separator.

Results and Discussion

Radish growth rate can be described as follows: Day 1 seeds seed. Day 3 sprouts above soil level can be observed. Day 11 the plants are about 3 cm high and have two leaves. Day 15 the plants are about 5 cm to 7 cm high. Day 22 the plants begin to form fetus. Day 28 the fetus has a diameter of 0.8 cm.

There was no evidence of plant wasting throughout the growth of the plants. Thus, it can be stated that the substances contained in the irrigation water did not act as inhibitors.

Figure 2 brings a graph representing the concentrations of the individual pharmaceutical substances in the irrigation water during the first and second experiment (index 1 and 2).

Figure 3 shows a graph representing the concentrations of the individual pharmaceutical substances in the solid materials, i.e., in the stalks + leaves, in the fetus + roots, in the soils. The graph summarizes the results the first and second experiment.

The measured concentrations (either in plant biomass or in soil) are up to 10 µg/kg (dry matter). Such low values often balance at the limit of determination. In addition, all concentrations in the solid matrix were related to biomass dry matter, which is only about 5% of the weight of the live plant.

Only gabapentin results were different. It was found both in soil and throughout the plant. The concentration of gabapentin was significantly higher than that of the other active substances. It dominates mainly in the above-ground parts of plants. The active substance tramadol is shown equally willing to penetrate into plant biomass. However, the concentrations recorded are far from those of gabapentin. Tramadol concentrations in the dry matter range in the order of units to tens of µg/kg dry matter.

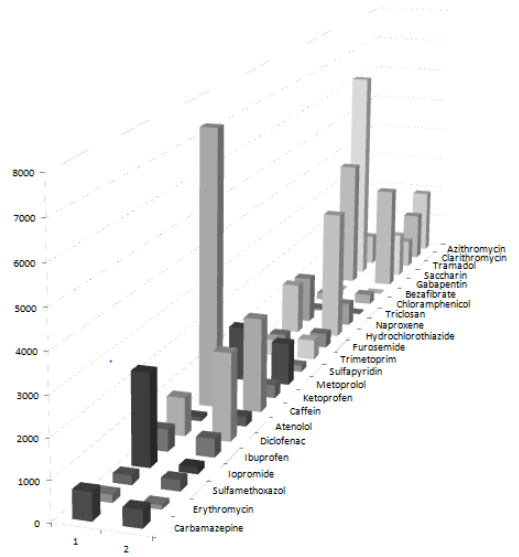


Figure 2: Results of pharmaceutical substance concentrations in irrigation water in experiments 1 and 2

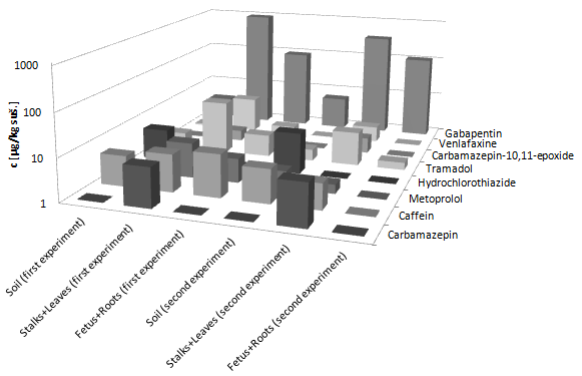


Figure 3: Results of pharmaceutical substance concentrations in solids

Conclusions

The presence of active pharmaceutical substances in irrigation water did not cause death or other damage to the plants. The measured concentrations of active substances in plants and soil were just only above the limit of determination. The exception was gabapentin. Its concentration has reached up to 1000 µg/kg of dry matter. This study should be seen as an example of risk assessment tests which will be required by new EU regulation on water reuse. More studies will be needed to determine the acceptable limits for active pharmaceuticals substances in irrigation water. Tertiary treatment of secondary effluents will be necessary before wastewater reuse in agriculture irrigation in order to reduce further down concentrations of pharmaceuticals like gabapentin.

Acknowledgement The research described in this paper was financially supported by the Technological Agency of the Czech Republic, project No. TH03030080 "*Wastewater reuse in water management of the cities of the future*".

References

Anastasis, Ch.; Popi, K.; Evroula, H.; Costas, M.; Despo, F. (2017) Long-term wastewater irrigation of vegetables in real agricultural systems: Concentration of pharmaceuticals in soil, uptake and bioaccumulation in tomato fruits and human health risk assessment. Water Research [Online] , 109,24-34. https://www.sciencedirect.com/science/article/pii/S0043135416308788 (accessed March 04, 2018).

Al-Farsia, R. S.; Mushtaque, A.; Al-Busaidia, A.; Choudri, B. (2018) Translocation of pharmaceuticals and personal care products (PPCPs) into plant tissues: A review. Emerging Contaminants [Online], 1-6. http://www.keaipublishing.com/en/journals/ emerging-contaminants.

EPA Method 1694: Pharmaceuticals and Personal Care Products in Water, Soil, Sediment, and Biosolids by HPLC / MS / MS. EPA-821-R-08-002 December 2007.

Kodešová, R.; Klement, A.; Kočárek, M.; Fér, M.; Nikodem, A.; Grabic, R.; Golovko, O.; Koba, O. (2018) Chování léčiv v půdním prostředí a jejich vstřebávání rostlinami. In Sborník přednášek ze semináře, Nové postupy a metody při provozování čistíren odpadních vod; , Ed.; ISBN: 978-80-86022-86-0: Moravská Třebová, 10. -11. 4. 2018, 2018; pp 24–33.

Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on minimum requirements for water reuse. Brussels, COM 2018/0169 (COD)

Urban raw or treated wastewater drip-irrigation for lettuce and leek crops: chemical and microbiological properties of soil and plants

Annabelle Mange[1], IRSTEA UMR GEAU[1], University Montpellier[1], Montpellier[1], France[1]; Nathalie Wéry[2], LBE[2], University Montpellier[2], INRA[2], Narbonne[2], France[2]; Nassim Ait-Mouheb[1]

Abstract:

The aim of this study is to evaluate chemical and microbiological properties of soil, as well as crop yields, when lettuces and leeks are irrigated by raw wastewater (RW), treated wastewater (TW) and drinking water (DW) while in a greenhouse. After 2 lettuce and 1 leek growth cycles, the soil analyses showed an increase of electrical conductivity (EC), Cl, Na and nitrate-nitrogen concentration (NO_3-N) after irrigation with TW and particularly with RW compared to DW. The fresh weight of both crop yields was significantly higher with TW compared to DW and RW irrigation. The decay of fecal indicators (*E. coli*, *Enterococcus* sp., bacteriophages) in soils was slow, as shown by cultivation-based techniques and qPCR. Fecal indicators were found in plants irrigated with raw wastewater.

Keywords: soil proprieties; drip irrigation; crop yields; fecal indicator bacteria

Introduction

Several studies related to the use of treated wastewater in agriculture have been developed for different crops including some eaten raw, such as lettuce (Urbano et al. 2017), eggplant and tomato (Cirelli et al. 2012). There are many benefits to using treated wastewater for irrigation such as increased soil nutrients, increased crop yield and reduction in fertilizer quantity. However, there are also numerous disadvantages e.g. soil salinization, damage of sensitive crops, loss of soil infiltration capacity and contamination by pathogens (Nogueira et al, 2013). These different studies focus mainly on high quality wastewater treatment cases and rarely assess the impact of low-treatment or raw wastewater, which covers the majority of water reuse in the world (Theboa et al. 2017).The aim of study is to analyze the effects of using three different types of wastewater: treated wastewater (TW), raw wastewater (RW) and drinking water (DW) to irrigate lettuces and leeks. We take into account various factors: chemical and microbiological properties of soil, crop yields and possible

transfer of microbial contaminants by measuring the concentration of fecal indicators in the roots and in the edible parts of the vegetables.

Material and Methods

The experiment conducted in a greenhouse at a wastewater treatment plant (treatment process with 3 waste stabilization ponds) in Murviel-Lès-Montpellier, France. The mean temperature and relative humidity during all test cycles were 27.2 ± 7.2 °C and 54 ± 21.7 % respectively. Global radiation varied between 463 MJ $month^{-1}$ (in June) and 696 MJ $month^{-1}$ (in July). In order to avoid field contamination, large bins (surface equal to 1 m^2) filled with a loamy clay soil (24% of clay, 25.6% of silt, 19.5% of very fine sand, 16.4 % of fine sand and 14.4 % of sand) were used to cultivate 16 Batavia lettuces (*Lactuca sativa*; four lettuces per bin) and 64 leek plants (*Allium porrum*; 16 leeks per bin). Lettuces and leeks were irrigated by 3 different water qualities: drinking water (DW), treated wastewater (TW) and raw wastewater (RW) which was pumped from the entrance of an anaerobic pond. To keep plants watered, humidity was controlled using time domain reflectometry sensors. A surface drip irrigation was installed at each lettuce and leek plant and a nominal flow rate equal to 2 $L.h^{-1}$ (at P=1bar) was used. Between June and September 2018, lettuce crops were cultivated for two cycles of 6 weeks and leeks for one cycle of 14 weeks. The total water irrigation for lettuce cycle 1 and cycle 2 was 52 mm and 58 mm respectively. For leeks, total irrigation was 198 mm.

Irrigation water analyses

Physico-chemical analyses of water quality were carried out weekly on each of the three water types. Total Suspended Solids (TSS), electrical conductivity (EC) and pH, nitrate and ammoniac nitrogen (NO_3-N, NH_4-N) and phosphorus (P) concentrations were measured. Macronutrient concentrations (Ca, Mg, Na, K) were analyzed once per crop cycle by an external lab (AUREA laboratory).Chemical properties analyzed for three types of water are given in Table 1. Electrical conductivity is higher for RW and TW compared to DW. This is probably related to the higher concentration of Ca, Mg, K, Na, Cl, and P in RW and TW.

Microbiological analyses using culturing techniques were performed by an external accredited laboratory (Eurofins). The concentration of *E. coli*, fecal streptococci, RNA-bacteriophages and spores of sulfite-reducing anaerobes were determined

following NF EN ISO 9308-3, NF EN ISO 7899-1, NF EN ISO 10705-1 and NF EN 26461-1 norms respectively.

Table 1: Chemical characteristics of drinking water (DW), treated wastewater (TW) and raw wastewater (RW).

Parameters	Units	DW	TW	RW
EC at 20°C	mS cm^{-1}	0.56 ± 0.16	1.28 ± 0.15	1.39 ± 0.10
$N\text{-}NO_3$	mg L^{-1}	0.4 ± 0.49	0.59 ± 0.17	0.98 ± 0.12
P	mg L^{-1}	0.57 ± 0.09	6.97 ± 1.49	7.80 ± 3.08
Cl	mg L^{-1}	41.68	120.1	168.84
$N\text{-}NH_4$	mg L^{-1}	0.39 ± 0.16	28.40 ± 0.17	33.4 ± 7.5
K	mg L^{-1}	1.03	20.21	24.79
Mg	mg L^{-1}	7.18	13.15	14.51
Ca	mg L^{-1}	51.74	93.26	82.49
Na	mg L^{-1}	18.95	83.68	125.34
SAR	meq L^{-1}	2.55	8.37	13.23

SAR: Sodium adsorption ratio

Soil analysis and crop yield

Various chemical parameters of soil (between 0-30cm depth) were evaluated by external lab (AUREA laboratory), before and after each growing cycles: pH, Organic matter (OM), EC, Ca, K, Mg, Na, P, NO_3-N, NH_4-N, total nitrogen (N), Cl, carbonate (CO_3), bicarbonate (HCO_3). Taking into account the water and initial soil analyses, results show the NPK concentration was not enough for plant demands. An inorganic fertilizer (to avoid bacterial contamination) of ammo nitrate 33.5% and phosphorus potassium 25% was placed in each bin before planting (Müller-Schärer (1996)) leeks and lettuces. The two crop yields were compared by measuring the fresh and dry weight of lettuces and leeks. Diameter of lettuces was measured weekly.

Microbiological analyses on soil samples

Samples of 50 g of topsoil (first 10 cm) were sent to an external accredited laboratory (eurofins) for analyses of fecal indicators by culturing techniques, according to the NF EN ISO 7899-1 norm for fecal streptococci, NPP method for E. coli and NF EN ISO 10705-1 for RNA-bacteriophages. For molecular analyses, samples of the topsoil of each bin were collected and immediately processed: a subsample of 0.3-0.4g was taken and frozen in dry ice before being stored at -20°C in the laboratory. Genomic

DNA of soil samples was extracted using the FastDNA SPIN kit for soil from MP Biomedicals. The number of *E. coli* was quantified by qPCR using a TaqMan system targeting the *uid A* gene that codes for β-glucuronidase (Frahm and Obst, 2003). Illumina sequencing for analysis of the bacterial community in soil was performed as reported in Lequette et al. 2019.

Results and Discussion

Irrigation water quality impacts on soil

An increase in EC and cumulative concentrations of Na and Cl was observed in the soil after irrigation (Tab. 2) for both lettuces and leeks, with TW and especially RW.

Table 2: Chemical characteristics of soil before planting and after the end of irrigation cycles by (DW), (TW) and (RW).

			Lettuces (After 2 Cycles)			Leeks (After 1 Cycle)		
Parameters	Units	Before planting	DW	TW	RW	DW	TW	RW
EC	mS/cm	0.13 ± 0,01	0.21	0.37	0.4	0.2	0.26	0.41
NO_3-N	mg/kg	7.20 ± 1,90	29.2	64.9	96.6	2.2	45	44.1
NH_4-N	mg/kg	0.43 ± 0,23	2.9	4.7	4.1	3.7	1.6	4.7
Na	mg/Kg	13.23 ± 1,93	40	172.8	150.5	46.5	232.3	249
Cl	mg/kg	44.67 ± 2,31	135	283	320	151	253	313

EC: electrical conductivity;

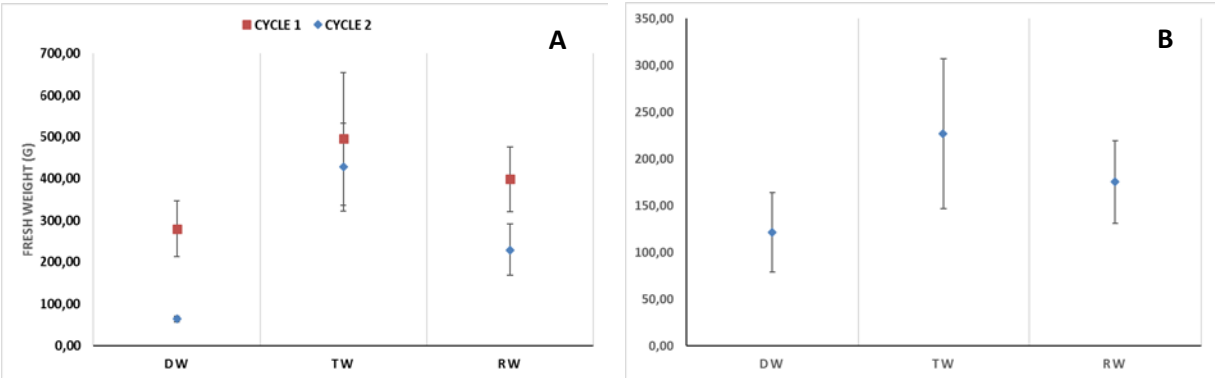
Soil nitrogen concentration is higher for TW and RW compared to DW in both crops but with higher values for the lettuce, probably due to lower nitrate requirements. Moreover, the increased in NO_3-N concentration in the soil is more pronounced than in NH_4-N, which is likely caused by the nitrification process. This accumulation can be explained by the soil proprieties; loamy clay soil used here has low hydraulic conductivity, which promotes element accumulation in the top (0-30 cm) soil layer (Musazura et al. 2019).

Wastewater irrigation effect on crops

Concerning crop yields after two lettuce cycles, Fig.1 shows the fresh weight of the lettuces and leeks after harvest. DW irrigation has less of an effect on fresh weight compared to TW and RW treatments. Leeks irrigated with DW have a smaller fresh mass compared to TW and RW. This can be explained by higher ammonium nitrogen (NH_4-N) concentration in wastewaters. During the RW irrigation we also observed

damage on those lettuce leaves in contact with the soil. This damage was probably caused by the high Na and Cl concentrations in raw wastewater.

Figure 1: Comparison of the fresh weight after lettuce (A) and leek (B) harvest.



Monitoring of fecal indicators in water, soil and plants

Fecal indicator bacteria and bacteriophages were monitored only in bins irrigated with RW. In July, RW contained in average 10^6 *E. coli*/100 mL and 10^5 fecal streptococci/100 mL (MPN).

Table 3: Concentration of E. coli and fecal streptococci sp. in soil (1h and 4h after an irrigation event by RW)

		E. coli (NPP/g)	*Fecal streptococci (NPP/g)*
bin1, replicate 1	1h	$5{,}8 \times 10^2$	$1{,}9 \times 10^2$
	4h	$2{,}6 \times 10^2$	$2{,}5 \times 10^2$
bin1, replicate 2	1h	$1{,}2 \times 10^3$	$1{,}8 \times 10^2$
	4h	$2{,}6 \times 10^3$	$5{,}0 \times 10^2$
bin2, replicate 1	1h	$5{,}8 \times 10^1$	$5{,}8 \times 10^1$
	4h	detected, $<5{,}6 \times 10^1$	detected, $<5{,}6 \times 10^1$
bin2, replicate 2	1h	$1{,}8 \times 10^2$	$5{,}6 \times 10^1$
	4h	$1{,}8 \times 10^2$	$1{,}2 \times 10^2$

Analyses of soils samples collected 1h and 4h after irrigation showed that concentration of *E. coli* and *Enterococcus* sp. in soil remain stable, indicating that an extended time period (>4h) is necessary to inactivate the fecal bacteria (Table 4). Vergine et al. (2015) also showed that in the first two days after a fecal contamination event (under dry conditions) the reduction observed in the topsoil was less than half an order of magnitude. *E. coli* was found to contaminate roots of lettuces (at concentration of 10-30 CFU/g fresh material) and roots of leeks (10^2-10^3 CFU/g) but fecal streptococci were below quantification limits in the same samples. Fecal streptococci were detected in one sample of lettuce leaves at low concentration,

which may be linked to internalization, although this hypothesis needs to be further investigated.

Conclusion

The rate of die-off of fecal bacteria was slow in topsoils irrigated with RW under experimental conditions. Although preliminary, contamination by fecal indicators of plants irrigated by RW was observed. Irrigation with TW and RW induced an increase of nitrogen in the soil. However, this concentration was not enough to meet the nutritive demands of plants, so fertilizer must be added. Lettuces and leeks irrigated with RW had a better yield in comparison with DW and those irrigated with TW even more so.

Acknowledgements

The authors gratefully acknowledge the financial support of Water RMC Agence (France), project ‘Experimental platform for the reuse of treated wastewater in irrigation, Murviel-Lès-Montpellier’ and H2020 Mad4Water project.

References

Cirelli, G. L., S. Consoli, F. Licciardello, R. Aiello, F. Giuffrida, et C. Leonardi. 2012. « Treated municipal wastewater reuse in vegetable production ». *Agricultural Water Management* 104 (février): 163‑70. https://doi.org/10.1016/j.agwat.2011.12.011.

Frahm, E and Obst, U. 2003."Application of the fluorogenic probe technique (TaqMan PCR) to the detection of Enterococcus spp. and Escherichia coli in water samples *Journal of Microbiological Methods*, 52 (1) : 123-131,

Lequette, K., Ait-Mouheb, N., & Wéry, N. (2019). Drip irrigation biofouling with treated wastewater: bacterial selection revealed by high-throughput sequencing. *Biofouling*, *0*(0), 1–13. https://doi.org/10.1080/08927014.2019.1591377

Müller-Schärer, Heinz. 1996. « Interplanting ryegrass in winter leek: effect on weed control, crop yield and allocation of N-fertiliser ». *Crop Protection* 15 (7): 641‑48. https://doi.org/10.1016/0261-2194(96)00033-6.

Musazura, W., A. O. Odindo, E. H. Tesfamariam, J. C. Hughes, et C. A. Buckley. 2019. « Nitrogen and phosphorus dynamics in plants and soil fertigated with decentralised wastewater treatment effluent ». *Agricultural Water Management* 215 (avril): 55‑62. https://doi.org/10.1016/j.agwat.2019.01.005.

Nogueira, S. F., Pereira, B. F. F., Gomes, T. M., de Paula, A. M., dos Santos, J. A., & Montes, C. R. (2013). Treated sewage effluent: Agronomical and economical aspects on bermudagrass production. *Agricultural Water Management*, *116*, 151–159. https://doi.org/10.1016/J.AGWAT.2012.07.005

Thebo, A. L., Drechsel, P., Lambin, E. F., & Nelson, K. L. (2017). A global, spatially-explicit assessment of irrigated croplands influenced by urban wastewater flows. *Environmental Research Letters*, *12*(7). https://doi.org/10.1088/1748-9326/aa75d1

Thicoipe, Jean-Pierre. 1997. *Laitues*. Ctifl. Monographie.

Urbano, Vanessa Ribeiro, Thaís Grandizoli Mendonça, Reinaldo Gaspar Bastos, et Claudinei Fonseca Souza. 2017. « Effects of treated wastewater irrigation on soil properties and lettuce yield ». *Agricultural Water Management* 181 (février): 108‑15. https://doi.org/10.1016/j.agwat.2016.12.001.

IMPACT OF TREATED WASTEWATERS REUSED FOR IRRIGATION IN STRAWBERRY CULTIVATION

Ester Coppini[1], Donatella Fibbi[1], Roberto Camisa[1], Maria Concetta Bruzzoniti[2], Edgardo Giordani[3], Luca Rivoira[2], Michele Castiglioni[2], Massimo Del Bubba[4]

[1]GIDA S.p.A, Via Baciacavallo 36, 59100, Prato, Italy
[2]Department of Chemistry, University of Turin, via P. Giuria 7, 10125, Turin
[3]Department of Agri-Food and Environmental Science, University of Florence, via delle Idee 30, 50019, Sesto Fiorentino, Florence
[4]Department of Chemistry "Ugo Schiff", University of Florence, via della Lastruccia 3, 50019, Sesto Fiorentino, Florence

Agriculture is characterized by a high-water demand. Indeed, about 70% of worldwide freshwater (FW) withdrawals is used for agricultural irrigation. Limited FW availability is a problem of increasing concern also exacerbated by climate-related impacts. In this regard, it should be also remarked that a strong inverse correlation between the volume of FW available in a certain country and the quantity of food imported by that country has been highlighted. In the last decades, a growing attention has been devoted to search alternative sources of water for agriculture, also in view of saving high-quality waters for human consumption.

The reuse of treated wastewater (TWW) for irrigation could be an efficient tool for reducing water shortage. However, the TWW reuse is currently far to be fully realized, due to several barriers, such as potential risks for the environment and the human health and social acceptability.

The research herein presented reports the main results obtained within the "IRRIGATIO" Project (grant 13-069 under the ERANET MED 2014 call), dealing with the evaluation of the possible transfer of the residual chemical contamination from TWWs reused for irrigation purposes for F*ragaria x ananassa* strawberry (cv. Camarosa).

Four wastewater treatment plants (WWTPs) managed by the company GIDA (Prato, Italy) were chosen to provide the treated wastewaters for crop irrigation. In detail, TWWs from the following facilities were analyzed to evaluate the presence of residual

PAHs and PCBs: Baciacavallo plant (TWW1) and its polishing systems which refine Baciacavallo effluent wastewater before entering in the industrial aqueducts of textile districts “Macrolotto 1” (TWW2) and “Macrolotto 2” (TWW3); Calice WWTP (TWW4). Fresh water, coming from drinking water, was also tested as the control.

Chemical contamination indicators (PCBs, including dioxin-like congeners and PAHs, perfluoroalkyl acids, ethoxylated alkylphenols and alkylphenols) were monitored along the whole agricultural production chain (TWW, soil and food) in order to unequivocally assess the impact of the wastewater reuse practice under a wide spectrum of experimental conditions.

Results clearly show the absence of propagation of residual contamination still present in treated waters.

References

[1] WWAP (United Nations World Water Assessment Programme) 2014. The United Nations World Water Development Report 2014: Water and Energy. Paris, UNESCO.

[2] Yang H. et al. Environmental Science & Technology 37 (2003) 3048 - 3054.

[3] Toze S. Agric. Water Management 80 (2006) 147–159.

High Yield and Nutritional Quality of Forage Rice (*Oryza sativa*) Achieved by Continuous Irrigation of Treated Municipal Wastewater without Synthetic Fertilizers in Pilot- and Real-Scale Experiments

Hiroyuki Arichi, Department of Water Supply and Sewerage Systems, Tsuruoka City Government, Tsuruoka, Japan; Toru Watanabe, Faculty of Agriculture, Yamagata University, Tsuruoka, Japan; Luc Duc Phung, The United Graduate School of Agricultural Sciences, Iwate University, Morioka, Japan; Hiroyuki Kato, NICHe, Tohoku University, Sendai, Japan; Dung Viet Pham, Faculty of Agriculture, Yamagata University, Tsuruoka, Japan; to-ru@tds1.tr.yamagata-u.ac.jp

Abstract:

Our newly-introduced rice cultivation method employing continuous irrigation with treated municipal wastewater (TWW) has already been demonstrated to be able to produce high yields of protein-rich rice without chemical fertilizers. This study represents for the first time the successful adoption of the method on a real paddy field under the management of a local farmer. Results have shown that the field continuously irrigated with TWW produced higher yield (6.6 t ha^{-1}) and superior rice protein content (9.7%) compared with that (5.6 t ha^{-1} and 6.6%, respectively) observed in a conventional field. This study has put the new cultivation method targeted for the effective reuse of TWW into practice, significantly contributing to the promotion of the feed rice production campaign in Japan.

Keywords: effective reuse of treated municipal wastewater; continuous irrigation system; protein-rich rice; feed rice production campaign

Introduction

Cultivation of rice (*Oryza sativa* L.) has been challenged by increasing water shortage while large amounts of treated municipal wastewater (TWW) are conventionally discharged from wastewater treatment plants (WWTPs) into the environment. Reuse of TWW to irrigate rice paddies, thereby, has been considered a positive measure to diminish the water scarcity, alleviate degradation of wastewater-receiving environments, and conserve other freshwater resources (Toze, 2006). In addition, irrigation with TWW is conducive to major advantages in the improvement of soil fertility and rice productivity while reducing the use of commercial fertilizers (Jung

et al., 2014) as a result of substantial amounts of plant nutrients such as N, P, K, and organic matter contained in TWW.

Our preliminary studies have been carried out to develop an innovative rice cultivation system employing continuous irrigation with TWW for effective recycling of the valuable nutrients and water sources from WWTPs without adverse impacts on rice plants, paddy soil, and surrounding environments (Phamt et al., 2017). Recently, feasible adoption of the system to promote sustainable production of feed rice has been assessed in northern Japan through a number of pilot-scale experiments, in which constructed arable plots simulating paddy fields were continuously irrigated with TWW either through an underground pipe (Sub-irrigation) or on the soil surface (Surface irrigation) (Tran et al., 2019). Results from the pilot-scale experiment in 2017 crop season (Table 1), for instance, showed that without supplementation of chemical fertilizers, continuous irrigation with TWW could produce high grain yields (7.1–7.5 t ha^{-1}) that were comparable with the average rice yield obtained in the local paddies (7.3 t ha^{-1}) conventionally fertilized with the fertilizers and irrigated with channel water (Tran et al., 2019). Specially, in term of nutritional quality of brown rice, rice protein contents observed in our test fields (11.6–13.1%) were superior compared with the standard value (8.8%) of rice for animal feed in Japan without significant accumulation of heavy metals (Cu, Zn, Cr, Cd, Pb, and As) in the rice (Tran et al., 2019). In addition, the continuous irrigation systems have been demonstrated to effectively decrease the amount of nutrients, especially N, discharged from WWTPs and rice paddies into surrounding water bodies (Tran et al., 2019), suggesting a reliable cost-effective alternative to treatment of the N-rich effluents.

Table 1 Computed yield, protein content (mean±SD, n=5) and real yield of brown rice harvested in the pilot-scale fields with different irrigation methods (Tran et al., 2019). Different small letters for each parameter indicate a significant difference ($p<0.05$) between the irrigation methods.

Irrigation method	Real yield (t ha^{-1})	Computed yield (t ha^{-1})	Protein (%)
Sub-irrigation	7.5	8.6±0.6 [a]	11.6±0.4 [a]
Surface irrigation	7.1	8.7±0.8 [a]	12.0±0.8 [a]

Based on the aforementioned positive findings, we got an opportunity to implement our continuous TWW irrigation system on a real paddy field with the help of a local farmer. This present study reports for the first time performance of the continuous irrigation system on real fields. The objective was to assess plant growth, grain yield, and nutritional quality of feed rice as influenced by the continuous TWW irrigation without supplementation of chemical fertilizers in contrast with those observed in a normal paddy managed by conventional irrigation and fertilization practices.

Material and Methods

A field experiment was carried out from May to September 2018. Two rice paddies, each has an area of 3,000 m^2 (Figure 1), located near a municipal WWTP (38°45' 31" N, 139° 50' 50" E) in Tsuruoka City, Japan were chosen for this study. The two fields were assigned to apply either of two cultivation methods: (1) continuous TWW irrigation without chemical fertilizers or (2) conventional practices of channel water irrigation and application of the fertilizers. In the paddy irrigated with TWW (Test field), TWW from the WWTP was continuously supplied on the soil surface without blending with other water sources at a flow rate of 0.08 m^3 h^{-1} adopted from Tran et al. (2019) to maintain a water level of 5 cm. The TWW was supplied into the paddy on one side, overflowed on the soil surface, and liberally outflowed from the opposite side of the paddy (Figure 1 a).

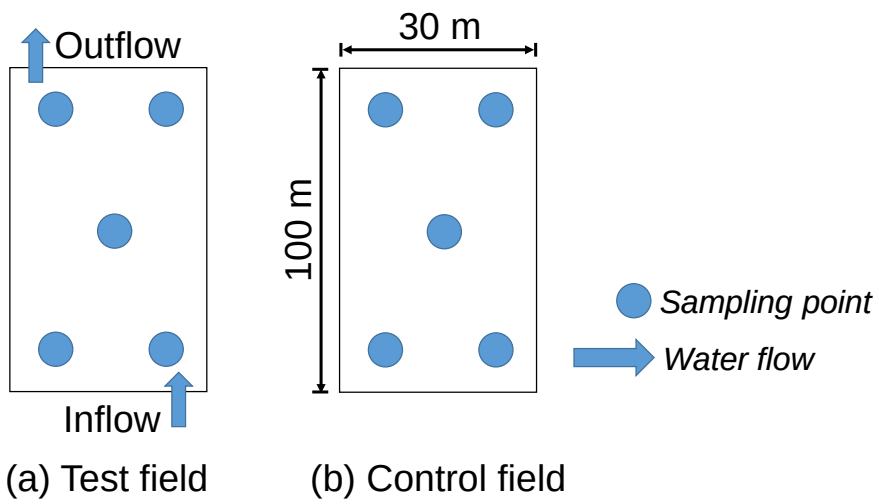


Figure 1 Schematic illustration of the test and control fields.

In the paddy employing the conventional practices (Control field), channel water was irrigated occasionally to maintain water levels of 1–5 cm according to

evapotranspiration and commercial fertilizers ($N:P_2O_5:K_2O$ = 56:56:56 kg ha^{-1} for basal and $N:P_2O_5:K_2O$ = 14:14:14 kg ha^{-1} for top-dressing) were applied. A feed rice cultivar, namely Yumeaoba, was used for transplantation at the density of 30 × 22 cm in both fields in the middle of May and harvested at the end of September. During the crop season, experimental data on plant growth characters, grain yield and nutritional quality of rice were collected in 5 representative sampling points (Figure 1) as described by Tran et al. (2019). Student's t-test was used to statistically compare examined parameters observed from the two experimental fields.

Results and Discussion

Growth of rice plants

The rice plants responded similarly to the examined cultivation systems for most of their growth parameters (Table 2). Plant height and leaf greenness (SPAD value) were statistically similar in both fields, while tiller number of the test field was 20% higher than that of the control field. The field irrigated with TWW likely produced more biomass (7.1 t ha^{-1}) than the control (6.4 t ha^{-1}). This tendency along with the higher tiller number were probably the results of a higher mass load of N input from the continuous TWW irrigation (Tran et al., 2019), though this difference was not statistically significant ($p>0.05$).

Table 2 Maximum values (mean±SD, n=5) of plant height, leaf greenness (SPAD value) and tiller number, and shoot dry matter in the test and control fields. Different small letters for each parameter indicate a significant difference ($p<0.05$) between two fields.

Experimental field	Plant height (cm)	SPAD value	Tiller number (tillers m^{-2})	Shoot dry matter (t ha^{-1})
Test	99.5±8.9 [a]	42.9±2.4 [a]	315.8±30.4 [a]	7.1±1.1 [a]
Control	88.6±6.5 [a]	42.8±0.2 [a]	261.6±16.2 [b]	6.4±0.3 [a]

Generally, wastewater or TWW can be considered a fertilization measure due to its high nutrient and organic matter contents that potentially increase soil fertility and

crop productivity (Jung et al., 2014). In this study, the overall similarity in the plant growth parameters in both fields, for instance, the leaf greenness as one important indicator of N status of the rice plants, conveyed that the rice plants were able to assimilate N and other nutrients supplied by TWW in the test field as effectively as the chemical fertilizers applied in the control field.

Grain yield and nutritional quality of brown rice

The average brown rice yield of the field irrigated with TWW (6.6 t ha^{-1}) was about 18% greater than that (5.6 t ha^{-1}) of the control field (Figure 2). Despite this difference was not significant ($p>0.05$), the higher yield archived in the test field, which was not supplemented with exogenous fertilizers, was primarily due to the high nutrient concentrations in TWW. This was in line with previous observations in the rice fields irrigated with TWW/wastewater (Tran et al., 2019; Jung et al.,2014).

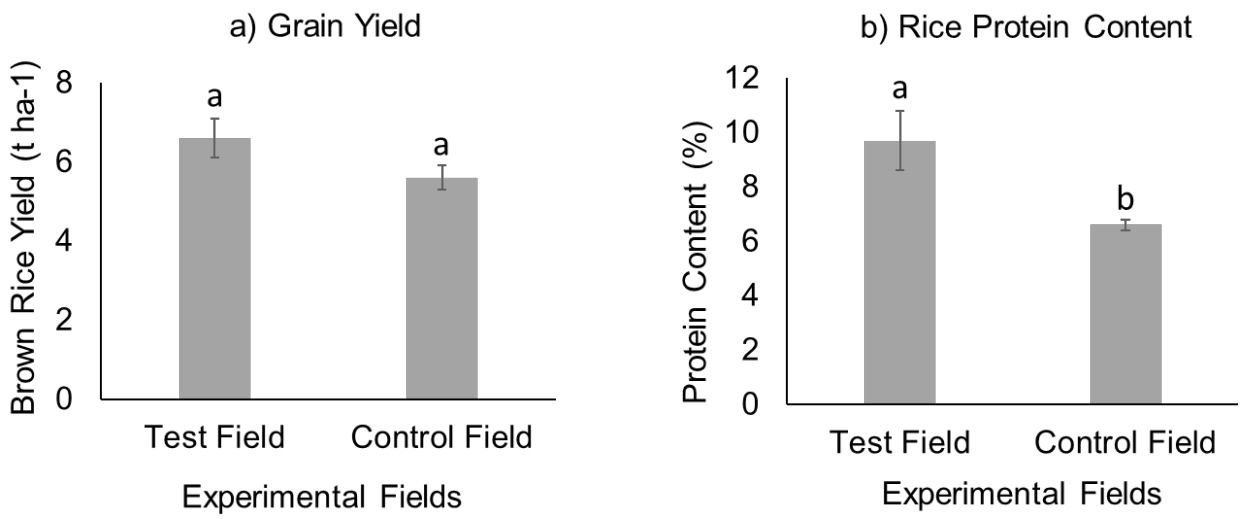


Figure 2 Yield and protein content of brown rice harvested in the test and control fields. Error bars indicate standard deviations (n=5). Different small letters for each parameter indicate a significant difference ($p<0.05$) between two fields.

Grain quality is a critical aspect to be considered as reusing TWW for irrigation. In term of feed rice, grain's protein content is one of the most important nutritional indicators. In comparison with the control field (6.6%), the test field yielded superior protein content (9.7%) that was also significantly higher than the standard value (8.8%) of rice for animal feed in Japan (NARO, 2009). Though high content of protein is undesirable for rice as human food because of its degraded taste, it is not

disadvantage for rice used in animal husbandry but preferable to save the cost by replacing relatively expensive protein feed like soybean partially with this rice. Overall, the results have conveyed that a high yield of protein-rich rice could be successfully produced in the real-scale field through continuous TWW irrigation without exogenous chemical fertilizers, as reported in the pilot-scale fields (Tran et al., 2019).

Conclusions

This study reported for the first time the successful adoption of our newly-introduced continuous irrigation with TWW on a real-scale rice paddy. Ultimately, our study demonstrated the positive evidence that the new cultivation method with reuse of TWW could yield high production and superior nutritional quality of the feed rice under field conditions, and simultaneously reduce the use of chemical fertilizers. The elimination of fertilizers probably brings more benefits to the farmer and decreases the amount of nutrients discharged into the environment. In addition, this study is significant in promoting the feed rice cultivation campaign in Japan, which could increase the self-sufficient feed ratio for domestic dairy farming.

References

Jung K., Jang T., Jeong H., Park S. 2014. Assessment of growth and yield components of rice irrigated with reclaimed wastewater. Agri. Water Manag., 138, 17–25.

National Agriculture and Food Research Organization (NARO) 2009. Standard table of feed compositions in Japan. NARO, Tsukuba.

Pham D. D., Kurashima S., Kaku N., Sasaki A., Pu J. & Watanabe T. (2017). Bottom-to-top continuous irrigation of treated municipal wastewater for effective nitrogen removal and high quality rice for animal feeding. Water Sci. Technol.: Water Supply, 18 (4), 1183-1195.

Toze S. 2006. Reuse of effluent water - benefits and risks. Agri. Water Manag., 80(1-3), 147–159.

Tran D.L., Phung D.L., Pham V.D., Pham D.D., Nishiyama M., Sasaki A., Watanabe T. 2019. High yield and nutritional quality of rice for animal feed achieved by

continuous irrigation of treated municipal wastewater. Paddy Water Environ. https://doi.org/10.1007/s10333-019-00746-x

The HypoWave-System - Nutrient and heavy metal flows within an integrated system of adapted wastewater treatment and subsequent water reuse in a hydroponic system

Alexa Bliedung, TU Braunschweig, Germany; Thomas Dockhorn, TU Braunschweig, Germany; Birgit Fiebig, Abwasserverband Braunschweig, Braunschweig, Germany; Jörn Germer, University of Hohenheim, Stuttgart, Germany; Gudrun Peters, Wolfsburger Entwässerungsbetriebe, Wolfsburg, Germany; Peter Rossmanith, ACS-Umwelttechnik GMBH & Co. KG, Rielasingen-Worbingen, Germany; Arne Wieland, Xylem Services GmbH, Herford, Germany

a.bliedung@tu-braunschweig.de

Abstract:

Within the research project HypoWave the authors investigate a hydroponic system for plant production, which is fed with wastewater that has undergone a specially adapted treatment. The principle aim is to develop a coupled water treatment - hydroponic plant production system, which utilises contained water and nutrients efficiently for marketable biomass production while ensuring high product quality in regard to hygienic safety and low pollutant loads. A pilot facility, comprising technologies such as the activated sludge process, ozonation and biological activated carbon filtration, is used to produce irrigation water of different qualities. This paper focuses on the material flows of nutrients and heavy metals.

Keywords: water reuse, validation, lettuce, mass balance, macro- and micronutrients, heavy metals

Introduction

Agriculture consumes most of the fresh water resources utilised by mankind. Climate change, growing population and urbanization are expected to increase the pressure on water resources, but also on the availability of arable land and nutrients. This makes it increasingly difficult to guarantee food security and to prevent the deterioration of ecosystems. The research project HypoWave investigates purpose oriented treatment and utilization of municipal wastewater in hydroponic systems (HS) for efficient water and nutrient reuse. The cultivation of plants without soil,

where the roots anchor in neutral substrates or extend just into nutrient solution without substrates allow very accurate nutrient management and avoid pollution of bodies of water. HS are already in many countries an important sector of agriculture and their contribution to vegetable and fruit supply is expected to grow further. Currently, however, hardly any scientific knowledge is available on the use of treated wastewater as a nutrient solution. This paper presents first results obtained (focusing on nutrients and heavy metals) using wastewater undergone different treatments as a nutrient solution for lettuce production.

Material and Methods

At the municipal wastewater treatment plant (WWTP) Wolfsburg-Hattorf, Germany, a modularly structured pilot facility was set up to analyse the suitability of differently treated wastewater (Fig. 1) for growing lettuce (*Lactuca sativa* L.) in a HS. An Expanded Granular Sludge Bed Reactor (EGSB) (ACS-Umwelttechnik GMBH & Co. KG), a Sequencing Batch Reactor (SBR) for nitrification, a biological activated carbon filter (BACF) and an ozone reactor (Xylem Services GmbH) are operated in a pilot scale. Further, the effluent of the secondary sedimentation tank (SST) of the WWTP was used. The different treatments were as follows:

- Treatment A: effluent SST WWTP Wolfsburg-Hattorf
- Treatment B: effluent SST WWTP Wolfsburg-Hattorf - ozone reactor
- Treatment C: influent aeration tank - EGSB - SBR (nitrification)
- Treatment D: influent aeration tank - EGSB - SBR (nitrification) - BACF

During the first piloting in 2017, the HS was operated as a flow-through system ($Q_{hS,line}$ = 30 L/h) without any further addition of nutrients (Bliedung et al., 2019). Before the seedlings were planted in the lines (68 plants per line), they were nursed 20 days. All treated wastewater qualities were sampled in an interval of about two to three days for elementary analyses. Lettuce shoots and roots were analysed after harvesting (Tab. 1). The data were used to set up mass balances for macronutrients under consideration of irrigation water and lettuce composition. These mass balances serve to validate the System and the achieved results for plausibility. Tab. 2 and Tab. 3 show the results for a trial period of 38 days. The results include 11-12 random samples of the influent and the effluent of the HS (irrigation water) and eight lettuce plants per line as well.

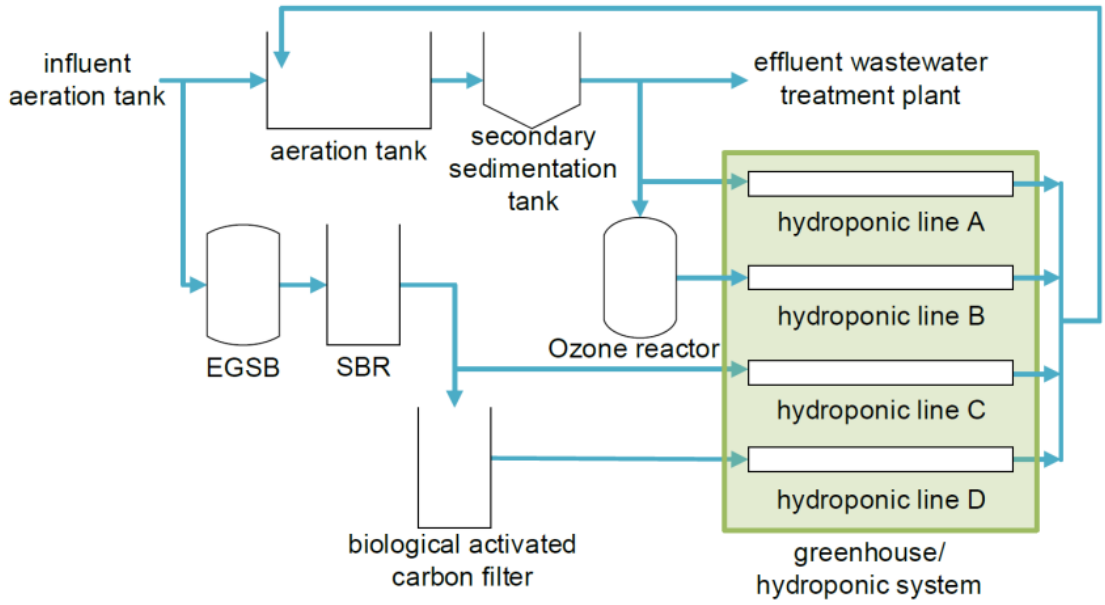


Figure 1: Scheme of the pilot facility during the first piloting in 2017

Table 1: Overview of the methods of analysis.

Sample	Parameter	Analysis
water	P, Ca, Na, Mg, K, S, B, Co, Fe, Al, Mn, As, Pb, Cd, Cr, Cu, Ni, Zn, Hg	ICP-OES (DIN EN ISO 11885 E22:2009-09)
water	N_{tot}, NO_3-N, NO_2-N	Cuvette test Co. Hach-Lange
water	NH4-N	ISE-Sensor NH 500/2; pH/Ion 7310, Co. WTW
lettuce	As, Cd, Co, Cr, Cu, Ni, Pb	ICP-MS (CFH 2019a)
lettuce	B, Cu, Fe, K, Mg, Mn, Na, P, Zn	ICP-OES (CFH 2019b)
lettuce	N, S	EA (CFH 2019c)
lettuce	Hg	KD-AAS (CFH 2019d)
Notation: N_{tot} were analysed in the influent of the aeration tank. For the determination in the irrigation water, the sum of NO_3-N, NO_2,-N und NH_4-N was formed at the other sampling points for the total nitrogen.		

Results and Discussion

Nitrogen and phosphorus were significantly reduced by the biological treatment of the WWTP. In contrast, these elements could be conserved by the treatments C and D to 66 % nitrogen and 58-63 % phosphorus as these treatments were operated without nutrient elimination. Other macronutrient concentrations such as potassium were not lowered by any of the treatments (Tab. 2). The macronutrients considered in the mass balances diverted little from their calculative sum (under 10 %) (Tab. 3). Only line B has higher losses concerning nitrogen. On the one hand, the ozone treatment could have had supported these losses. On the other hand, the lower loads in the

irrigation water compared to lines C and D have to be considered, which could benefit a higher error. Nevertheless, the nitrogen losses are significantly lower than in conventional agriculture. Furthermore, the nutrient load in lettuce C and D is higher than in lettuce A and B. This corresponds to the loads in the irrigation water. However, in order to assess the quality of the lettuces, the concentrations must be taken into account. As represented in Tab. 4, the concentrations of nitrogen and phosphorus in lettuces show similar tendency compared to the loads already presented in Table 3. In addition, the concentration of phosphorus in all lettuces is similar to reference data (e.g. 330 mg P/kg FM, USDA, 2018).

Table 2: Average concentrations of macronutrients in irrigation water in comparison to the influent of the aeration tank.

		N	P	K	Ca	Mg	S
Influent aeration tank	**[mg/L]**	66,8	11,0	24,7	71,8	11,5	28,5
Irrigation water A	**[mg/L]**	1,3	2,7	22,1	72,3	11,3	30,9
Irrigation water B	**[mg/L]**	1,6	2,7	22,1	72,5	11,3	30,9
Irrigation water C	**[mg/L]**	44,1	6,9	24,1	73,8	11,9	24,4
Irrigation water D	**[mg/L]**	43,8	6,4	23,3	72,6	11,9	23,7

Table 3: Mass balances of macronutrients for the "greenhouse-system".

			N	P	K	Ca	Mg	S
water A	**influent hS**	**[g]**	35	74	606	1979	309	845
	effluent hS	**[g]**	23	66	574	1982	307	834
lettuce A		**[g]**	8,9	1,5	19,1	4,7	0,5	0,8
delta A		**[%]**	**7,6**	**9,8**	**2,1**	**-0,4**	**0,3**	**1,3**
water B	**influent hS**	**[g]**	43	74	605	1984	309	846
	effluent hS	**[g]**	21	62	573	1971	304	831
lettuce B		**[g]**	11,6	1,9	22,8	7,0	1,0	0,9
delta B		**[%]**	**22,4**	**13,4**	**1,6**	**0,3**	**1,2**	**1,6**
water C	**influent hS**	**[g]**	1207	189	659	2019	327	668
	effluent hS	**[g]**	1126	176	587	1997	325	637
lettuce C		**[g]**	27,7	3,7	39,4	10,1	1,6	1,7
delta C		**[%]**	**4,4**	**5,0**	**4,9**	**0,6**	**-0,1**	**4,5**
water D	**influent hS**	**[g]**	1198	174	636	1987	325	649
	effluent hS	**[g]**	1207	168	587	1971	321	644
lettuce D		**[g]**	25,4	3,8	33,1	8,9	1,4	1,4
delta D		**[%]**	**-2,9**	**1,7**	**2,6**	**0,4**	**0,8**	**0,6**

Some heavy metals are essential for plant growth at low concentrations in the soil or nutrient solution, but become toxic at higher concentrations. Concentrations of heavy metals in the influent of the aeration tank and the different qualities of treated water, especially of those that are not essential plant nutrients, were low. Except for

chromium and lead all concentrations of non-essential heavy metals in the lettuce remained under the detection limit (Tab. 4). As concentrations toxic to plants are much higher (Shanker et al., 2005) negative impact on the lettuce production is expected. The European Union has defined upper thresholds for cadmium (200 µg Cd/kg FM) and lead (300 µg Pb/kg FM) in vegetables (Commission Regulation (EC) No 1881/2006). Therefore, none of the detected values implies any restriction for human consumption.

Table 4: Average concentrations of selected nutrients and heavy metals in plants.

			lettuce A	lettuce B	lettuce C	lettuce D
macro-nutrients	N	[mg/ kg FM]	1 624	1 668	2 221	2 496
	P	[mg/ kg FM]	268	275	300	374
	K	[mg/ kg FM]	3 476	3 268	3 160	3 254
	Ca	[mg/ kg FM]	861	1 001	813	870
	Mg	[mg/ kg FM]	100	140	126	136
	S	[mg/ kg FM]	153	131	140	136
micro-nutrients	B	[µg/ kg FM]	1.749	1 466	1 128	1 330
	Cu	[µg/ kg FM]	149	350	273	89
	Fe	[µg/ kg FM]	4 886	5 274	3 547	5 401
	Mn	[µg/ kg FM]	4 310	7 861	4 300	599
	Ni	[µg/ kg FM]	9	15	8	24
	Zn	[µg/ kg FM]	3 514	5 397	3 514	2 371
heavy metals	As	[µg/ kg FM]	< 3	< 3	< 2	< 3
	Cd	[µg/ kg FM]	< 3	< 6	< 3	< 3
	Co	[µg/ kg FM]	< 3	< 3	< 2	< 3
	Cr	[µg/ kg FM]	37	87	37	63
	Hg	[µg/ kg FM]	< 3	< 3	< 2	< 2
	Pb	[µg/ kg FM]	8	12	8	24

Conclusions

The results demonstrate that a hydroponic system can be operated successfully with nutrient solutions produced from wastewater. Using mass balances enabled both to validate the system and to show that the losses of nutrients are negligible. Furthermore, the nutrient uptake does not depend only on the availability, but also on the treatment process themselves. This applies to heavy metals, too. However, with the small sample size, caution must be applied. Therefore further investigations are necessary for the comparison and reproducibility of these results.

Acknowledgements

The authors would like to thank the German Federal Ministry of Education and Research for funding the research project “HypoWave – New Pathways Towards Wastewater Re-Use in Agriculture” (grant number: 02WAV1402).

References

Bliedung A., Dockhorn T., Ebert B., Germer J., Mohr M., Schramm E., Winker M. (2019). HypoWave - Ressourceneffiziente Nutzung von gereinigtem Abwasser in hydroponischen Systemen. Zbl. Geol. Paläont. Teil I, Jg. 2019, H. 1, 95-104.

CFH (2019a): Core Facility Hohenheim - Elements with ICP-MS - Method description, accessed 26 April 2019, https://cfh.uni-hohenheim.de/en/icp-ms

CFH (2019b): Core Facility Hohenheim - Elements with ICP-OES - Method description, accessed 26 April 2019, https://cfh.uni-hohenheim.de/en/icp-oes

CFH (2019c): Core Facility Hohenheim - Element-Analysis - Method description, accessed 26 April 2019, https://cfh.uni-hohenheim.de/en/elem-analysis

CFH (2019d): Core Facility Hohenheim - Mercury - Method description, accessed 26 April 2019, https://cfh.uni-hohenheim.de/en/mercury

Commission Regulation (EC) No 1881/2006 of the commission of the 19. December 2016 for setting maximum levels for certain contaminations in foodstuffs, official Journal of the European Union, p 5-24

DIN EN ISO 11885 E22:2009-09, Wasserbeschaffenheit - Bestimmung von ausgewählten Elementen durch induktiv gekoppelte Plasma-Atom-Emissionsspektrometrie (ICP-OES) (ISO 1188:2007); Deutsche Fassung EN ISO 11885:2009

Shanker A. K., Cervanted C., Loza-Tavera H., Avudainayagam S. (2005): Chromid toxicity in plants. Environmental International, 31 (5), 739-753.

USDA (2018): National Nutrient Database for Standard Reference - Full Report (All Nutrients) 11250, Lettuce, butterhead (includes boston and bibb types), raw; [online] https://ndb.nal.usda.gov/ndb/foods/show/11250 [09.04.2019].

Quantitative microbial risk from wastewater reuse for irrigation in a peri-urban setting

Jennifer Weidhaas, University of Utah, Salt Lake City, United States;
McKinley Olsen, University of Utah, Salt Lake City, United States

Municipal wastewater treated by sedimentation, activated sludge, membrane bioreactor and UV disinfection is distributed to approximately 8,000 residents of Hyrum, Utah, USA for use outside the home for irrigation. The reclaimed wastewater is not chlorinated prior to distribution. Surveys of 200 households in Hyrum indicated 75% of the households used the reclaimed water to irrigate their fruits or vegetable gardens, 30% allowed children to play in the water during sprinkler irrigation of lawns, and 12% filled swimming pools with the water. A total of 38% of surveys households agreed with the statement that there was no health risk involved with reusing treated wastewater for irrigation, and 57 to 69% supported using treated wastewater for residential or agricultural irrigation, respectively. Waterborne pathogens were quantified by culture (*E. coli*, enterococci) and quantitative polymerase chain reaction (qPCR for norovirus, adenovirus, polyomavirus, *E. coli*, enterococci, *Giardia*) in the treatment plant effluent, along the distribution line, in garden soils, vegetable surfaces and internalized into vegetables. Effluent from the treatment plant (n = 4 sampling dates) contained 0.5 ± 0.14 CFU/100 mL of *E. coli* and 2.0 ± 2.7 CFU/100 mL of enterococci (average ± standard deviation), while the distribution system (n = 18 sampling sites) contained 263 ± 636 and 99 ± 186 CFU/100 mL of *E. coli* and enterococci. Norovirus (1 to 3 genome copies/L [GC/L]), adenovirus (100 to 4000 GC/L) and Giardia (3000 to 6000 GC/L) were also detected in the treatment plant effluent and along the pressurized distribution line. Seventeen rinse water samples from 40 homegrown fruit and vegetable samples (i.e., apples, beets, bell peppers, cucumbers, lettuce, onion, raspberries, strawberry, string beans, tomatoes, zucchini) contained culturable *E. coli* (45 ± 118 CFU/100 mL rinse water) and enterococci (121 ± 254 CFU/100 mL rinse water). The 11 of the 40 fruits and vegetables also internalized culturable *E. coli* (88 ± 322 CFU/g) and enterococci (206 ± 489 CFU/g). Soils next to the vegetable plants contained fewer *E. coli* (0.09 ± 0.3 CFU/g) and enterococci (3.7 ± 6.5 CFU/g) than per gram of vegetable and fruit flesh. Vegetable gardens were irrigated with a variety of spray or drip irrigation systems. During air

sampling adjacent to spray irrigation in agricultural fields, bioaerosols collected on six-stage Anderson samplers indicated the presence of viruses and bacteria. For example, norovirus, Giardia and E. coli genomes were detected on different stages of the Anderson sampler as well as in droplet collection buckets. Concentrations of the pathogens tended to decrease with distance from the spray irrigation system. Two quantitative microbial risk assessments were conducted. First, all potential exposure routes to pathogens associated with using the reclaimed wastewater for agricultural irrigation were evaluated including: incidental ingestion or inhalation during irrigation, ingestion from the surface of food versus peeled foods, and ingestion of soils associated with food surfaces. Further, an additional quantitative microbial risk assessment was conducted to evaluate other mechanisms of exposure to pathogens from the use of reclaimed wastewater outside the home including: children's play in the irrigation water, filling home pools with the water, washing sidewalks or automobiles with cars. Recommendations for risk management were suggested, including irrigation water withholding, good food washing techniques and limitations of children's play.

Tackling wastewater reuse issues in Tunisia with a multithematic and multiscale approach

Jacques Béraud, Société du Canal de Provence (SCP), Aix-en-Provence, France;
jacques.beraud@canal-de-provence.com
Thierry Jalabert, Société des Eaux de Marseille (SEM), Marseille, FRANCE;
Hachmi Kennou, Institut méditerranéen de l'Eau (IME), Marseille, France

Abstract

Treated wastewater (TWW) reuse is a long-standing practice in Tunisia, starting in 1965. 20% of the global wastewater treatment plants effluents are reused every year. Nevertheless behind the numbers, several, technical, economic and social difficulties occur, and percentage of TWW REUSE stagnates.

SCP and SEM achieved in 2017 and 2018 a diagnostic study on water reuse in Tunisia on a national scale, and are working in 2019 on a technical assistance mission coordinated by IME, on local scale, focusing on two irrigated perimeters: Zaouïet Sousse (250 ha, operating since 1987), and Mahdia Tkhila (50 ha, under construction).

Bottlenecks come both from national and local constraints, which can be tackled providing a multi-thematic and participative approach.

1. Introduction

1.1. Reuse in Tunisia, long-time experience, good facts and numbers, professional expertise...

In 2017, 115 wastewater treatment plants (WWTP) produce 330 m^3 of TWW. 20% is reused: 60 million m^3 are reused, of which more than half targets environmental uses such as wetlands conservation, and one third targets agriculture (see **Figure 1**). 32 irrigated perimeters deliver TWW to 8 500 ha, corresponding to 2% of the total irrigated area in Tunisia (including conventional resources).

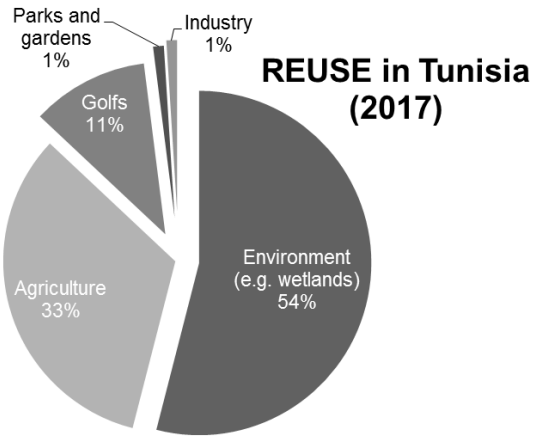


Figure 1: volumes of treated wastewater in Tunisia reused according to different types of uses

Stakeholders from agriculture, health and sanitation sectors are well trained and skilled. Academical references from INRGREF, CITET and several universities confirm the countries' history, knowledge and expertise of reuse: Hachicha (2015), Trad Raïs (2012), Belaïd (2010) and Bahri (2002).

Government also recently focused studies on different aspects of reuse, in order to encourage its enhancement:

- Groundwater recharge, though not visible in the previous figure, has been tested for several years, and occurs but for a small amount of TWW. Ministry of environment considers developing this practice where it is relevant
- Transfer of TWW from greater Tunis area to possible agricultural areas was studied, including evaluation of costs per m^3:
- Social acceptability for TWW and sewage sludge reuse is taken into account, and a policy for rising awareness and communicating was recently drafted.

1.2. …but numbers that don't reflect a deteriorating situation…

Nevertheless, several difficulties occur. Among these difficulties: sanitation and irrigation infrastructure maintenance is deficient for economic reasons, TWW quality standards are uncoordinated, and authorized crops list is very restrictive.

The main issue is water quality, which, when it is degraded or inadequately monitored, alters users' confidence, en compromises whole schemes.

Considering all the aspects involved, it seems that an initiative to tackle TWW reuse bottlenecks and solve them will need a holistic approach. The **Figure 2** below illustrates how the good operation of a reuse scheme relies, among others, on water quality control, as well as local governance, pricing, reasonable regulations, or optimized cropping system…

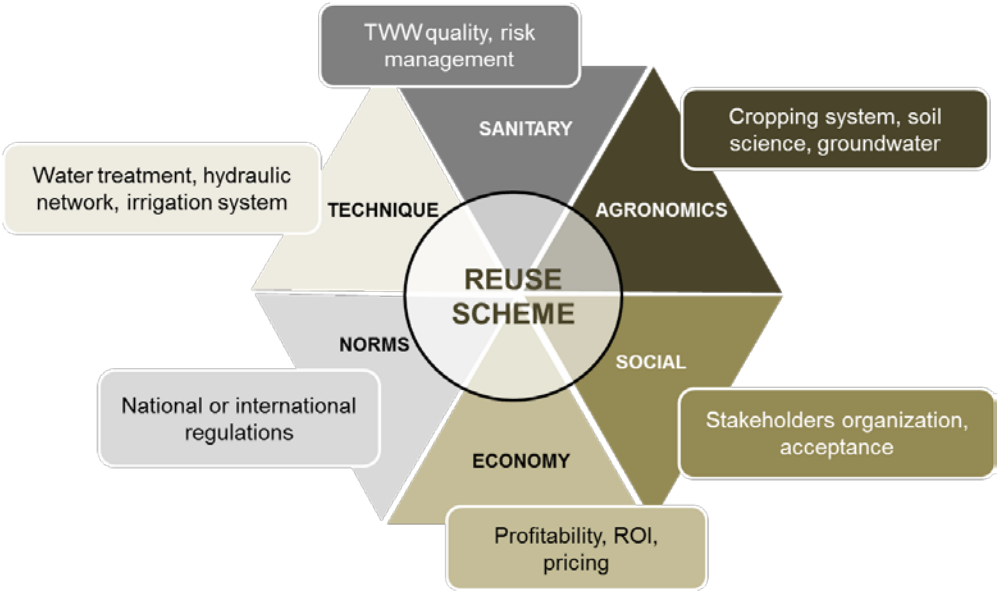


Figure 2: complexity of a wastewater REUSE scheme

1.3. …and real opportunities for the future

At the same time, renovation and upgrading campaigns of wastewater treatment plants (WWTP) and irrigation hydraulic networks are currently going on. Tertiary treatments are developing, such as sand filters and UV disinfection.

Considering climate change issue and the need to optimize integrated water resource management, Tunisian government mobilized international funding for several studies in the last years, in order to re-impulse a new dynamic on reuse.

SCP and SEM achieved in 2017, 2018 and are currently running in 2019 two different projects. The first one being a diagnostic study on water reuse in Tunisia on a national scale, on the orders of Agriculture and Health Tunisian ministries, as well as national sanitation office (ONAS), and funded by the World Bank. And the second, coordinated by IME and started in 2019 being a technical assistant mission on local scale, studying two agricultural reuse schemes, funded by Agence de l'eau Rhône Méditerranée et Corse (AERMC) and Agence française de développement (AFD).

2. Material and methods

2.1. Diagnostic prior to national masterplan

First project, the national diagnostic study started in June 2017 for 8 months, and consisted of several components, described in **Table 1.**

The objective of this study was to gather information, facts and first level analysis on water reuse national situation, prior to a Tunisian masterplan.

The team was composed of SCP and SEM experts, local consultants driven by SCP agency in Tunis, and a French reuse consulting firm, ECOFILAE.

Table 1: preparing a national reuse masterplan

COMPONENT 1: State of the art of water reuse in Tunisia	Interview of national stakeholders, analysis of main structuring studies on water reuse and previous masterplans, scientific bibliography on TWW impacts… International benchmark
COMPONENT 2: Water quality system and risk assessment	Description of Tunisian water quality norms and monitoring system. Organization and conduct of a campaign of inter laboratories analysis, for water as well as soils and crops
COMPONENT 3: Database organization	Architecture setup and test of a future national database aggregating stakeholders updated information on water reuse operations
COMPONENT 4: Two deficient operations diagnostic	Investigation on two water reuse irrigated perimeters: El Hajeb (from Sfax WWTP) and Borj Touil (from Tunis WWTP), and identification of main strengths and weaknesses

2.2. Local holistic approach on two local irrigated perimeters

Second project, the technical assistance mission started in January 2019 for 12 months, on two irrigated perimeters, and aimed first at posing a diagnostic and then describing and costing actions, according to a ten thematic matrix.

The objectives of this project is to gather multi-thematic expertise in order to tackle all the issues facing two TWW reuse perimeters, chosen as pilots, so to help local actors to optimize their technical, economical, social and sanitary operation (see **Table 2**). The two perimeters are an existing one from an urban WWTP (Zouïet Sousse) and a future one from a dairy food industry (Mahdia Tkhila).

The team was organized by IME and composed of SCP and SEM experts, as well as local consultants driven by SCP agency in Tunis.

Table 2: exploring 10 different themes

TH1 stakeholders interactions	What is the history of the PI? Who are the local stakeholders? How do they interact? What works and doesn't work?
TH2 wastewater treatment	How does the WWTP work? Does water quality respect regulations? What are the critical points of the process?
TH3 hydraulic irrigation network	How does the current hydraulic network work? Pumping stations? Feeders? How to improve regulation storage?
TH4 field irrigation	What are current field irrigations practices? How to develop soil salinity and risk management through irrigation practices?
TH5 water quality and risk management	Do current practices meet standards and regulations regarding sanitary risk management? How to improve practices?
TH6 soil, crops and agronomy	What are soils and crops on the IP? How to improve cropping system, fertilization, organic matter management?
TH7 agricultural production sales	What are the current and possible commercial networks for crops sales? Is there a risk? What are the perspectives?
TH8 sludge management	What is current sludge management? How is assessed agronomic and sanitary quality? What is the need for organic matter in soils?
TH9 global economics	What are current and possible costs and benefits for different stakeholders? What could be the selling price for TWW?
TH10 environmental impacts	What are the current and possible environmental impacts of the system on water resources, energy and other compartments?

3. Results and Discussion

One of the two projects is still ongoing. Nevertheless, results can lead to some conclusions, either on a national or local scale.

3.1. National institutional scheme

Many actors on a national and local point of view are involved in TWW operations (Ministries of agriculture and health, ONAS), but coordination is lacking especially regarding water quality analysis, which is the backbone for confidence. Requirements of the two existing norms (discharge and reuse) were in 2017 hardly inapplicable.

3.2. TWW pricing

Regulated tariffs for TWW is too low (0.7 cts € / m^3) to allow operational costs coverage, especially energetic costs due to pumping. Maintenance on the irrigation networks is minimal, water quality and service degrades, and agriculture is limited to resistant and low added value crops.

3.3. End users involvement and participatory approach

Public incitements from Ministry of Agriculture to develop certain crops (cotton in Zouïet Sousse, forage in Mahdia Tkhila) may be relevant on a rational and macro-economic basis, but meets farmers' reluctance. A top down approach for developing reuse schemes seems risky, and participation of end users preferable.

3.4. Sustainable tertiary treatments

Current TWW quality only offers a small choice for crop uses according to restrictive Tunisian regulations as well as more pragmatic World Health Organization (WHO) guidelines. Renovation policy of treatment plants often includes tertiary treatments units. According to local situations and needs, this equipment may open a window to authorizing higher added value crops.

4. Conclusions

Providing taking into account local and national bottlenecks, and using a holistic approach, reuse improvement can play a role in optimizing integrated water resources management (IWRM) in a context of climate change and droughts amplification in the Mediterranean area.

5. References

Hachicha M. (2015). The safe use of treated wastewater in agriculture. ICBA Technical Report Period 2010 – 2014

Trad Raïs M. (2012). Valorisation des eaux usées traitées pour l'irrigation de complément de l'olivier (olea europaea L.): effets sur les comportements végétatif et productif de l'arbre et sur la qualité sanitaire des fruits. PhD thesis

Belaïd N. (2010). Evaluation des impacts de l'irrigation par les eaux usées traitées sur les plantes et les sols du périmètre irrigué d'El Hajeb-Sfax : salinisation, accumulation et phytoabsorption des éléments métalliques. PhD thesis

Bahri A. (2002), Water reuse in Tunisia: stakes and prospects, Vers une maîtrise des impacts environnementaux de l'irrigation, Actes de l'atelier du PCSI, 28-29 mai 2002,

Reduction of Greenhouse Gas Emissions from Paddy Fields in Response to Continuous Irrigation with Treated Municipal Wastewater

Luc Duc Phung, The United Grad. School of Agri. Sci., Iwate Univ., Morioka, Japan; Dung Viet Pham, Fac. of Agri., Yamagata Univ., Tsuruoka, Japan; Shuhei Masuda, National Inst. of Technol., Akita College, Akita, Japan; Fumiaki Takakai, Fac. of Biores. Sci., Akita Pref. Univ., Akita, Japan; Nobuo Kaku, Fac. of Agri., Yamagata Univ., Japan; Masateru Nishiyama, Fac. of Agri., Yamagata Univ., Japan; Toru Watanabe, Fac. of Agri., Yamagata Univ., Japan; phungducluc0305@gmail.com

Abstract:

We recently introduced novel cultivation systems employing continuous irrigation with treated municipal wastewater (TWW) which can produce high yields of protein-rich rice without chemical fertilizers and tremendously mitigate CH_4 emissions from paddy fields. However, the systems were challenged by a trade-off between CH_4 and N_2O emissions. This study aims at optimizing irrigation regimes of the systems to overcome the trade-off while maintaining high rice productivity. Results have demonstrated that continuous sub-irrigation with TWW following a proper water regime, which applies suitable supply rates within relevant timings, could effectively reduce CH_4 and N_2O emissions by 83 and 27%, respectively, and eliminate the trade-off without reductions in grain yield and rice protein content.

Keywords: Agricultural reuse of treated municipal wastewater; continuous sub-irrigation; protein-rich rice; CH_4 and N_2O emissions

Introduction

In attempt to recycle and make the best use of valuable plant nutrients and water sources discharged from wastewater treatment plants, while diminishing CH_4 emissions from rice paddies, we have recently developed innovative cultivation systems, in which treated municipal wastewater (TWW) was continuously supplied into paddy fields throughout crop seasons either through an underground pipe system (sub-irrigation) or on the soil surface (surface irrigation), providing both required moisture and sufficient nutrients for vigor plant growth, high yield production, and superior protein content of harvested rice (Pham et al., 2017; Tran et al., 2019).

In addition, the continuous surface and sub-irrigation with TWW were able to extensively decrease the net global warming potential (GWP) of the paddies by 58 and 88% compared with that of conventional paddy fields, respectively, primarily as a result of enormous CH_4 mitigations (94–96%) (Pham et al., 2019). Nevertheless, a trade-off between CH_4 and N_2O emissions was recorded due to significantly-elevated emissions of N_2O as a result of high N loads of the continuous irrigation regimes (Pham et al., 2019), which have challenged the sustainable adoption of the systems.

In general, the emissions of such greenhouse gases (GHGs) from rice paddies are strongly influenced by agronomic practices, especially irrigation and N inputs (Zou et al., 2009). We hypothesized that a suitable adjustment in water regimes of the continuous irrigation systems would effectively overcome the trade-off by minimizing emissions of both GHGs, while maintaining the high productivity and favorable nutritional quality of rice grains. Therefore, this follow-up study was carried out to quantify the emissions of CH_4 and N_2O, yield and protein content of rice grains as influenced by different water regimes of the continuous TWW irrigation systems.

Material and Methods

A bench-scale experiment was conducted in 2018 crop season, using growth chambers simulating paddy fields, each with an area of 0.18 m^2 (0.3 × 0.6 m), in which four hills of a forage rice (cv. Bekoaoba) were transplanted (Figure 1 a). Because the sub-irrigation system (Figure 1 a) has been demonstrated to reduce the

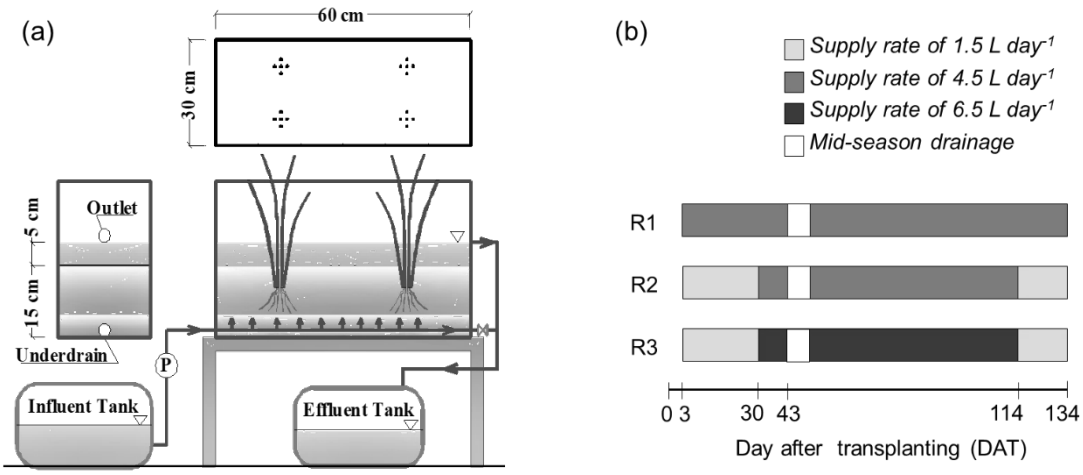


Figure 1 Schematic illustration of (a) the continuous sub-irrigation system and (b) the examined water regimes R1, R2, and R3.

GHG budgets more effectively compared with the surface irrigation system (Pham et al., 2019), therefore, it was elaborated in this study under different water regimes to improve the mitigation effectiveness. During the experiment, TWW stored in an influent tank was continuously supplied into the chambers at different irrigation regimes (Figure 1 b) and excessive water liberally overflowed out of the simulated paddies via the outlets (Figure 1 a). The examined water regimes included: a constant supply rate of 4.5 L day^{-1} throughout the crop season (R1); a supply rate of either 4.5 (R2) or 6.5 L day^{-1} (R3) employed from the active tillering stage (30 days after transplanting-DAT) to the hard dough stage (114 DAT) in combination with a lower rate of 1.5 L day^{-1} for the rest growth durations (Figure 1 b).

Three continuous TWW irrigation systems were facilitated with electronic pumps and not supplemented with any chemical fertilizers, while another chamber applied synthetic N-P-K fertilizers and manually irrigated with tap water was simultaneously implemented as a control. The continuous irrigation with TWW was initiated at 3 DAT and ceased at 1 day before harvesting. A one-week mid-season drainage was applied at the end of tillering stage (43 DAT) following the local practice (Figure 1 b). Gas sampling and analysis were done weekly following the closed static chamber method (Minamikawa et al., 2015), while grain yield and rice protein content were measured after harvesting following the standard methods (Tran et al., 2019).

Results and Discussion

Overcoming the trade-off between CH_4 and N_2O emissions

In general, irrigation with wastewater has been claimed to increase CH_4 emissions from paddy fields due to appreciable amounts of plant nutrients, especially N, and organic matters contained in the wastewater (Zou et al., 2009). However, the continuous sub-irrigation examined in this study staggeringly diminished the seasonal emissions of CH_4 by 67–83% relative to the conventional cultivation practices in the control (Figure 2). This reduction was probably due to the substantial amounts of dissolved oxygen supplied into the rice rhizosphere as TWW was continuously pumped into the deep soil layers, which might subsequently inhibit methanogen communities and their activities. Among three continuous irrigation systems, regime R2 yielded the highest effectiveness in CH_4 mitigation (Figure 2), probably due to the lowest amount of readily available C inputted (data not shown).

However, the continuous irrigation with TWW substantially increased seasonal N_2O emissions by 108–187%, which was in line with the trade-off found in our previous study (Pham et al., 2019), except the sub-irrigation system employing regime R2 that reduced the cumulative amount of N_2O by 27% compared with the control (Figure 2).

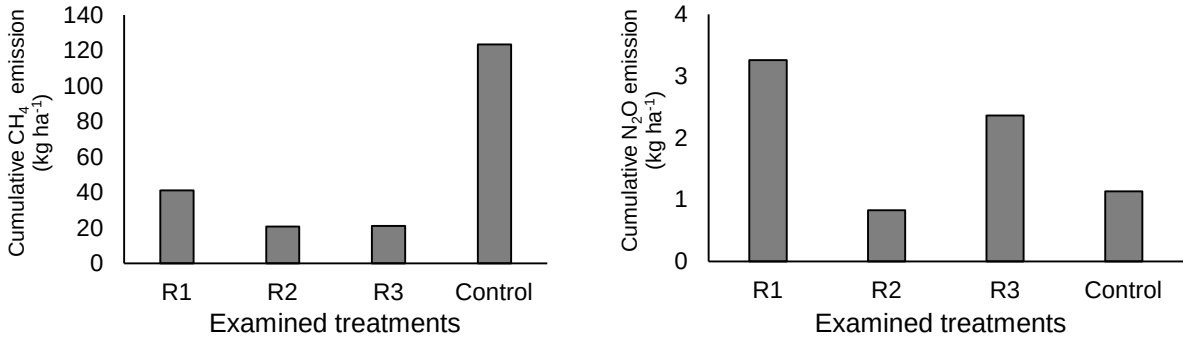


Figure 2 Cumulative emissions of CH_4 and N_2O from the experimental paddies.

Higher N_2O emissions from regimes R1 and R3 were essentially due to the enhanced nitrification and denitrification induced by the high N contained in the TWW (Tran et al., 2019) and high supply rates (Pham et al., 2019). On the other hand, rich sources of organic matter supplied by TWW could further benefit N-cycling bacterial communities (Zou et al., 2009), subsequently increasing N_2O emissions. The N loading rate in regime R2 was considerably lower compared with regimes R1 and R3 (data not shown), thereby increasing N use efficiency and reducing N loss via N_2O emissions as a result of appropriately matching a small (1.5 L day^{-1}) and a relevant higher supply rate (4.5 L day^{-1}) within the periods of low and high N demand of the rice plants, respectively. Overall, R2 was the most favorable water regime to overcome the trade-off between the two gases.

The GWP and yield-scaled GWP minimized under the optimized regimes

Relative to the control, the continuous TWW irrigation systems tremendously decreased the GWP (CO_2 equivalent-CO_2eq) over a 20-year horizon (Table 1) mainly because of the massive reduction of CH_4 emissions (Figure 2). A combination of two supply rate levels in regimes R2 and R3 tended to lessen the seasonal amounts of CH_4 and N_2O emitted (Figure 2) and subsequently the GWPs in contrast with a constant supply rate in regime R1. The highest mitigation effectiveness of regime R2 resulted in its minimum GWP as compared with the other continuous irrigation regimes and the control, suggesting that suitable supply rates in proper timings to meet the N demand of the rice plants would diminish GHG budget of the

paddies. The yield-scaled GWP is generally used to estimate effects of producing a certain grain yield on the climate during the cultivation. In this study, since there was no significant difference (p>0.05) in grain yields among the four treatments, the yield-scaled GWP decreased notably following the same trend of the GWP as follows: the control>R1>R3>R2 (Table 1).

Table 1 Grain yield, rice protein content, GWP and yield-scale GWP

Treatment	Grain yield ($t\ ha^{-1}$)	Protein content (%)	GWP* ($kg\ CO_2eq\ ha^{-1}$)	Grain yield-scaled GWP ($kg\ CO_2eq\ t^{-1}$ yield)
R1	$11.0±2.2^{a**}$	$12.3±0.6^{b}$	4306	390
R2	$10.1±1.9^{a}$	$12.0±0.2^{b}$	1956	194
R3	$10.4±1.7^{a}$	$13.6±0.4^{a}$	2399	231
Control	$8.6±1.0^{a}$	$9.8±0.3^{c}$	10660	1239

**The GWP factors for CH_4 and N_2O are 84 and 264 in the time horizon of 20 years, respectively (IPCC, 2013). ** Different letters indicate significance (p<0.05) of the treatments.*

High grain yield and superior rice protein content achieved without chemical fertilizers

The rice paddies irrigated with TWW tended to produce higher yields (10.1–11 t ha^{-1}) than the control (8.6 t ha^{-1}), regardless of the water regimes (Table 1), although the difference was not significant (p>0.05). This was in line with Jung et al. (2014), who claimed substantial supply of nutrients from wastewater irrigation resulted in higher rice yields. Interestingly, the continuous irrigation with TWW significantly improved the rice protein content relative to the control (Table 1). This conveyed that the continuous TWW irrigation could supply sufficient plant nutrients required for high productivity without necessitating commercial fertilizers, suggesting a cost-effective strategy for recycling water and nutrients that reduces the demand of chemical fertilizers and the amount of nutrients discharged into surface water bodies (Tran et al., 2019). Relative to the constant supply rate in regime R1, the combination of suitable supply rates in proper timings (R2 and R3) could maintain the high yielding capacity and the superior protein contents of the harvested rice (Table 1).

Conclusions

The continuous sub-irrigation with TWW effectively mitigated GHG emissions of the rice paddies. Especially the combinatory supply rates of 1.5 and 4.5 L day^{-1} (R2) minimized the emissions and eliminated the trade-off between the two gases.

Although no chemical fertilizer was supplemented, high grain yields and superior rice protein contents could be achieved through recycling the valuable plant nutrients contained in TWW. This study has demonstrated an effective reuse of TWW in rice cultivation to mitigate the GHG emissions and reduce the chemical N inputs that might contribute to promotion of sustainable rice paddy farming.

References

IPCC, 2013: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Jung K., Jang T., Jeong H., & Park S. (2014). Assessment of growth and yield components of rice irrigated with reclaimed wastewater. Agricultural Water Management, 138, 17-25.

Minamikawa K., Tokida T., Sudo S., Padre A. and Yagi K. (2015). Guidelines for measuring CH4 and N2O emissions from rice paddies by a manually operated closed chamber method. National Inst. for Agro-Environmental Sciences, Tsukuba, Japan.

Pham D. D., Kurashima S., Kaku N., Sasaki A., Pu J. & Watanabe T. (2017). Bottom-to-top continuous irrigation of treated municipal wastewater for effective nitrogen removal and high quality rice for animal feeding. Water Sci. Technol.: Water Supply, 18 (4), 1183-1195.

Pham D. D., Phung D. L., Kaku N. and Watanabe T. (2019). Methane and nitrous oxide emissions from rice paddies under continuous irrigation with treated municipal wastewater. Irrigation Science (Under review).

Tran D. L., Phung D. L., Pham V. D., Pham D. D., Nishiyama M., Sasaki A. & Watanabe T. 2019. High yield and nutritional quality of rice for animal feed achieved by continuous irrigation with treated municipal wastewater. Paddy and Water Environment. https://doi.org/10.1007/s10333-019-00746-x

Zou J., Liu S., Qin Y., Pan G. & Zhu D. (2009). Sewage irrigation increased methane and nitrous oxide emissions from rice paddies in southeast China. Agriculture, Ecosystems and Environment, 129, 516-522.

Influence of Nitrogen Contained on Growth and Composition of Essential Oil in Basil (*Ocimum basilicum L.*)

A.S. Melo[1], Agreste Academic Centre, Federal University of Pernambuco, Caruaru, Brazil[1]; E.F. Gomes[2], Agreste Academic Centre, Federal University of Pernambuco, Caruaru, Brazil; W. Leite[3], Civil Engineering Department, Federal University of Pernambuco, Recife, Brazil; M. Kato[4], Civil Engineering Department, Federal University of Pernambuco, Recife, Brazil; K.K. Barros[5], Agreste Academic Centre, Federal University of Pernambuco, Caruaru, Brazil; keniakellybarros@gmail.com

Abstract:

Essential oils are volatile aromatics compounds derived from plant secondary metabolism. Basil plants (*Ocimum basilicum L.*) were cultivated in a greenhouse and irrigated with potable water and treated urban wastewater. The effects of nitrogen present in treated wastewater on the composition of essential and basil growth were evaluated in this study. Fertigation with treated wastewater increased the essential oil and linalool contents and provided more nitrogen and crude protein contents in leaves. Moreover, the irrigation with non-diluted wastewater even enhanced the chemical composition of basil essential oil and supported plants growth promotion as they achieved a maturity condition earlier than the others.

Keywords: Basil; essential oil; linalool; reuse; treated effluent

Introduction

Essential oils (OE) are volatile aromatic compounds, with complex chemical composition, derived from the secondary metabolism of some plants. They are frequently used as feedstock across several industry sectors. Commonly known as Tuscan or Sweet basil, *Ocimum basilicum L.* is a source of various chemicals compounds (such as monoterpenes, sesquiterpenes and phenylpropanoids), and it has medicinal properties, such as antifungal, antioxidant and antiseptic. The basil cultivation is mainly focused on essential oil extraction (Burducea et al., 2018), which is used in food, pharmaceutical, perfume and cosmetics industries. However, some strategic actions have been taken to improve the productivity of basil essential oil, due to the increasing consumer demand.

According to Vilanova et al. (2018), plant nutrition management is one of key strategies to achieve a sustainable agricultural system. Nitrogen inputs generally increase the EO yield in aromatic plants by intensifying biomass yields per unit area, photosynthetic rate and efficiency in the use of solar radiation (Chen et al., 2016; Shi et al., 2016; Khan et al., 2017).

Regarding organic fertigation, Bensabah et al. (2015) have reported that treated urban wastewater has a beneficial effect on plants and may increase OE production in herbs because of its nutrients and trace elements richness that once properly used can increase the crop productivity, consequently. In view of these arguments, this work aimed to evaluate the influence of the N present in the treated urban wastewater on the chemical composition of essential oil and *Ocimum basilicum L.* growth.

Methods

The basil was cultivated in polypropylene pots, in greenhouse. Plants were irrigated with potable water (W) and treated urban wastewater (TUW) produced in a real maturation pond installed in the STP of Caruaru, northeast Brazil. The main characteristics of the treated wastewater were: total ammonium nitrogen (NH_4^+-N) and nitrate (NO_3^-N) were 16.2±4.5 and 3.6±2.2 mg.L^{-1}, respectively; pH 7.0±0.3. Experiments followed a completely randomized statistical design, with 5 treatments and 5 replicates (Table 1).

Table 1. Description of treatments studied in the experiment

Treatments	Description
T1 (W)	Irrigation with potable water.
T2 (TUW+W; 1:3)	Irrigation with TUW diluted in potable water (1:3, vol./vol.)
T3 (TUW+W; 1:1)	Irrigation with TUW diluted in potable water (1:1, vol./vol.)
T4 (TUW+W; 3:1)	Irrigation with TUW diluted in potable water (3:1, vol./vol.)
T5 (TUW)	Irrigation with non-diluted TUW.

The evapotranspiration method was used to determine how much water to apply based on estimates of the amount of water lost from the crops (Marques et al., 2015). The soil used in this experiment was a typical Planosol collected in the semiarid region of Pernambuco state, Brazil. The physical-chemical characterization of potable water and treated urban wastewater were carried out according to methods described in Standard Methods for the Examination of Water and Wastewater (APHA, 2012). At the end of experiment, crop growth parameters,

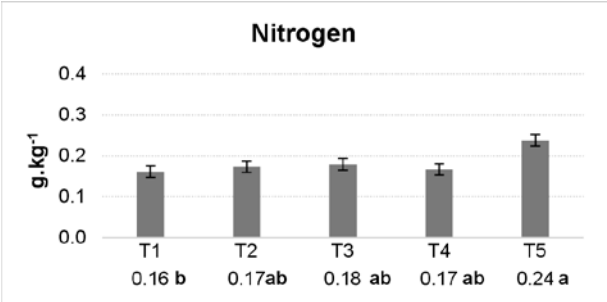
nitrogen concentrations (N) and contents of crud protein (CP) in leaf tissue were assessed. Moreover, the chemical composition of EO was investigated in order to verify compositional changes among the treatments. The results were evaluated by analysis of variance (ANOVA), F and Tukey tests, at significant level of 5%, and MSD (minimal significant difference), according to Banzatto and Kronka (2006).

The basil seeds (germination percentage equal to 99%) were provided by a private company. At the 90th DAP (day after planting), measurements of plant growth were performed before harvesting. The leaf biomasses were dried in an aerated oven, at 40ºC, until constant weight. The dry leaf biomass of each plant was pulverized and used for N and CP determinations (Bezerra Neto and Barreto, 2011) and for EO extraction by hydrodistillation, in a Clevenger-type extractor (Clevenger, 1928). The chemical composition of the extracted EO was checked by high performance liquid chromatography-mass spectrometry (HPLC-MS Agilent Technologies, model 7890A and 7975C, respectively). The EO content was calculated based on the dried biomass, i.e., the volume of essential oil in relation to the dry plant biomass (v/w, %) (Alves et al., 2015).

Results and Discussion

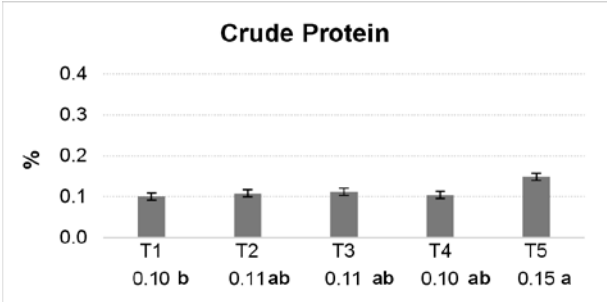
Most plants irrigated with TUW bloomed in 64 days average value), except those submitted to the treatment T3 (TUW+W, 1:1), which bloomed earlier (50 days, on average). The ones irrigated with water bloomed after 74 days. Despite many basil species bloom between 50 and 70 days, the bloom time for *Ocimum basilicum L.* is considered late (over 70 days) (Pereira and Moreira, 2011). Therefore, the early plants maturity may be addressed to the treated urban wastewater used for irrigation.

Regarding N and CP presented in basil leaves, the most outstanding treatment was T5 (TUW) (0.24 g N.kg^{-1} and 0.15% of CP, respectively). The CP content verified in T5 was about 75 times greater than the typical CP amount found in leaf tissue (0.02%) (TACO, 2011). Furthermore, only T5 was significantly different from T1 (W) (Figures 1 and 2). According to Chen et al. (2016), the more N is provided to cropping system, the more the concentration of that element increases in the leaf tissue. In addition, CP content relies on the N availability, because the presence of N increases the production of CP in the plants. Thus, the outcomes suggest that the irrigation with TUW provided a significant increase in N and CP contents in the basil leaf tissues.



MSD = 0.08 g.kg^{-1}; Standard error = 0.02 g.kg^{-1}

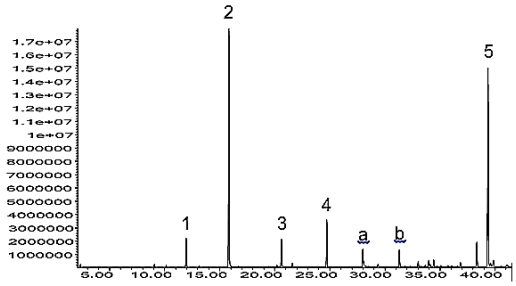
Figure 1. Nitrogen in leaf tissue



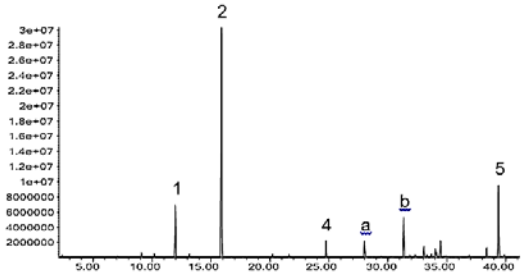
MSD = 0.05 %; Standard error = 0.01 %

Figure 2. Crude protein in leaf tissue

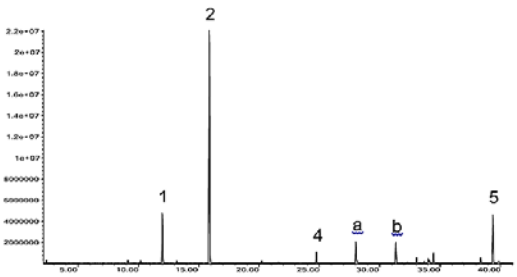
More than sixty chemical compounds were identified in the basil EO; however, quantitatively, only linalool contents were calculated. Considering the highest peaks (Figures from **a** to **e**), the main compounds found were likely: eucalyptol (1), linalool (2), estragole (3), bornyl acetate (4), τ-cadinol (5), eugenol (a) and bergamotene (b).



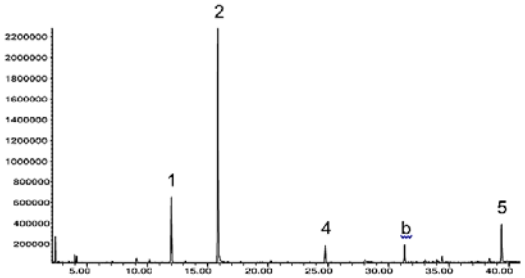
(a) Treatment T1 (W)



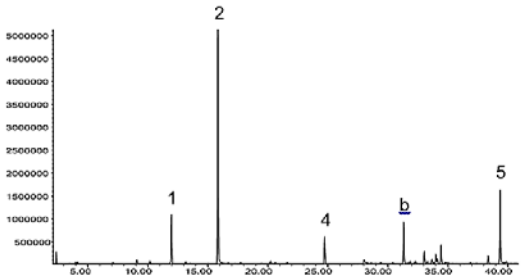
(b) Treatment T2 (TUW+W; 1:3)



(c) Treatment T3 (TUW+W; 1:1)



(d) Treatment T4 (TUW+W; 3:1)

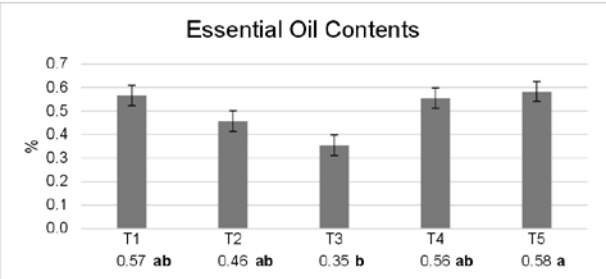


(e) Treatment T5 (TUW)

Figure 3. Chromatograms of chemical composition of essential oil

Concerning the chemical composition, several studies have reported the concentrations of eucalypitol, bornyl acetate and τ-cadinol (Burducea et al., 2018); linalool (Avestisyan et al., 2012) and eugenol (Ekren et al., 2012) in essential oils extracted from basil plants. In the current study, the higher values for EO and linalool

were registered in T5 (TUW), 0.58% and 8.19%, respectively (Figures 4 and 5). Askary et al. (2018) depicted that inputs of N generally increases EO contents in aromatic herbs, because they enhance the leaf area development and the photosynthetic rate. Onofrey et al. (2018) and Burducea et al. (2018), reported EO contents in basil leaf tissues between 0.2 and 0.42% and concluded that biofertilization improved and positively affected the synthesis of some compounds, such as linalool. These evidences are in accordance with the results founded in the current experiment.



SMD = 0.23 %; Standard error = 0.06 %

Figure 4. Essential oil contents in basil

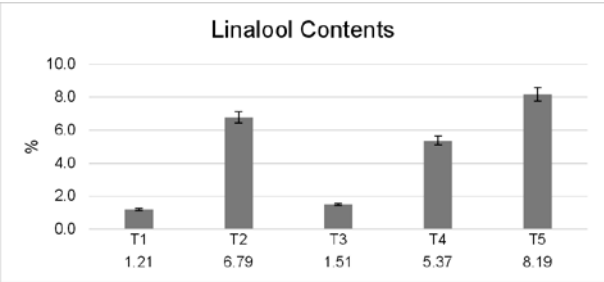


Figure 5. Linalool contents in basil

Conclusions

Fertigation with treated urban wastewater increased the EO and linalool contents, improved positively its chemical composition, increased the N and CP contents, in leaf tissue and caused a shorter blooming time, especially in the plants submitted to treatment T5 (TUW).

References

Alves, L. S., Paz, V. P. S., Silva, A. J. P., Oliveira, G. X. S., Oliveira, F. E. R. and Amorim, E. L. (2015). Content, yield and chemical composition of essential oil of sweet basil plants subjected to NaCl saline stress. *Revista Brasileira de Plantas Medicinais*, *17*(4), 807-813.

APHA, AWWA, WPCF. (2012). Standard Methods for the Examination of water and Wastewater. Washington D.C., 22ª ed.

Askary, M., Behdani, M. A., Parsa, S., Mahmoodi, S. and Jamialahmadi, M. (2018). Water stress and manure application affect the quantity and quality of essential oil of *Thymus daenensis* and Thymus vulgaris. *Industrial crops and products*, *111*, 336-344.

Avetisyan, A., Markosian, A., Petrosyan, M., Sahakyan, N., Babayan, A., Aloyan, S. and Trchounian, A. (2017). Chemical composition and some biological activities of the essential oils from basil *Ocimum* different cultivars. *BMC complementary and alternative medicine*, *17*(1), 60.

Banzatto, D. A. and Kronka, S. N. (2006). Agricultural Experimentation. 4.ed. Jaboticabal: FUNEP, 237p.

Bensabah, F., Lamiri, A. and Naja, J. (2015). Effect of purified wastewater from the city of Settat (Morocco) on the quality of *Lippia citriodora* essential oil and infusion. *Journal of the Saudi Society of Agricultural Sciences*, *14*(2), 101-108.

Bezerra Neto, E. and Barreto, L. P. (2011) Chemical and Biochemical Analysis in Plants. University Publishing House of UFRPE, Recife (PE), 261p.

Burducea, M., Zheljazkov, V. D., Dincheva, I., Lobiuc, A., Teliban, G. C., Stoleru, V. and Zamfirache, M. M. (2018). Fertilization modifies the essential oil and physiology of basil varieties. *Industrial crops and products*, *121*, 282-293.

Chen, B., Yang, H., Song, W., Liu, C., Xu, J., Zhao, W. and Zhou, Z. (2016). Effect of N fertilization rate on soil alkali-hydrolyzable N, subtending leaf N concentration, fibre yield, and quality of cotton. *The Crop Journal*, *4*(4), 323-330.

Clevenger, J. H. (1928). Apparatus for the determination of volatile oil. *J. Am. Pharm. Assoc*., *17*, 346p.

Ekren, S., Sönmez, Ç., Özçakal, E., Kurttaş, Y. S. K., Bayram, E. and Gürgülü, H. (2012). The effect of different irrigation water levels on yield and quality characteristics of purple basil (*Ocimum basilicum* L.). *Agricultural water management*, *109*, 155-161.

Khan, S., Anwar, S., Kuai, J., Ullah, S., Fahad, S. and Zhou, G. (2017). Optimization of nitrogen rate and planting density for improving yield, nitrogen use efficiency, and lodging resistance in Oilseed Rape. *Frontiers in plant science*, *8*, 532.

Marques, P. A. A., José, J. V., da Rocha, H. S., Fraga, J., Soares, D. A. and Duarte, S. N. (2015). Water consumption of basil using drainage lysimeter. *IRRIGA*, *20*(4), 745-761.

Onofrei, V., Benchennouf, A., Jancheva, M., Loupassaki, S., Ouaret, W., Burducea, M., Lobiuc, A., Teliban, G. and Robu, T. (2018). Ecological foliar fertilization effects on essential oil composition of sweet basil (*Ocimum basilicum L.*) cultivated in a field system. *Scientia horticulturae*, *239*, 104-113.

Pereira, R. C. A. and Moreira, A. L. M. (2011). Basil: Cultivation and Use. Embrapa Tropical Agroindustry, Fortaleza (CE), 31p.

Shi, D. Y., Li, Y. H., Zhang, J. W., Peng, L. I. U., Bin, Z. and Dong, S. T. (2016). Increased plant density and reduced N rate lead to more grain yield and higher resource utilization in summer maize. *Journal of integrative agriculture*, *15*(11), 2515-2528.

TACO – Brazilian Table of Food Composition. (2011). NEPA/UNICAMP. 4ª ed. Campinas: NEPA/UNICAMP, 161p.

Vilanova, C. M., Coelho, K. P., Luz, T. R. S. A., Silveira, D. P. B., Coutinho, D. F. and de Moura, E. G. (2018). Effect of different water application rates and nitrogen fertilisation on growth and essential oil of clove basil (*Ocimum gratissimum* L.). *Industrial Crops and Products*, *125*, 186-197.

Water reuse in process industry – case studies and impact

Christina Jungfer[1], Thomas Track[1]

[1]DECHEMA e.V., Theodor-Hess-Allee 25, 60486 Frankfurt a.M., Germany

contact: christina.jungfer@dechema.de

Keywords

Water reuse, alternative water resources, integrated solutions

Introduction

Sustainable integrated water management is essential for efficient water management in process industry. It is also a key element for circular economy approaches and addressing global societal, environmental and economic challenges. Industrial specific challenges are to increase resource efficiency while decoupling the increase in production. Drivers are water stress, stricter regulations, sustainability goals. One strategy for improving water management in process industry is the implementation of an integrated water resources management, where water reuse plays a key role.

Process industry is a keystone of the European economy. While being a significant water user, especially chemical industry is also an important solution provider of innovative products, technologies and services that enable more sustainable water management. The chemical industry offers significant potential for increasing eco-efficiency in industrial water management also applicable for other industries. To deal with critical challenges, such as the need to reduce water use, wastewater production and energy use, the EU FP7 funded project E4Water ("Economically and ecologically efficient water management in the European chemical industry" – www.E4Water.eu) has demonstrated water reuse opportunities in several case studies.

The project has built on state-of-the-art and new basic R&D concepts. Their realization, improvement, utilization and validation, with the compromise of early industrial adaptors, were clearly innovative. E4Water has realized this by:

- developing and testing innovative materials, process technologies, tools and methodologies for an integrated water management,

- providing an open innovation approach for testing E4Water developments with respect to other industries,
- implementing and validating the developments in 6 industrial case studies, representing critical problems for the chemical industry and other process industries,
- implementing improved tools for process efficiency optimization, linking water processes with production processes- and eco-efficiency assessment.

The Case Studies

In the regional approach of the Dow Terneuzen case study **CS1** the concept for „Mild Desalination“ was developed *(Groot et al., 2015)*. The case study showed that this mild desalination technology of miscellaneous brackish water streams is feasible and can be an attractive approach to produce water for industrial applications in delta areas across the world, which typically are characterized by the presence of limited fresh but abundant brackish water sources *(Bisselink et al., 2016)*.

Enhanced water management was shown in the INOVYN Belgium case study **CS2**. A symbiotic concept for reuse of concentrated water streams from a neighboring company was developed and demonstrated towards zero liquid/zero waste discharge (European responsible Care Award 2014). The DEMO studies describe the technical and economic feasibility of a full-scale installation to working up of wastewater, phreatic & dock water to high quality water and to reuse the concentrated salty water from an external company. The results of the DEMO units will also study the basis to generate the design parameters for a possible full-scale plant for the production of process water & demineralized water.

In the INOVYN SPAIN PVC production of **CS3** a new concept with adapted/optimized technologies was developed going towards zero fresh water dependency in a water scarcity region. This concept is applicable to PVC sites. A pilot plant study confirms that water reclamation from PVC effluents is possible through coupling a MBR and a double pass RO process *(Blanco et al., 2016)*. Further the economic feasibility of water reuse within a PVC plant was shown *(Prieto et al., 2016)*.

The Procter&Gamble case study (**CS4**) demonstrated a circular economy approach by the development of full recycling of water and surfactants by an in-process water loop closure by combining segregation/separation technologies with traditional wastewater treatment technology and biocidal technologies. A new treatment approach (innovative concept), based on nanofiltration, has been demonstrated at industrial scale in a detergent production *(Linclau et al., 2016)* and is already used in several production facilities (P&G) across the globe.

In the TOTAL case study (**CS5**) an integrated water management approach in a petrochemical site was developed. The project approach is considered by the partners as valuable and its outcomes significant to better tackle potential water saving measures in Europe, Middle-East and China as well as to balance even more expending freshwater fees. The technical developments carried out can be made beneficial in many other industrial sectors.

An overall concept inside the Kalundborg Industrial Symbiosis was demonstrated by **CS6**. It was demonstrated that pre-gasified industrial process water could be redefined as a plant substrate and support a local production of microalgae biomass and produce water fit for reuse. Furthermore, this represents a development of the concept of Industrial Symbiosis and sustainability, where nutrients (e.g. phosphorous) and CO_2 are not only removed from the water resources but also upcycled to higher value biocomponents such as plant protein, plant lipids (e.g. EPA), and pigments (e.g. luten) *(Safafar et al., 2016)*. In addition, it has been demonstrated that a pre-filtration step can cost-effectively improve water and microalgae separation without compromising quality of the two value streams, water and microalgae biomass.

Summary

The E4Water case studies demonstrated new integrated approaches, methodologies and process technologies for a more efficient and sustainable management of water in the chemical industry with cross-fertilization possibilities to other industrial sectors *(E4Water 2016)*. Six industrial case studies demonstrated a reduction in water use (≥40%), waste water production (≥20%), and energy use (up to 20%) with economic

benefits of up to 30% at the same time. Equally important, in each case study policy compliance was achieved. Moreover, the developments are also applicable to other industry sectors. The outcomes of the project illustrate the possibility to decouple economic growth in the chemical sector from actual water use.

References

Bisselink, R., de Schepper, W., Trampé, J., van den Broek W., Pinel, I., Krutko, A., and Groot, C.K. (2016). Mild Desalination demo pilot: new normalization approach to effectively evaluate Electrodialysis Reversal technology. *Water Resources and Industry*, **14**, 18-25, doi:10.1016/j.wri.2016.03.003.

Blanco L., Hermosilla D., Blanco A., Prieto D., Swinnen N., Negro C. (2016). MBR + RO combination for PVC production effluent reclamation in the resin polymerization step – a case study. Ind. Eng. Chem. Res., 55(21), 6250–6259. doi: 10.1021/acs.iecr.6b00913.

Economically and ecologically efficient water management in the European chemical industry -Solutions for practice (2016). E4Water Final Brochure. www.e4water.eu.

Groot C.K., vandenBroek W.B.P., Loewenberg J., Koeman-Stein N., Heidekamp M., deSchepper W. (2015). Mild desalination of various raw water streams. Water Sci. Technol., 71, 371–376.

Linclau, E., Ceulemans, J., De Sitter, K., Cauwenberg, P. (2016). Water and detergent recovery from rinsing water in an industrial environment. Water Resources and Industry, 14, 3-10, doi:10.1016/j.wri.2016.03.001.

Prieto de la Parte, D., Swinnen, N., Blanco, L., Hermosilla, D., Cauwenberg, P, Blanco, Á, Negro, C. (2016). Drivers and economic aspects for the implementation of advanced wastewater treatment and water reuse in a PVC plant. Water Resources and Industry, 14, 26-30, doi:10.1016/j.wri.2016.03.004.

Safafar H., Nørregaard P.U., Ljubic A., Møller P., Løvstad Holdt S., Jacobsen C. (2016). Enhancement of Protein and Pigment Content in Two Chlorella Species Cultivated on Industrial Process Water. Journal of Marine Science and Engineering, 4(4), 84. doi:10.3390/jmse4040084.

Overcoming urban water scarcity through the reuse of energy-efficient treated grey and black water: SEMIZENTRAL's large-scale plant case study

T. Blach[a], J.Tolksdorf[b], M. Engelhart[a], M. Wagner[a]

[a]Technische Universität Darmstadt, Institute IWAR, 64287 Darmstadt, Germany

[b]Kocks Consult, 56068 Koblenz, Germany

(E-Mail: T.Blach@iwar.tu-darmstadt.de)

Abstract:

The SEMIZENTRAL concept is an integrated approach to meet the needs of fast growing urban areas: Providing service water for urban reuse, treating wastewater adequately and optimizing energy efficiency by co-digestion of biowaste. The special feature comprises the semicentral scale on district level, between central and decentral scale. The Resource Recovery Center (RRC) represents the first full scale implementation of the SEMIZENTRAL concept in Qingdao (ShanDong Province, China). To ensure sufficient quality for reuse, relevant parameters were considered and their limits complied. High removal rates for COD and NH_4-N of 95-97% and 97-99% were realized. At times, up to 100% of the daily effluent was reused locally. To evaluate the energy demand for providing service water based on operation data, two different calculations resulted in an energy demand of 0.4 - 0.8 kWh/m³ (grey water) and 1.4 - 1.7 kWh/m³ (black water) for a utilization rate of 100%. These results are comparable to conventional infrastructure systems for water reclamation.

Keywords: Semizentral; water reuse; energy; resource efficiency; integrated treatment

Introduction

In 1970 China's population was about 0.83 billion people, which is predicted to be about 1.47 billion in 2030. At the same time the urban population will increase from 18% in 1970 to estimated 71% in 2030. Growth rates of Chinese cities are among the highest growth rates worldwide (UN, 2018). The high growth rates of the cities challenge the water supply quantitatively as well as qualitatively and require alternative ways to provide water. To meet the challenge of water scarcity the SEMIZENTRAL approach has been developed and has been implemented in full scale in Qingdao (China), a fast-growing urban area with annual growth rates of

113,700 inhabitants. Focusing on resource recovery, SEMIZENTRAL integrates the sectors wastewater and waste disposal as well as non-potable service water and energy supply. So it aims to reduce the demand of drinking water by providing service water for purposes with lower required quality such as toilet flushing, irrigation and street cleaning. The special feature is the semicentral scale on district or neighborhood level, which is between central (whole city) and decentral (single building) scale. This allows the adjustment to the current growth rate of a city and the territorial direction of a city's development (Bieker et al., 2010). The Resource Recovery Center (RRC) is the first full scale realization to validate the functionality of SEMIZENTRAL and the locals' acceptance of non-potable water for urban water reuse. Built in 2014, the RRC is being operated by a local operator since 2015. The RRC has a treatment capacity of 1,200 kg COD/d (corresponds to 12,000 PE) and 1,500 m^3/d. The comparison to conventional WWTPs is misleading, since the RRC produces water for reuse purposes. Therefore, grey water (GW) and black water (BW) are collected and treated separately for an individual treatment of less polluted GW (wastewater from showers, washbasins, laundries) and higher polluted BW (wastewater from toilets, kitchen). Both treatment units are customized for effluent reuse and therefore equipped with membrane bio-reactors (MBR) and chlorination. To enable an energy self-sufficient operation of the RRC, biowaste from surrounding canteens and restaurants is co-digested with the sewage sludge of the wastewater treatment units.

Material and Methods

Presented operation data were gathered in the RRC from 2016 to 2018. The wastewater characteristics were determined using 24-h-composite samples, which were taken in the influent and in the effluent of the treatment units. Various analyses were performed with cell tests from Merck KGaA including chemical oxygen demand (COD) and ammonium (NH_4-N). For recycling, treated water has to meet standards according to Chinese GB/T 18920-2002. The energy demand was recorded via electricity meters, not for every single device but for groups of devices. Fig. 1 illustrates the process technology for the treatment units as well as their assignment to a group. Chlorination and post-storage tanks were not considered due to their minor energy demand. For interpretation of the energy demand two different estimations were conducted: Firstly, a correlation between volumetric load and

specific energy demand in kWh/m$^3_{Influent}$ and secondly, the usage of the installed power, the runtime and the linear regression of operation data for main devices.

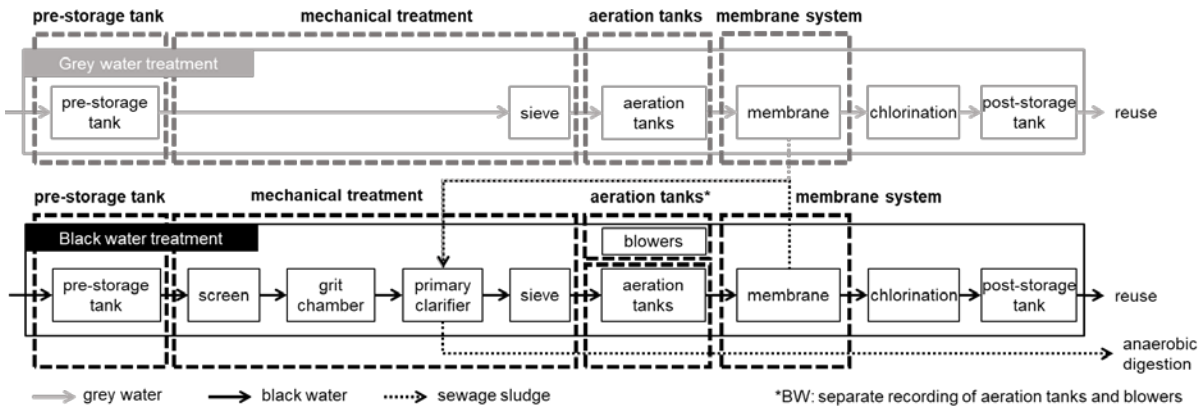


Figure 1 *Treatment steps of GW, BW and grouping of energy consumers*

Results and Discussion

The plant's average COD and NH_4-N loads show high standard deviation (Tab. 1), indicating strong fluctuations. This is due to seasonal variations, in particular two hotels in the catchment experience highly seasonal occupancy. This leads to higher loads during summer and lower loads during winter to the RRC.

Table 1 Daily loads of COD, NH_4-N and influent for grey and black water

	COD [kg/d]		NH_4-N [kg/d]		Influent [m³/d]	
	GW	**BW**	**GW**	**BW**	**GW**	**BW**
Average	107.9	241.2	6.6	27.1	129	297
STD	75.7	100.9	3.2	9.6	-	-
Design	147.6	1,052.4	2.6	99.0	718	81
Load rate [%]	73.1	22.9	253.8	27.4	18.0	35.8
Number [-]	326	339	324	340	-	-

The comparison of the average measured values with design data illustrates a significant underload of the plant. For BW, only 22.9% (COD) to 27.4% (NH_4-N) of the maximum capacity were used. The main reasons for the low utilization rate are the closure of one hotel at the end of 2016 as well as the slow settlement of the newly developed catchment area, which is associated with many vacant apartments. These circumstances increased the uncertainties in the planning process and were not foreseeable. In contrast to the BW load, GW load is 73.1% (COD) and 253.8% (NH_4-N) and therefore exceeds the design. These observations could be attributed to misconnections in the separated drainage system as described by Tolksdorf and Cornel (2017), which result in a mixing of GW and BW. This leads to higher GW concentrations and lower BW concentrations compared to design. The lower load also reflects in the influent flow rate, which is only about 18.0% (GW) and 38.8%

(BW). A significantly higher influent of GW was assumed in the design due to a higher water demand of the two hotels.

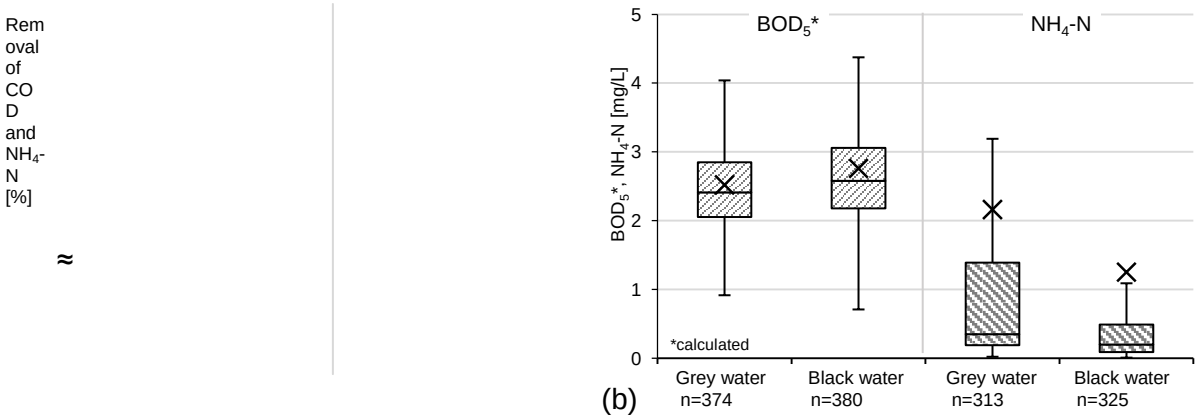


Figure 2 Removal rates for COD and NH_4-N (a) and effluent concentrations for BOD_5 and NH_4-N (b)

Despite the plant's underload, COD removal rates are high at any time, ranging from 95.7% (GW) to 97.0% (BW) (Fig. 2, a). NH_4-N removal rates are >97% and show slight deviations due to different setting of the aeration system during operation and process optimization. GW treatment shows good NH_4-N removal, even though it was not designed for biological nitrogen removal. Nitrogen removal could be achieved due to the flexible design of the plant. This includes sufficient aeration capacity as well as a cascade of two separate treatment tanks and thus the possibility of a strict separation of anoxic and aerobic volumes. Critical parameters for the water reuse for toilet flushing, irrigation and street cleaning, which are the effluent's main purposes, are BOD_5 (10 mg/L) and NH_4-N (10 mg/L). As the effluent was filtered via membranes, other limits such as turbidity were not detectable. BOD_5 could not be measured and therefore was calculated using the measured COD-concentration and a BOD_5/COD ratio of 0.13 for effluent of MBRs in municipal wastewater (Radjenovic et al., 2009). The box plots in Fig. 2, b show effluent concentrations of 2.5 - 2.7 mg BOD_5/L and 1.3 - 2.1 mg NH_4/L in compliance with the Chinese reuse limits. Consequently, both treated water types are appropriate for the intended water reuse.

To offer a suitable alternative to conventional water sources, costs for providing service water should be as low as possible. One key factor therefore is an optimized energy demand for adequate and adjusted treatment steps. Due to the RRC's underload specific costs in kWh/m^3 were excessively high, which does not allow any comparison with other projects for service water supply. Fig. 3 shows the planned energy demand and the measured energy demand for different process steps of both

treatment units. Some plant components such as influent pumping stations, aeration tanks and blowers correspond to the lower load rate due to adjustments during operation, which mainly are the setting of a lower output for blowers, agitators and pumps. These modifications result in up to 60% lower energy demands, especially for aeration tanks. Mechanical treatment and the membrane system, in particular for BW treatment, could not be adjusted to the lower load, resulting in an energy demand comparable to the planning. The membrane system includes components for cross-flow with aeration, feed pumps and backwash. It was operated despite the plant's underload to prevent irreversible fouling on and in the membranes caused by decommissioning. The energy demand of the GW treatment was about 50% higher than designed due to the higher suspended solids load and therefore frequent backwash of the microsieve.

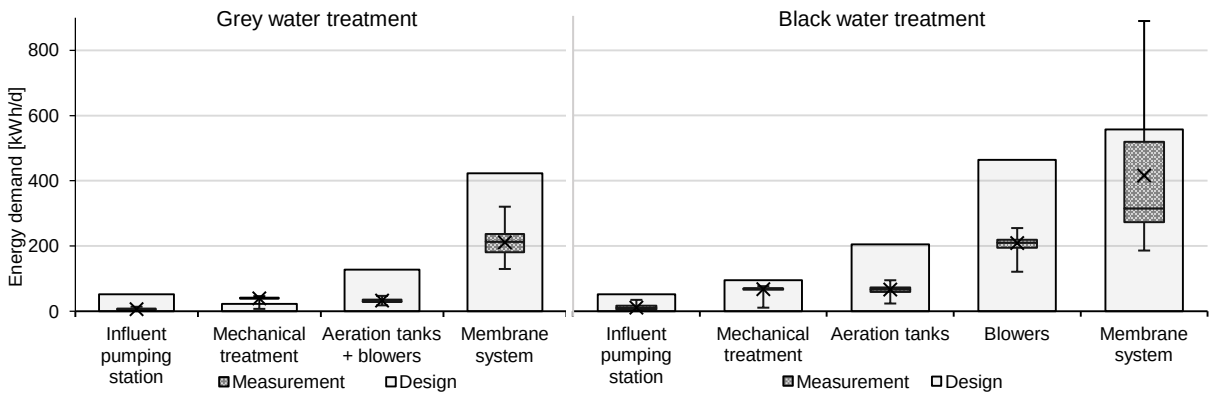


Figure 3 Comparison of designed and measured energy demand for different treatment steps

To obtain a differentiated view of the energy consumption under consideration of the low load, the first graphical approximation in Fig. 4 shows the specific energy demand as a function of the volumetric load. In the period under review it is approx. 10 - 40% for GW and 15 - 60% for BW. With increasing volumetric load, the specific energy demand decreases significantly showing a correlation. It also shows the significant share of the membrane system in the total energy demand, which is the major energy consumer of the treatment steps. Extrapolating the measured values for the treatment units, the specific energy demand for 100% load may be estimated to 0.4 $kWh/m^3_{Influent}$ (GW), 1.4 $kWh/m^3_{Influent}$ (BW) and 0.9 $kWh/m^3_{Influent}$ (total amount of wastewater). For the second calculation, the energy demand at full volumetric load results in 0.8 $kWh/m^3_{Influent}$ (GW) and 1.2 $kWh/m^3_{Influent}$ (BW). The design energy demand was about 0.8 $kWh/m^3_{Influent}$ (GW) and 1.7 $kWh/m^3_{Influent}$ (BW). The first solution fits better to the designed BW energy demand, while the second approach

fits better to the designed GW energy demand. Both calculation approaches allow an approximation of the energy demand, which is slightly lower than the planning. For Fig. 4, an evident reason is the missing of higher loads leading to inaccuracies of the extrapolation. For the second calculation, inaccuracies arise due to assumptions for small units like metering pumps and characteristic curves as well as the linear extrapolation of the measured energy demand. Nonetheless, both calculations verify the energy demand of the planning. The estimated energy demand of the RRC is within the range of water reclamation of 0.5 - 1.0 kWh/m^3 and significantly below other possibilities of water treatment such as sea water desalination (up to 4 kWh/m^3) and indirect potable reuse (up to 2 kWh/m^3) (Voutchkov, 2018). This demonstrates the practicability and advantages of the SEMIZENTRAL approach to face urban water scarcity by reusing treated wastewater.

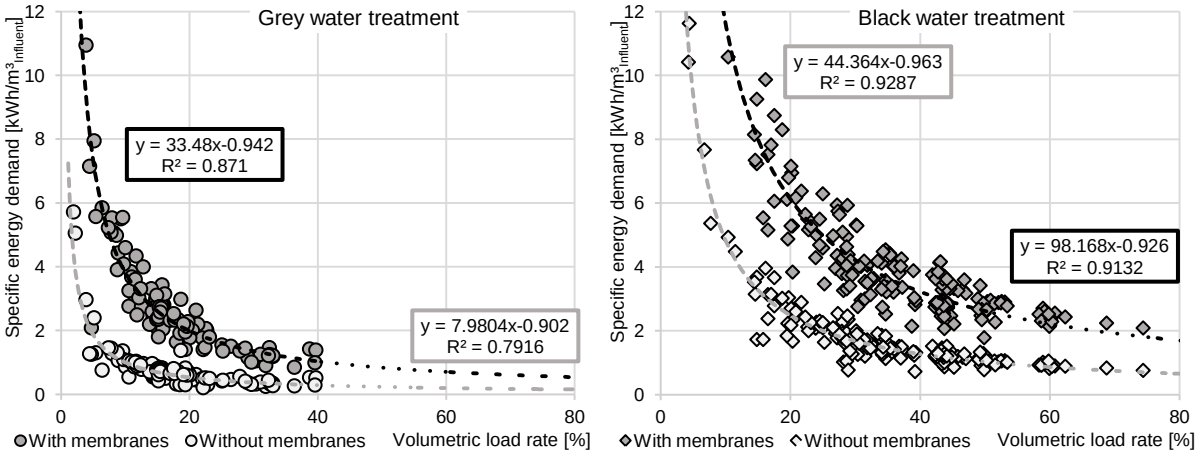


Figure 4 Decrease of the specific energy demand in kWh/m$^3_{Influent}$ with increasing volumetric load rate in %

Conclusions

SEMIZENTRAL's case study at the RRC demonstrates the feasibility of the alternative infrastructure concept for urban water reuse by providing non-potable water with high effluent quality. High reuse rates also show the locals` interest and demand for alternative water sources. Low volumetric loads to the RRC result in a high specific energy demand and need to be considered for further interpretation. Relating the loads and the energy demand two different approaches for calculation confirm, that the RRC achieves energy demands similar to literature as well as design.

References

Bieker, S., Cornel, P., Wagner, M. (2010). *Semicentralized supply and treatment systems: integrated infrastructure solutions for fast growing urban areas*. Water Science and Technology. 61(11). 2905–2913. doi: 10.2166/wst.2010.189

United Nations (2018). *World Urbanization Prospects: The 2018 Revision*.

Radjenovic, J., Petrovic, M., Barcelo, D. (2009*). Fate and distribution of pharmaceuticals in wastewater and sewage sludge of the conventional activated sludge (CAS) and advanced membrane bioreactor (MBR) treatment*. Water Research 43 (3), 831-841, https://doi.org/10.1016/j.watres.2008.11.043

Tolksdorf, J., Cornel, P. (2017). *Semicentralized greywater and blackwater treatment for fast growing cities: how uncertain influent characteristics might affect the treatment processes.* Water Science and Technology. 75 (7). 1722-1731. doi: 10.2166/wst.2017.047

Voutchkov, N. (2018). *Energy use for membrane seawater desalination – current status and trends*. Desalination 431, 2-14, https://doi.org/10.1016/j.desal.2017.10.033

Feasibility of water reclamation for agricultural and urban reuse in Northern Franconia, Germany

C. Schwaller[1], B. Helmreich[1], D. Keilmann[1], F. Zumkeller[2], H. Gerdes[3], J.E. Drewes[1]

[1]Chair of Urban Water Systems Engineering, Technical University of Munich, Garching, Germany; [2]District Government of Lower Franconia, Würzburg, Germany; [3]BGS Umwelt, Darmstadt. Germany; c.schwaller@tum.de

Abstract

Northern Franconia, Germany is a region with low precipitation and is characterized by limited water resources and increasingly competing water demands by various sectors. Thus, a planning process has been initiated with the goal of expanding the conventional water resource portfolio by including water reclamation and stormwater harvesting as potentially viable solutions to combat seasonal water scarcity. The comprehensive evaluation of the quantitative potential of these options revealed that the agricultural and urban landscape irrigation demand could easily be met. However, adaptions and transformations in the existing water supply infrastructure are necessary.

Keywords: Water reclamation; stormwater harvesting; water reuse; urban landscape irrigation; agricultural irrigation

Introduction

Worldwide, the rapid growth of population, increasing urbanization, progressive industrialization and agricultural activities are putting enormous stress on our global water resources and therefore have significant consequences for drinking water supply and sanitation (McDonald et al. 2014; Vörösmarty et al. 2010).

Even in Germany some regions are characterized by increasing conflicting interests in the water sector (Jacob et al. 2008). LAWA (2017) published a report on the effects of climate change on water management in Germany. In addition, the impact of climate change on the flow regime of surface waters in a water-scarce region such as Lower Franconia has been extensively studied in recent years (Altmayer et al. 2017). According to the findings of these two studies, extreme weather events such as heavy rainfall and long-lasting dry periods may occur more often. Lower Franconia is the driest region in Bavaria and one of the driest in Germany (RUF 2006, 2010). Especially in the region around the city of Schweinfurt the limited water resources are

causing increasing conflicts of water use among several sectors such as agriculture, industrial/commercial needs, public drinking water supply, and maintaining ecological base flows. Thus, a long-term regional planning process has been initiated with the goal of expanding the conventional water resource portfolio by including water reclamation and stormwater harvesting as potentially viable solutions to tackle seasonal water scarcity. Seasonal agricultural irrigation in this region is needed for growing high-value crops including a wide range of vegetables and herbs. Potable water supplies currently used for urban landscape irrigation practices could also be substituted by non-potable water qualities. However, the challenge exists in implementing alternative water management approaches in an environment characterized by an existing infrastructure of traditional wastewater collection, treatment and disposal and no track record in water reclamation or stormwater use. Therefore, the aim of this study was to assess the feasibility of long-term water reclamation for agricultural and urban reuse in this region.

Material and Methods

The project is accompanied by a stakeholder process and a participatory approach is adopted to ensure a structured and transparent dialogue among all stakeholders in order to identify potential alternative water resources and requirements for potential fields of application for reclaimed water. Based on these requirements three case study areas in the planning region representing urban landscape (Schweinfurt) and agricultural irrigation (Gochsheim, Schwebheim) were identified. For these study areas, the local demand but also sources of reclaimed water as well as stormwater run-off were specified. Potentially viable roof areas for stormwater collection in commercial neighborhoods were identified and categorized using ArcMap. Stormwater run-off quantities were calculated using the German technical guidance document DWA-A 138. Due to the lack of comprehensive measurement data, the agricultural irrigation demand was estimated through appropriate modeling using the CROPWAT 8.0 software provided by the United Nations “Food and Agriculture Organization”. For the estimation of the agricultural irrigation requirements in “extreme dry and hot” years, the climate data for the year 2003 was utilized. In order to estimate the irrigation requirements for a “normal” year, the climate data from the last 20 years (1999 - 2018) were averaged and fed into the model. Targeted produce has been assumed as mainly irrigated crop with a planting period from mid-April to

mid-July, a sandy soil and an irrigation efficiency of ~ 80 %. Climate data were obtained from the "Climate Data Center FTP server of the German Weather Service", measured at the climate station "Bad Kissingen". The estimation of urban landscape irrigation requirements was based on data provided by corresponding stakeholders.

Results and Discussion

Quantitative assessment of potentially usable alternative water resources

In Schwebheim the potential usable total roof area for stormwater collection summed up to approximately 140,000 m^2, in Gochsheim to approximately 160,000 m^2. The yearly distributions of the mean monthly collectable stormwater volumes for two different scenarios (normal and for extreme dry years) were determined (**Figure 1**). During a normal year represented as short term average of the monthly precipitation data from 1999 – 2018 large volumes of stormwater (> 7,000 m^3) could be potentially collected during January, May, June, July, November and December. However, in an extreme dry and hot year represented as monthly mean of precipitation of the extreme dry and hot years 1949, 1964, 1976, 2003, 2015 and 2018 especially during the period from June to September the collectable stormwater volumes were quite low (< 5,000 m^3). This time represents more than half of the main period for agricultural irrigation (April to end of July). However, the winter months January, November and December had a higher potential regarding collectable stormwater (> 7,000 m^3). Potentially ~ 9.3 million m^3/year or ~ 25,000 m^3/day of reclaimed water would be available as alternative water resource originating from the wastewater treatment plant (WWTP) Schweinfurt.

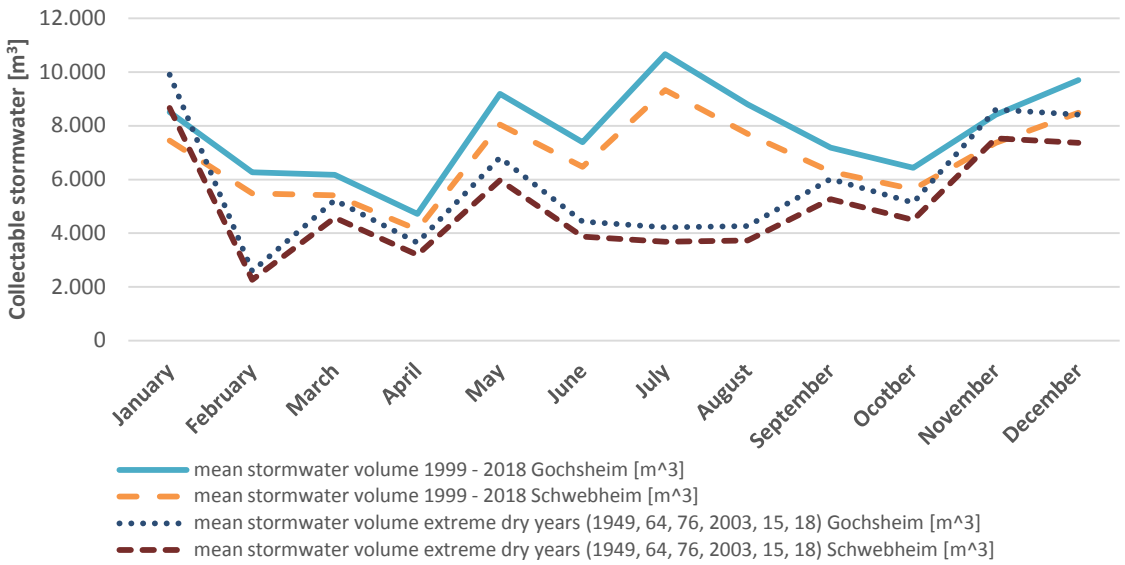


Figure 1: Annual distribution of the potentially monthly collectable stormwater volumes from commercial roof areas in Gochsheim and Schwebheim

Assessment of agricultural and urban landscape irrigation requirements

The modeled total annual irrigation volume for an extreme dry year such as 2003 was 332 mm (= 3,320 m^3/ha), daily peak irrigation was ~ 30 mm (300 m^3/ha) in July. The modeling of the irrigation requirement for a normal year yielded a total annual irrigation requirement of ~ 200 mm (= 2,000 m^3/ha) and a daily peak irrigation of ~ 25 mm (= 250 m^3/ha) in July. Total irrigation requirements are given in **Table 1**. Urban landscape irrigation demand was ~ 2,100 – 2,800 m^3/ha for a normal year and ~ 3,500 – 4,500 m^3/ha for an extreme dry year. With a total potentially irrigable urban area of ~ 41 ha this translates into an absolute required irrigation volume of ~ 86,000 – 115,000 m^3/year for a normal and ~ 144,000 – 185,000 m^3/year for an extreme dry year.

Table 1: Comparison annually potentially collectable stormwater volumes / agricultural irrigation requirements

Region	Precipitation [mm]	Annually collectable stormwater volume [m^3]	Annually total agricultural irrigation requirements [m^3]	Stormwater / irrigation requirements
Gochs-heim	650 („normal“ year)	~ 93,000	80,000 – 170,000	0.55 – 1.16
	480 (extreme dry year)	~ 69,000	140,000 – 300,000	0.23 – 0.49
Scheb-heim	650 („normal“ year)	~ 82,000	120,000 – 200,000	0.41 – 0.68
	480 (extreme dry year)	~ 61,000	210,000 – 350,000	0.17 – 0.29

Quantitative comparison of alternative water resources and water demand

For the evaluation of the actual potential of the alternative water resources, namely collected stormwater runoff and reclaimed water, the water availability was compared

to the water demand **Table 1**. Just for the case of an irrigated agricultural area of only 40 ha in a “normal” year, the annually potentially collectable stormwater exceeded the irrigation requirement (ratio storm runoff / irrigation requirement = 1.16). In all other scenarios, and particularly in extreme dry and hot years the irrigation requirement could not be met by the mere collection of stormwater. Apart from that, all the scenarios with stormwater collection would require the provision of appropriate storage volumes – this encounters two problems: Firstly, in extreme dry and hot years the main period of precipitation did not coincide with the time during which the irrigation requirement was highest. This in turn means that corresponding large stormwater volumes would have to be stored until water is needed. Secondly, the currently existing irrigation infrastructure, which completely relies on groundwater extraction via distributed wells has to be adapted to this new water resource – this in turn will be associated with potentially higher costs for new distributions systems. However, (modeled) daily peak requirements which are in the range of 10,000 – 25,500 m^3/day for Gochsheim and in the range of 15,000 – 30,000 m^3/day for Schwebheim may be considered being economically feasible to store, e.g. by above ground storage lakes or subsurface storage tanks. Thus, stormwater because of its seasonality and its associated unreliability has to be supplemented by other water sources.

In contrast, by utilizing just ~ 7 % ((350,000+300,000) / 9,300,000 ~ 0.07) of the available reclaimed water provided by the WWTP Schweinfurt the total irrigation demand could be covered even for the “worst case scenario” of an irrigated area of 185 ha (Gochsheim and Schwebheim) in an extreme hot and dry year. By potentially utilizing another 1 - 2 % of available reclaimed water, also the urban landscape irrigation requirements could be completely covered.

Water reuse concepts for agricultural and landscape irrigation

Since stormwater as only alternative water resource for agricultural irrigation is in most scenarios quantitatively not sufficient, since its availability is highly seasonable and since adequate large water volumes are unfeasible to store, reclaimed water from the WWTP Schweinfurt had to be considered as additional alternative water resource. Given the seasonality of the demand, flexible and modular treatment options were desired. Treatment options for the various applications favored secondary treated effluent quality followed by ultrafiltration (UF) and UV disinfection,

potentially also powdered activated carbon (PAC) application prior to UF. Combination of both alternative water resources could e.g. provide daily peak irrigation requirement through stored stormwater and long term agricultural requirements especially during main irrigation period through groundwater extraction supported by infiltrated reclaimed water. The advantage of this concept is that only little modifications have to be made to the existing infrastructure, namely transformation of locally existing rainwater retention basins into adequate storages for the provision of daily peak irrigation requirement and constructing infiltration systems for feeding reclaimed water into the groundwater, which is traditionally exploited via a well-established well infrastructure. Irrigation of urban areas in Schweinfurt is either performed by trucks filled with water originating from the river Main or by local groundwater. These water resources could be (partially) substituted by reclaimed water.

Conclusions

In Lower Franconia in the region of Schweinfurt groundwater has to be sustained as safe drinking water resource. Besides, water management has to address issues such as stressed surface waters with more frequent and severe low water conditions. Collected stormwater and reclaimed water are promising alternative water resources. However, only a combination of both ensures a reliable irrigation water supply, whereas reclaimed water constitutes the more promising option because of its high quantity, well managed quality, independence from season and the potential flexible, resilient, reliable as well as robust treatment technology.

Acknowledgements

This research is funded by the Bavarian State Ministry of the Environment and Consumer Protection (StMUV), AZ: 52-4429-10 while the District Government of Lower Franconia (RUF) is responsible for the project management.

References

Altmayer M., Belau M. and Foltyn M. (2017): Strategien zum Umgang mit Niedrigwasser in Zeiten des Klimawandels in Bayern. In gwf Wasser/Abwasser (158 (12)), pp. 29–37.

DWA-A 138: Arbeitsblatt DWA-A 138: Planung, Bau und Betrieb von Anlagen zur Versickerung von Niederschlagswasser 2005.

Jacob D., Göttel H., Kotlarski S., Lorenz P. and Sieck K. (2008): Klimaauswirkungen und Anpassungen in Deutschland – Phase 1: Erstellung regionaler Klimaszenarien in Deutschland, Umweltbundesamt, Forschungsbericht 204 41 138.

LAWA (2017): Bund/Länder-Arbeitsgemeinschaft Wasser: Auswirkungen des Klimawandels auf die Wasserwirtschaft. Bestandsaufnahme, Handlungsoptionen und strategische Handlungsfelder 2017.

McDonald R. I., Weber K., Padowski J., Flörke M., Schneider C., Green P. A. et al. (2014): Water on an urban planet: Urbanization and the reach of urban water infrastructure. In Global Environmental Change 27, pp. 96–105. DOI: 10.1016/j.gloenvcha.2014.04.022.

RUF (2006): Regierung von Unterfranken: Trinkwasserversorgung in Unterfranken.

RUF (2010): Regierung von Unterfranken: Wasserversorgungsbilanz Unterfranken 2025 - I Bericht.

Vörösmarty C. J., McIntyre P. B., Gessner M. O., Dudgeon D., Prusevich A., Green P. et al. (2010): Global threats to human water security and river biodiversity. In Nature 467 (7315), pp. 555–561. DOI: 10.1038/nature09440.

Demonstration of Environment Friendly Water Reclamation Plant: Beijing Bishui Underground Water Reclamation Plant Case Study

Yanjun Liu, Hongtao Pang, Xiaoxin Cao, Yuanyuan Guo, Peng Li, Chang Su, Yi Peng*

China Water Environment Group Limited, Beijing, 101101, China

**Corresponding author, caoxiaoxin@citicwater.com*

Abstract:

Beijing Bishui project, upgrading the traditional sewage treatment plant (STP) to underground water reclamation plant (WRP), presents an environment friendly water reclamation case. It increases the treatment capacity from 100,000m^3/d to 180,000m^3/d and covers only one third of the original footprint. The treatment processes in the new plant consists of step-feed Anoxic/Oxic process and advanced treatment to reduce the nitrogen and phosphorus levels. Meanwhile, by applying the environment friendly concept, 29.3 hectares of land is released to construct an ecological complex in Bishui project. This integrates sewage treatment with live water garden, public recreation and R&D platform etc.

Keywords: underground water reclamation plant; step-feed Anoxic/Oxic process; ecological complex.

Introduction

The original Beijing Bishui sewage treatment plant was built in 2002, with treatment capacity 100,000m^3/d. With the urbanization of Beijing, Tongzhou district as the sub-civic center started blooming developing, which accompanying with stricter STP discharge standard. Further, sound and odor caused by traditional STP affect surrounding resident, so upgrading Bishui STP is in urgent demand. Bishui upgrading project upgrades the traditional STP to underground water reclamation plant and constructs an ecological complex that utilizes the space above and under ground efficiently. The discharge standard was improved to class I-B of Beijing Discharge Standard(DB11/890-2012) and treatment capacity increased to 180,000 m^3/d. Fig. 1 shows the comparison of Bishui plant before and after upgrading.

(a) (b) (c)

Figure 1 Bishui plant before upgrading (a), under construction (b) and ecological complex（c）

Sewage Treatment and Reuse Process: The treatment process of Bishui plant is shown in Fig.2. The footprint of new Bishui plant (0.4 m^2/t wastewater) is far less than that of conventional plant

(1.0 m^2/t wastewater). The advanced step-feed multistage A/O process was used as biological treatment, which consisted with 4 streams, and each stream flows into three A/O tanks, Hydraulic Retention Time (HRT) and return sludge ratio are 14.8h and 75%. The method of step feed effectively balances the carbon source need of nitrogen removal by denitrification in anoxic zone and biological phosphorus release in anaerobic zone, enhancing the flexibility of process operation[1]. Using biological deodorization technology to eliminate odor, four biofilters with carbon carriers were set, whose whole treatment capacity was 116,000 m^3/h.

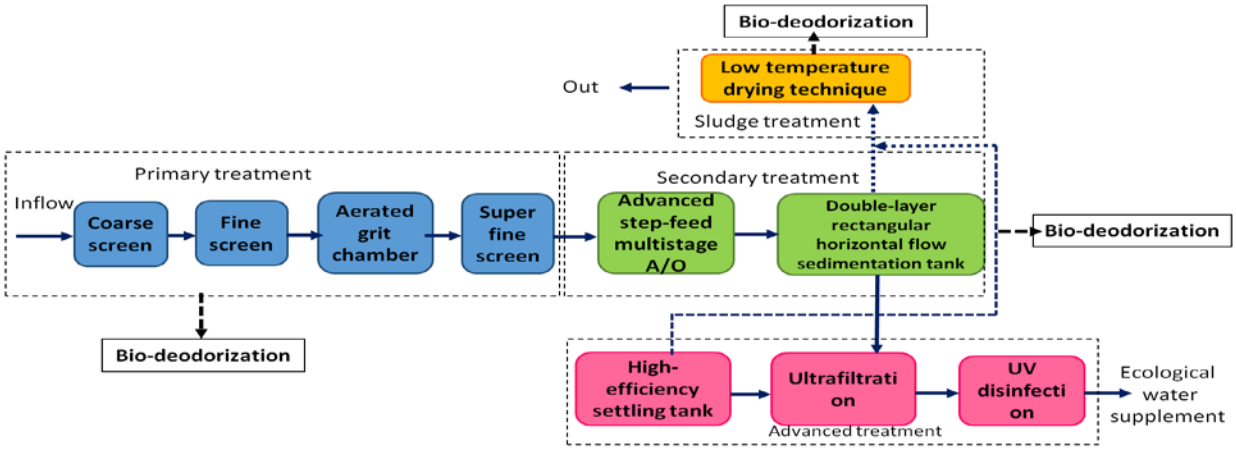


Fig. 2 Treatment process of new Bishui WRP

Ecological Complex Construction: Bishui project combines sewage treatment with landscape and public facilties to contribute an ecological complex. This ecological complex, covering 56.6 hectares, provides facilities and service to public, which consisting recreation park, science museum and water R&D platform.To achieve energy and resource renewable, water source heat pump is applied, by which the thermal energy in sewage heat the plant and buildings. 80,000 m^3/d reclaimed water from Bishui plant is ultilzed as cooling water of nearby electricity power plant, while the other effluent recharges to Yudai River to improve water quality and remediate ecosystem.

Conclusions

By using advanced technologies and carrying out the environment friendly concept, the upgrading project of Bishui plant not only achieves high-quality water discharge and utilizes water resource and energy efficiently, also constructs an ecological complex providing service to the public.

Acknowledgments

Thanks to Major Science and Technology Program (2017ZX07103-003).

References

[1] Ge S, Zhu Y, Lu C, et al. Full-scale demonstration of step feed concept for improving an anaerobic/anoxic/aerobic nutrient removal process. [J]. Bioresource Technology, 2012, 120(3):305-313.

ZLD Installations in India for F&B, Chemistry and Metal Processing

Dr. E. Döpkens, D. Bernhardt, Dr. M. Lebek, REMONDIS Aqua Industrie, Lünen, Germany;
V. N. Diwakar, T. Block, REMONDIS Aqua International, Pune, India

1 Introduction

Since several years the Zero Liquid Discharge (ZLD) approach is discussed and several tests in various industrial branches have been performed. The ZLD approach is able to reach high water recycling rates which is an urgent need in several water shortage areas. This paper describes design and experience of three ZLD installations in India. All units consist of standard waste water technologies which are well known and are designed and operated by REMONDIS as BOOT contracts. Each ZLD installation include several treatment steps like biological treatment, sand filtration, active carbon, membrane filtration (UF and RO), IOX, UV, evaporation, crystallization and drying. Successful operation of ZLD plants require that operation of all single units does fit together to match changing raw water qualities at any time.

2 Example Metal Processing Industry

In 2017 a new production site for moulded and galvanized plastics was erected by Euro American Plastic Products (EAP) in Bhiwadi near New Dehli. Part of the permit was the ZLD requirement with respect to production wastewater. EAP assigned REMONDIS with design, construction and operation by a BOOT contract. The wastewater composition is typical for this kind of industry. The total daily wastewater flow is 200 m³ which includes Chrome and acid containing wastewater, alkali wastewater and general industrial wastewater. Typical numbers of the mixed waste water during commissioning in November and December 2017 are shown in Table 1.

Table 1: Characterization mixed waste water

Parameter	Value
Flow [m³/d]	200
pH	4 - 6
TDS [mg/L]	6.015
COD [mg/L]	113
Cr total [mg/L]	1.418

Ni [mg/L]	54
Cu [mg/L]	67
Fe [mg/L]	9

First treatment steps are Cr (VI) reduction by sodium bisulfite and sulfuric acid, batch pretreatment of a complexing agent containing waste water stream, mixing of all streams and heavy metal precipitation by lime, caustic and polyelectrolyte. A lamella clarifier removes the formed flocs and further sludge treatment takes place by sludge collecting tank and filter press. Fine flocs and organic substances are removed by a sand filter and active carbon filter afterwards. Final pretreatment step before entering the RO salt removal units is an UF (Type Inge dizzer XL 1,5 MB 50 WT) to ensure full removal of all suspended particles. Feed of RO 2 is the permeate of RO 1 and slightly polluted water from flushing processes. Design of the RO units are as shown in Table 2.

Table 2: Design RO units

Unit	Membranes	Recovery rate
RO 1 (3 stage design)	17 modules a 34 m²	80 %
RO 2 (1 stage design)	14 modules a 34 m²	70 %

Demineralized water for the production requires different qualities depending on the specific needs of each production step. Therefore both streams of RO 2, permeate and concentrate, are directly fed to production. One part of the permeate receives an additional polishing by a mixed bed ion exchange resulting in TDS values below 1 mg/L and is used as boiler feed water. Remaining permeate and concentrate of RO 2 are used for electroplating bathes, flushing of products or other utilities. Use of three different water qualities allows an optimization of CAPEX and OPEX. The qualities of the RO outlet streams are described in Table 3.

Table 3: Typical qualities RO output

Process Step	TDS [mg/L]
Permeate RO 1	110
Concentrate RO 1	19.170
Permeate RO 2	15
Concentrate RO 2	1.850

Commissioning of production and ZLD installation started in November 2017. A water recycling rate of app. 90% was achieved by operation of precipitation and membrane treatment steps. Nearly all organic and inorganic pollutions were concentrated in a combined concentrate feed to the evaporator.

Most challenging during the first months of operation were handling of precipitation and lamella clarifiers due to fast changing raw water quality and developing of a suitable membrane cleaning strategy. Due to limited buffer capacities within the ZLD plant every down time of only one single treatment step interrupts all other processes including production. Therefore it was several times needed to discharge waste water during commissioning to get sufficient time for e.g. testing of membrane cleaning procedures. Especially cleaning frequency of the first RO-stage is the bottleneck of plant reliability. After some weeks of testing and optimization the following cleaning frequencies were obtained.

Table 4: Typical cleaning frequencies

Unit	Frequency	Used Chemicals
UF	monthly	NaOCl and citric acid
RO 1 (3 stage design)	every 7 – 10 days	HCl and NaOH
RO 2 (1 stage design)	monthly	HCl and NaOH

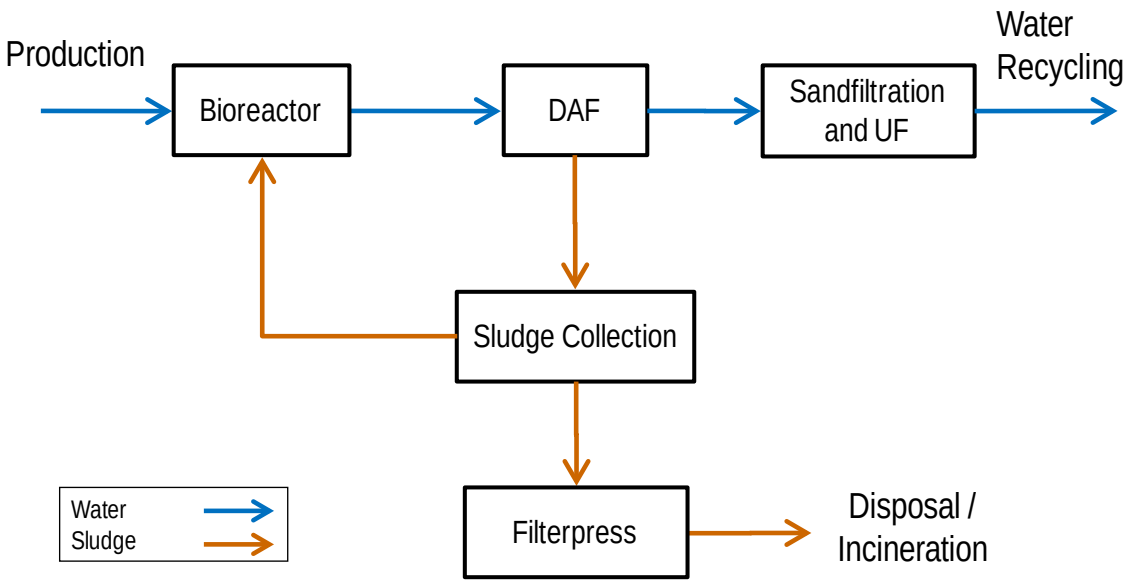
The evaporator was commissioned after a stable concentrate effluent was obtained. Operation of the evaporator reduces the volume of another 60%. That means that including evaporator operation the ZLD plant reaches a recycling rate of app. 96% in which losses by evaporation are not considered.

3 Example Food&Beverage Industry

An international Food company established a new production facility near Pune in 2018. Due to general water shortage in that area the ZLD approach was required by the authorities. For the F&B industry it is normally not acceptable to reuse waste water within the production even if this would be possible from a technical point of view. Therefore the purified waste water of app. 120 m³ per

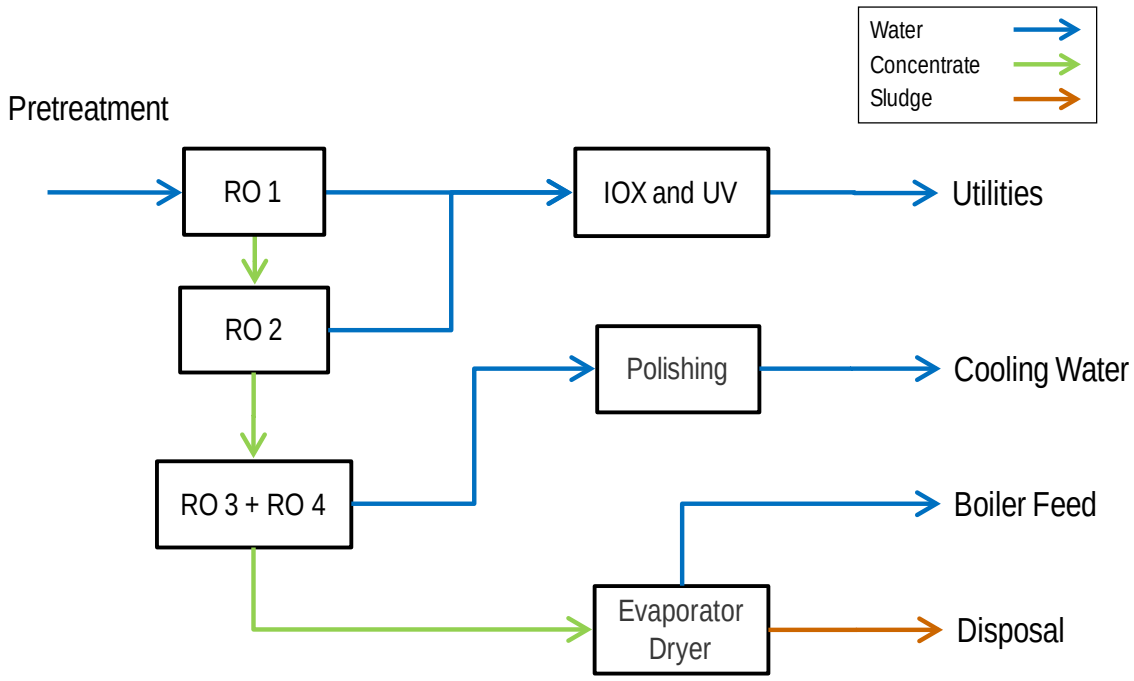
day is used for cooling water make up, boiler feed or utilities like toilets or cleaning activities without product contact.

The ZLD plant consist of two steps pretreatment and water recycling. Before entering the water recycling plant the wastewater is pretreated in an aerobic WWTP followed by sand filtration and active carbon filtration. A DAF is used for sludge removal instead of a sedimentation tank. Picture 1 shows the pretreatment step.



Picture 1: Pretreatment F&B Waste Water

After pretreatment the water enters the water recycling plant which consists of two UF units, four RO-units, one evaporator/dryer unit, ion exchange and UV radiation. Due to the complex water recycling process several different recycling water qualities are available. Depending on purification level they are used for irrigation, cleaning facilities outside production, process water and cooling tower make-up water. Commissioning of the plant did start in February 2019.



Picture 2: Water Recycling Plant for F&B Waste Water

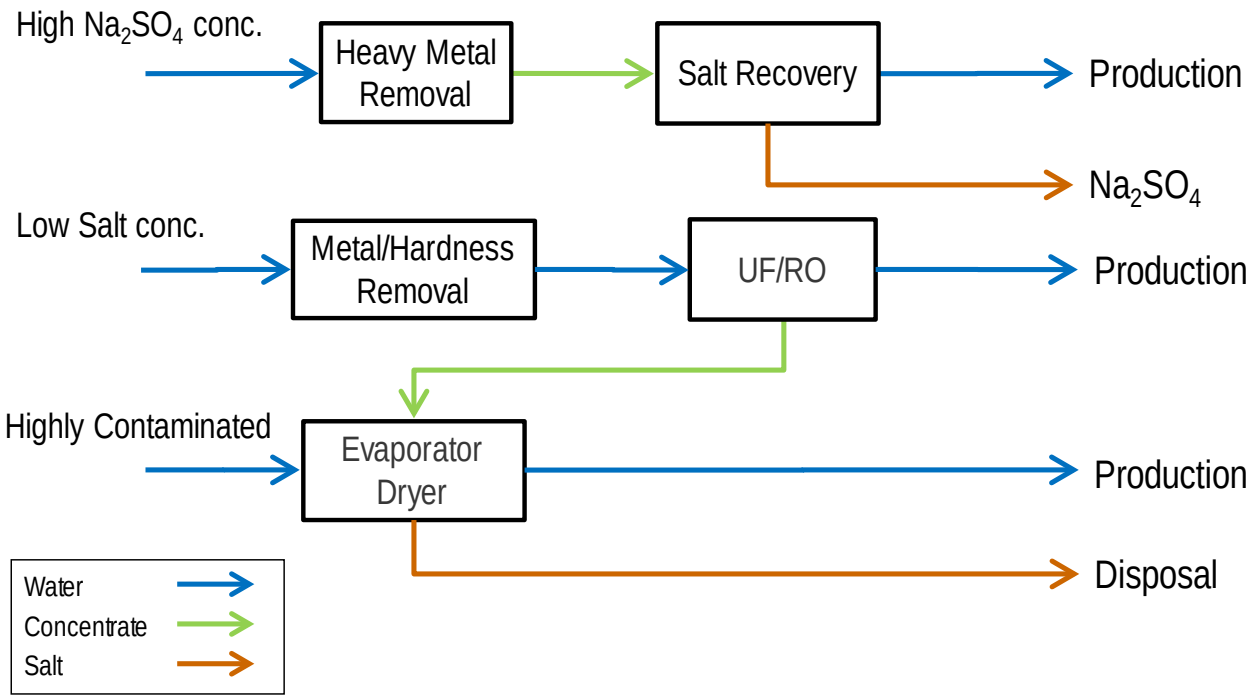
3 Example Chemical Industry

REMONDIS designed a complex water recycling and salt recovery installation for an inorganic catalyst production near Mumbai.

The waste water of 550 m³ per day is separated in three streams which allows optimized treatment depending on the specific waste water composition. One stream contains more than 130.000 ppm sodium sulfate which makes a salt recovery step economically useful. This waste water will be pretreated by a heavy metal precipitation before entering an evaporator, crystallizer and dryer. Product pureness will be >99% and thereby sufficient for many technical applications.

The second stream contains only low salt concentrations and will be pretreated by precipitation and ion exchange to remove heavy metals, Aluminium and hardness. Further treatment takes place by UF and RO resulting in a water recovery rate above 80%. The permeate quality is sufficient for direct reuse in the production. Concentrate of RO and a third waste water stream are directed to a second evaporation and dryer. Salt output of this stream is highly contaminated with heavy metals and organic substances and has to be disposed.

Picture 3 shows a simplified overview about the complex ZLD installation.



Picture 3: Simplified Scheme ZLD Plant Chemical Industry

Up to 100% Reuse: Zero Liquid Discharge versus Production-integrated Water Management

Elmar Billenkamp, EnviroChemie GmbH, Rossdorf, Germany

In most industries water is consumed and wastewater is produced. Water recycling and reuse is becoming more and more important for many companies under economical and ecological aspects. Beside this water recycling and reuse can improve production security in regions with a lack of water and wastewater infrastructure.

In this context the concept of Zero Liquid Discharge (ZLD) is discussed critically among international expert as technologically most mature and ecologically most valuable treatment concept. In a strict definition ZLD is understood as complete reduction of the water volume leaving a system. Solids are recycled or disposed in dry form. These concepts are very expensive in terms of investment and operating costs. In most cases a combination of membrane technology and energy-intensive evaporation technology is required as final treatment step. The question is whether or under what conditions it is economical and sustainable to completely close industrial water cycles. An alternative could be optimized production-integrated water management which considers the specific boundary conditions on site. These conditions are usually very complex, as an understanding of the entire production or factory is necessary. In general, however, it offers higher efficiency and saving potentials.

During the presentation different national and international practical examples will be presented which show the range of optimized production-integrated water management up to ZLD concepts. The respective driving forces for the concepts are addressed and discussed. Special emphasis will be placed on the complex environmental, economic and administrative constraints which had to be considered. The range of practical examples includes:

- A ZLD concept according to the strong definition of ZLD (100% water reuse, disposal of dry solids) which was worked out for a production site in India. The ZLD concept includes all water and wastewater streams within the production as well as sanitary wastewater and drinking water. The procedure for development of the concept (mass balances, etc.) is addressed.

- A ZLD concept according to the less strong definition of ZLD in the automotive industry. Since 2011 the production wastewater is treated via chemical-physical, biological and membrane treatment steps. Concentrates are further reduced via evaporation. The recycled water is reused within the factory and for irrigation.
- A concept for production-integrated water management at a laundry in Germany. Since 2009 significant amounts of heat and water are recovered from production wastewater and reused for washing processes again. The concept includes biological and membrane treatment steps. On average up to 70% of the wastewater is reused and energy savings of up to 1.100.000 kWh per year are achieved.

Bioanalytical Tools for Monitoring of Recycled Water – Advisory Panel Recommendations for the State of California (USA)

K.A. Maruya, Southern California Coastal Water Research Project, Costa Mesa CA, USA; J.E. Drewes, Technical University of Munich, Garching, Germany; P.D. Anderson, Arcadis US Inc., Chelmsford MA, USA; N.D. Denslow, University of Florida, Gainesville FL, USA; W. Jakubowski, WaltJay Consulting Inc., Spokane WA, USA; A.O. Oliveiri, EOA Inc., Oakland CA, USA; D. Schlenk, University of California, Riverside CA, USA; S.A. Snyder, Nanyang Technological University, Singapore; A.C. Mehinto; Southern California Coastal Water Research Project, Costa Mesa CA, USA.

Current targeted monitoring of water quality falls short in addressing the gamut of individual known and unknown chemicals, including transformation products, and the mixtures they may form at various stages of recycled water treatment. Cell (*in vitro*) assays engineered to respond to chemicals by initiating a molecular event (e.g. gene expression) that can be linked to an adverse health outcome are now available to screen water quality via an integrative, “mode of action” approach. Thus, successful development and application of such bioanalytical tools will provide a welcome supplement to existing targeted monitoring methods in demonstrating the high quality of recycled water used for potable reuse.

A science advisory panel (“Panel”) was recently re-convened to update monitoring recommendations for recycled water applications across the State of California (USA). Among the hundreds of cell assay endpoints that exist today, the Panel focused on those whose results can be 1) expressed as an equivalent concentration; and 2) linked to an adverse health outcome for consideration as water quality screening tools. Selecting from a handful of endpoints that have undergone various stages of adaptation and standardization by water quality professionals (**Table 1**), the Panel recently concluded that two such endpoints – the estrogen receptor (ER-α) and aryl hydrocarbon receptor (AhR) – were ready for pilot screening applications.

Although standardized protocols for bioanalytical endpoints in their later stages of development are now considered as sufficiently robust for water samples,

Table 1 Candidate cell (in vitro) assays for screening of recycled water quality.

Endpoint Activity	Relevant CECs	Adverse effect	Development Stage[a]
I. Endocrine disrupting chemicals (EDCs)			
Estrogen receptor (ER)	estradiol, bisphenol A, nonylphenol	Feminization, impaired reproduction, cancer	4
Anti-estrogen receptor (ER-)	synthetic pyrethroids	Disrupted reproductive development, impaired reproduction	2
Anti-androgen receptor (AR-)	musks, phthalates, pesticides	Androgen insensitivity, impaired reproduction, cancer	2
Glucocorticoid receptor (GR)	anti-inflammatory steroids	Development, immune diseases, diabetes	3
Progesterone receptor (PR)	progestins	Cancer, hormone resistance syndrome, impaired reproduction	2
II. Carcinogenic chemicals			
Aryl hydrocarbon receptor (AhR)	dioxin-like chemicals, polycyclic aromatic hydrocarbons, pesticides	Cancer, impaired reproduction, Development	3
Tumor suppressor protein Response Element (p53RE)	DNA alkylating agents, oxidants, PAH metabolites	Oxidative stress, tissue and DNA damage, cancer	1
III. Immunosuppressants, neurotoxins and other chemicals of concern			
Thyroid hormone receptor (TR)	pesticides, bisphenol A, flame retardants	Impaired metabolism, auto-immune diseases	1
Peroxisome proliferator activated receptor (PPAR)	pharmaceuticals, phthalates	Metabolic disorders, impaired immune function, cancer	1
Acetylcholine receptor (AChE)	neonicotinoid and other neurotoxic pesticides	Neurotoxicity, behavior	1

Stage 1 (exploratory): is endpoint amenable to screening of water quality?
Stage 2 (optimization): is performance consistent with monitoring goals?
Stage 3 (standardization): can standard operating procedures (SOPs) and thresholds be developed?
Stage 4 (pilot evaluation): does it provide value in practice?
Stage 5 (implementation): can it be certified as a standard method and run by commercial labs?

interpretive guidelines as they relate to protection of human or ecological health are less well-developed. In their updated recommendations to California water quality regulators, the Panel thus identified a process to interpret, and as warranted act upon bioanalytical results, as well as an initial monitoring threshold of 3.5 ng E2/L for the ER-α screening assay. Should an "above threshold" situation persist upon repeated sampling, targeted analysis of known chemicals likely to elicit the bioanalytical response (e.g. known estrogens for the ER-α assay) would be recommended to identify the problematic chemicals. If targeted results were inconclusive, non-targeted mass spectrometry could be applied to broaden the universe of chemicals addressed in this "toxicity identification evaluation-type" approach (**Figure 1**).

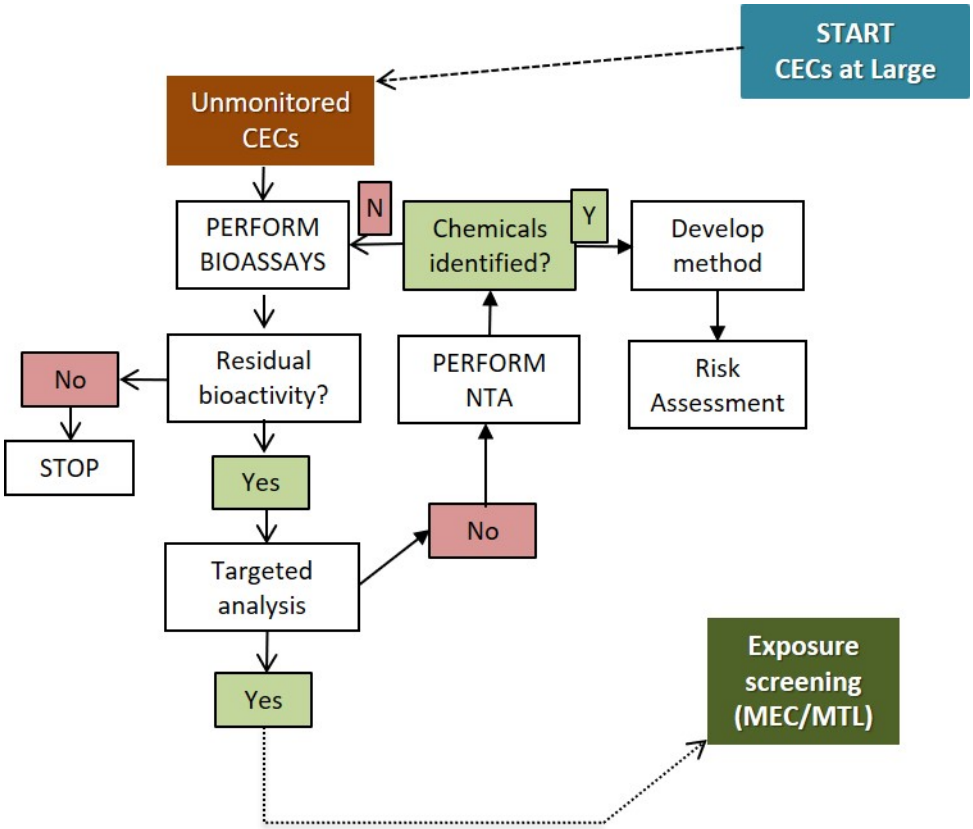


Fig. 1. Screening approach for unmonitored chemicals in recycled water using bioanalytical tools and non-targeted chemical analysis (NTA).

Per the Panel's recommendations, the State of California is considering the collection of ER-α and AhR bioanalytical monitoring data for potable reuse applications as part of their ever-evolving monitoring requirements. To allow for the

interpretive science to catch up with measurement capability and capacity, the Panel has proposed a systematic, stepwise roll-out of bioanalytical screening that de-emphasizes response actions requirements during the first 2-3 years of data collection. An iterative process would follow that would evaluate an expanded set of endpoints, as well as the robustness of available screening thresholds used to interpret bioanalytical monitoring results. To our knowledge, incorporation of the Panel's bioanalytical monitoring recommendations in the State's Recycled Water Policy would be the first such implementation of in vitro assays for screening of recycled water quality anywhere in the world.

Development of a Validation Process for UV-AOPs for Potable Water Reuse

Stuart J. Khan, University of New South Wales, Sydney, Australia;
Amos Branch, University of New South Wales, Sydney, Australia.

Abstract

Potable water reuse is increasingly recognised as an important water management strategy for future cities around the world. In order to produce the highest quality drinking water from municipal wastewater sources, advanced treatment by ultraviolet radiation advanced oxidation processes (UV-AOPs) is a prominent feature of some of the most sophisticated potable reuse projects. Validation and monitoring of the UV aspects of UV-AOPs are well established and effective. However, validation of the AOP aspects (i.e., the production of oxidative radical species) is poorly developed and ongoing performance monitoring methods are currently impractical for most projects. This is a significant gap in advanced water treatment process reliability for chemical contaminant degradation. Furthermore, it fails to capitalise on potentially significantly enhanced inactivation of some relatively UV-resistant viruses.

Despite the growing use and importance of UV-AOPs to produce radical oxidation species for advanced water treatment, there is currently no widely accepted procedure for validating or monitoring radical oxidant production performance in full scale plants. The lack of ongoing performance monitoring ability is in contrast with other important water treatment processes including membrane filtration processes, chlorine-based disinfection processes and UV-photolysis processes.

One approach for UV-AOP performance validation is based on the use of indicator chemicals, with diverse functional groups, to assess organic chemical oxidation {Dickenson, 2009 #5476}. A version of this approach was adopted into potable reuse regulations by the State of California, USA {California Office of Administrative Law, 2018 #5138}. In that case, a project proponent must demonstrate that the oxidation process can achieve a specified level of performance for at least seven detectable indicator chemicals. The procedure is complex, requires high levels of specialised

expertise, and has limited capacity for ongoing performance monitoring. Since most UV-AOP applications are subsequent to highly effective treatment processes such as reverse osmosis, the availability of suitable target compounds is severely limited.

A more robust and universally applicable approach to UV-AOP validation and performance monitoring is required {Khan, 2017 #5211}. This presentation will describe the development of such an approach, based on the identification of robust relationships between process performance and directly monitorable operational parameters. This concept is universally applied in the use of “CT” values as a measure of disinfectant concentration (C) and contact time (T) for chlorine disinfection of drinking water.

This concept is now being further developed using a novel pilot system, designed to facilitate flexible operation and detailed monitoring. Through carefully designed experiments, observed operational parameters are related to treatment performance for a range of contaminants. A final outcome of this work will include the development of a framework to provide validation of process performance relationships and ongoing performance monitoring. Reliable real-time performance monitoring, would satisfy a key requirement of water quality public health regulators when assessing and licensing potable water reuse projects.

References

Proxies to monitor the inactivation of viruses by ozone

Camille Wolf, Laboratory of Environmental Chemistry, School of Architecture, Civil and Environmental Engineering (ENAC), École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland; Annalisa Pavese, Laboratory of Environmental Chemistry, ENAC, EPFL, Lausanne, Switzerland; Urs von Gunten, Laboratory of Water Quality and Treatment, ENAC, EPFL, Lausanne, and Eawag, Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland; Tamar Kohn, Laboratory of Environmental Chemistry, ENAC, EPFL, Lausanne, Switzerland.

Background

Ozone is rapidly becoming an integral part of many reuse treatment trains, thanks to its high efficacy at inactivating pathogens and mitigating trace organic contaminants. A remaining barrier to fully exploiting the potential of ozone as a disinfectant is the difficulty of monitoring its effect in real-time. Specifically, real-time methods to monitor pathogen infectivity loss are rare, or in the case of viruses, non-existent. Alternatively, for pathogens with known ozone inactivation kinetics, disinfection efficacy could be estimated based on the ozone exposure in the treatment train, but the measurement of ozone exposure in real-time is not practical in wastewaters because of its short life time. A good alternative is therefore the use of an easy-to-measure proxy that is correlated with ozone exposure, and to monitor this proxy rather than ozone exposure itself at critical points in the treatment train. This proxy, in turn, can then be correlated with disinfection efficacy.

Objectives and approach

The goal of this study was to identify and evaluate proxies to monitor virus inactivation during water and wastewater treatment by ozone. We first quantified inactivation kinetics as a function of the ozone exposure for a series of human and surrogate viruses. Second-order rate constants were determined in well-controlled buffer systems and were subsequently confirmed in real water matrices, specifically two different surface waters and a secondary wastewater effluent. We then evaluated proxies as a function of the specific ozone dose (mg O_3 / mg DOC) and the resulting ozone exposure (Ms) in the three water matrices: the change in UV_{254} (ΔUV_{254}), and the abatement of carbamazepine (CBZ), a ubiquitous organic micropollutant with a

similar abatement rate constant as human viruses. Finally, the proxies were correlated with virus inactivation, and their applicability to virus inactivation monitoring was tested in a pilot-scale water treatment setup.

Results

All tested viruses exhibited second-order ozone inactivation rate constants on the order of 10^6 $M^{-1}s^{-1}$, confirming ozone's high potency toward viruses. Inactivation kinetics in surface water were comparable to those in buffered ultrapure water, but inactivation in wastewater inactivation tailed off at exposures $>10^{-4}$ Ms (corresponding to 3-5 $\log_{10}$ inactivation), indicating that wastewater matrix constituents exert a protective effect on viruses.

Both proxies tested were well correlated with virus inactivation. However, in WW a threshold ΔUV_{254} of 15-20% had to be overcome before virus inactivation was observed. Beyond this threshold, ΔUV_{254} was linearly correlated with up to 7 $\log_{10}$ of virus inactivation. A limitation of ΔUV_{254} as a proxy is that matrices have to contain sufficient dissolved organic matter (DOM, measured as dissolved organic carbon, DOC) to capture ΔUV_{254} reduction during ozonation. Therefore, this proxy is not practical in low DOM waters. In contrast, CBZ could be used as a proxy in all waters tested. Our analytical methods allowed to measure a 2-log CBZ abatement by ozonation, which corresponded to a 2-4-$\log_{10}$ virus inactivation, depending on the water matrix. However, the applicability of CBZ as a proxy depends on its presence at measurable concentrations in the water matrix. The correlation between the proxies and inactivation were independent of the virus species studied, but differed between the three water matrices tested. Generally, a higher DOM content led to less efficient disinfection for the same proxy signal.

Conclusions

Our study confirms that ozone is a highly effective disinfectant for viruses, though its efficacy depends on the type of water, in particular the content of DOM. Both ΔUV_{254} and CBZ can serve as proxies to estimate virus inactivation in real-time, and these proxies may be used to assign log removal credits for ozonation in potable water reuse.

Economic Viability of Recycled Water Scheme – Can We Afford it?

Andrzej Listowski [a], Long Nghiem [a], Saravanamuth Vigneswaran (Vigi) [a]*

[a] *School of Civil and Environmental Engineering, University of Technology Sydney, NSW 2007, Australia.*
** Corresponding and presenting author: andreli2011@gmail.com*

Abstract:
Recycled water must play a much greater role in delivering services to a growing population and helping to secure the future water supplies to our cities. The uptake and investment in water reclamation and reuse has plateaued in recent years, creating concerns that the economic framework, water pricing policy and regulatory requirements could be contributing to this situation. Current decisions to undertake the water reclamation underline cost effectiveness as a primary objective, while other significant benefits are not properly valued and i assessed in the cost-benefit analysis. This study confirmed, that the cost-benefits analysis (CBA) technique is the most comprehensive assessment of the water reclamation scheme, because it relies on a as the most effective and systematic approach to calculating, evaluating and compering investment options.

Introduction

Without a doubt, water reclamation is one of the most challenging water supply options technically, economically and socially. Relatively little or inaccurately quantified information has been produced on water recycling from an economic perspective, particularly cost and beneficial outcomes. Technology performance and costs analysis are essential foundation for the decision-making, successful implementation and continued operation of the water reuse scheme. In addition some uncertainty exists in assessing water reclamation scheme, due to fragmentation and not well developed role of economic assessment tools and application of economic logic in project appraisal technique. One of the key constraints to development of recycled water markets is its poor cost efficiency and economic viability analysis. Consequently, least-cost approach is dominating decision making, resulting in selection of options without major consideration of the total impact and benefits. The decision-makers, engineers and planners face often challenges to correctly understand and interpret sophisticated economic principles and to apply them practically. The economic evaluation of the wastewater treatment

and reuse projects is determined by cost-effectiveness analysis, which is distinct from cost–benefit analysis, because it assigns a monetary value to the measure of effect while it is constraint by the inability to monetise direct and indirect benefits such as avoided costs from not having to develop new water sources, reduced wastewater discharges, environmental pollution and the economic value of the recycled water (Listowski, A, 2011)

Financial analysis and economic evaluation are two most common methods being used in evaluation of water reuse schemes. The economic and financial analyses appraise the profit of an investment. For a project to be economically viable, it must be financially sustainable, technologically advanced and operationally efficient. Economic and financial analysis are conducted in monetary terms, with the major difference lying in the definition and allocation of costs and benefits. (Falconer, G., Mitchell,S.,(2012).

Pricing of recycled water is not the only policy setting that will influence the decisions to develop recycled water scheme. It is equally important, that policy settings provide incentives for the most efficient recycling solutions. Based on the current monopoly cost structures and water pricing policies, it is uneconomic to treat wastewater to produce recycled water. This argument supports claim, that supplying drinking water from fresh water source is still the cheapest cost option, but not necessary the most socially and environmentally equitable. At the same time, while water pricing is to be based on the principles of full cost recovery, recycled water price is set below its production cost as it is perceived to be a lower quality product. In fact, water quality test confirmed, that recycled water is actually better quality than drinking water. The dilemma and misconception between water costs, charges and prices often jeopardize chances for development of recycled water scheme. (A. Listowski, 2011)

This scenario is further skewed by considerable disparity in potable water pricing. In in Sydney, potable water price in 2000 was $0.90/ kL and it has gradually increased to a $1.01 per kL in 2005. However, in subsequent five years water price has increased dramatically and it has doubled in 2010 to $2.01 per kL. The high water prices coincided with the Government’s decision to proceed with installation of $2bn desalination plan. In recent years seawater desalination projects have rapidly emerged in all major coastal cities in Australia. This seems to be a rapid “insurance policy”, while the role of urban water reuse was considerably unrecognized. In 2012 when the dam storage level reached 90% capacity, the desalination plant ceased

production. Despite desalination plans being turned off, the price of potable water continue to increase until 2014 to $2.276./kL, until unexpectedly it has been lowered to $2.00 per kL in 2016. Recycled water pricing had to follow the same course.

Traditionally, urban water systems have been designed to operate as a linear process. Typically, water is extracted from rivers, lakes, or aquifers, transported, distributed and after single use treated and dumped into its primary source, rivers or oceans. This linear water system is unsustainable and can not coupe with unprecedented urbanisation, high water drawdown for agriculture and industry and climate change, and it should be redesigned. Sea water desalination could be a viable solution where energy prices are very low and finance is available, however in inland locations and many parts of the world desalination remains prohibitively expensive. Cities can reuse wastewater, collect, store and treat stormwater rather than throwing it away. Direct Potable Reuse (DPR) relies on highly effective technologies, that can treat wastewater to such high quality, that it can be used for potable water. A major advantage of DPR is its significant reduction in transportation, energy and reticulation costs. However, potable reuse solutions require a high level of public trust in decision makers, education and change of attitudes towards reusing wastewater. Integrated Urban Water Management (IUWM) is a comprehensive approach for the whole of catchment urban water management and water reuse including :

- Water supply and diversity of resources available,
- Wastewater and stormwater collection, storage and beneficial treatment
- Demand management and conservation of water resources
- Pollution control and minimisation of impact on receiving water, land and air

The Water Reclamation & Management Scheme (WRAMS) concept was developed and implemented for the first time in Sydney for 2000 Olympics (Listowski, A., 2002). This proven model provides strategic direction and universal solution to future urban water systems. Clear benefits of IUWM include:

- **Providing water security** through efficient supply/water and diversification of water resources; surface, ground, recycled water, stormwater, roof water, desalination, etc

- **Demand management** involves use of structural and non-structural measures and management techniques to reduce water use, through improved efficiency, education, water pricing, incentives, regulations and when necessary restrictions.
- **Reducing impact on Environment** considers urban area as catchment and managing landscape to improve environmental performance; habitat for fauna and flora, ecological diversity in waterways and estuaries by using approaches such as: low impact development, sustainable drainage systems, water sensitive urban design.
- **Improving Governance** requires coordination, participation and collaboration between key stakeholders, to make multi-objective decisions that are aligned with the principles of sustainability. Effective management of water supply, wastewater, stormwater and protection of receiving water in urban area, will result in better long-term outcomes.
- **Improving system wide performance -** the total water cycle system involves accounting for interactions between all components of the system and understanding system dynamics, rather than focussing on the behaviour of individual components.

The Water Reclamation & Management Scheme (WRAMS) at Sydney Olympic Park is a demonstration of specific adaptation of IUWM to rapid changes in urban area. WRAMS demonstrates its flexibility and ability to adaptation strategies that are integrated across all urban sectors and prioritise flexible and sustainable management options.

Material and Methods

The most prevalent barriers to the successful implementation of recycled water projects are; the relative funding and capital cost constraints, cost of recycled water compared to potable water and commercial risk associated mainly with the water demand and public acceptance. As the capacity to carry out commercial assessment varies in some instances economic costs and benefits have been incorrectly allocated, estimated and calculated resulting in a poor outcome and decision making. To improve future prospects for new recycled water projects, it is important to develop consistent framework and practical guide to develop a business case, that will ensure thorough evaluation of future recycled water schemes. The most

comprehensive assessment framework relies on a cost-benefits analysis (CBA) technique. This is a systematic approach to calculating, evaluating and compering investment options. The CBA relies on accurate allocation of costs, values, revenue, income, avoided costs, environmental and community benefits, etc. Costs allocation is not always straight forward; therefore the following primary criteria have been adopted as illustrated in **Figure 1** below:

Figure 1: Economic framework showing primary costs and benefits

- Capital Costs – represent essential expenditure during project delivery including items such as design, construction, installation, testing and commissioning of all : required civil structures, buildings, mechanical, electrical equipment, distribution network , pumps and storages including major repairs and replacement;
- Direct costs related to operation and management of the scheme and reticulation including: maintenance, repairs, replacement, energy, materials, chemicals, etc. Direct costs include two costs categories; fixed and variable expenses that are the two main components of total overhead expenditure. Scheme costs vary greatly depending on a range of factors including the level of treatment, distribution costs, land use zoning, and economies of scale
- Indirect Costs – are overhead costs, that have no direct bearing on production costs, but are indirectly related to the production e.g. advertising, computing, office administration, security, insurance, rents, lease costs. These costs can incur whether there is production or not.
- Distribution network – the cost of infrastructure required to supply recycled water to individual residential or commercial properties. Traditionally distribution network is installed by land developers and handed over to the recycled water service provider. Cost of building installation and connection costs are also paid by the developer. These costs should be calculated separately from capital, direct or indirect project costs;
- Other environment/community costs: a range of other costs that have not been separately identified including costs of using natural **resources** or making infrastructure changes, building or roads to support the project.

The primary benefits identified in the framework above include:

- recycled water value - the benefit that will be gained from supplying recycled water. Where recycled water substitutes for potable water, the value of potable

water must be subtracted from the total use value. Since the price of potable water is higher, then the use of recycled water will represent a net benefit.

- avoided wastewater costs: the present value of avoided capital and operating costs associated with reduced wastewater volumes, in particular reduced wastewater disposal costs. Many inland water recycling schemes have been implemented to avoid the high cost of meeting environmental discharge obligations, which may require high levels of treatment or long distance outfall pipelines. Metropolitan schemes often have lower avoided costs due to the lower unit operating costs and the large historic (sunk) investment in ocean outfall infrastructure;
- avoided potable water costs: the present value of avoided capital or operating costs associated with reduced potable water use. The avoided potable water costs are often dominated by water source deferral benefits, some savings in distribution, storage and reticulation system.
- willingness to pay for non-use - research has indicated that the broader community is prepared to make a significant contribution toward the costs of water recycling, even if they do not directly use the recycled water. To avoid double counting, the costs must exclude the direct benefits such as avoided wastewater and potable water costs;
- environmental / community benefits: this represents unqualified, tangible and intangible benefits including environmental and community benefits such as healthy, recreation, conservation of potable water, environmental protection, emission and pollution reduction, etc. (Marsden Jacob Associates, 2013)

The analytic framework developed in this study is shown in **Table 1**. It applies cost benefits principles across all the assessment elements, involved parties, organisations and process. It recognises critical relationships between costs, benefits, services, customers, pricing arrangement, etc.

Table 1 Cost Benefits Analysis - Model Structure for a typical water reuse scheme.

Table 3 illustrates potential to develop variety of LCC options, because NPV is based on the time value of money and measures entire obligations arising from scheme's operation. The LCC is defined as the total cost in present value or annual value (columns), that includes the initial costs, maintenance, repair and renewal costs over the project life cycle. The proposed NPV model developed below selected the most

affordable scenario. The NPV model takes a conceptual look at a 25 year life cycle and includes overall treatment costs such as intake and distribution power, chemicals, maintenance, replacement, labour, capital costs and interest on capital. The following are key assumption criteria that have been incorporated into the above model:

a) NPV calculations allow for variable time scale from one to 35 years
b) Electricity costs include standard rate and also network charges, meter service charges and taxes.
c) Energy costs could be broken down to allow more specific project details and to include any additional information eg, energy used for BOD5 removal,
d) The model allows a have maximum flexibility and variability to conduct unlimited number of runs, investigations, analysis and comparisons for any individual process or combined treatment trains involving wastewater treatment, water recycling using wastewater and stormwater, membrane filtration and desalination.
e) Evaluation of technical, economic and environmental aspects such as:

- relative energy consumption,
- actual production and treatment process efficiency rate
- economic implications,
- air emission attributable to energy use and biological sewage treatment
- Flexibility in applying interest and inflation rates

f) Energy recovery aspect was incorporated into the model to allow for complete energy budget and also to allocate GHG emission savings

g) Sensitivity analysis to determine parameters and treatment phases that contribute most to energy use and environmental emission.

The cost benefit framework indicates that, if the scheme is not economically justified, then it should not be recommended and the project should not proceed unless justified by other (unquantified) considerations.

Recycled water is an important source and critical element of the urban water cycle. To implement new water scheme requires a more considered approach and a desire to explore the full range of costs and benefits based on well-established economic

principles. Data analysis and comprehensive cost benefits modelling from the WRAMS scheme at Sydney Olympic Park demonstrates that urban recycled water schemes are viable, cost effective, safe and reliable. This Scheme has high degree of public confidence in the fundamental role recycled water plays in securing future urban water supply.

Conclusions

Sydney Olympic Park WRAMS scheme has a long and successful history of water recycling, which commenced in July 2000. The Scheme provides unique opportunity to support future initiatives by providing correct assessment and being transparent in equitable sharing of costs, risks and benefits in environmental, economic and social terms. With the greatest likelihood, future investment decisions in water recycling projects will be based on economic viability as well as:

- cost effectiveness – proponents are required to assess the economic viability of new recycled water schemes. Costs and benefits should be estimated for the entire duration of the project, using available econometric techniques, valuations and costs forecast tools. The tendency exist to overestimate the rate of growth of benefits and to underestimate the rate of growth of costs. The cost– benefit studies rely of conventional economic methodologies and the objective to maximize the total benefits derived from these projects. The internal cost and benefits are directly linked with the treatment process, production of recycled water and ultimate reuse. Consequently the internal benefit is the difference between revenue from the sale of recycled water and internal costs which include the investment costs (land, construction works, plant and equipment, buildings, facilities, piping infrastructure, operating and maintenance costs (labour, energy, waste management) financial costs and taxes.
- commercial risk – keeps project proponents aware of the contractual and operational arrangements that can be utilized to reduce commercial risks, and in particular the water demand risk.
- process barriers – implementation of water recycling projects particularly within established urban water sector monopoly, will continue to encounter complex regulatory and administrative procedures.

Sustainable water management requires thorough understanding and application of a cross-disciplinary analysis and credibility of scientific research influencing various

technical and non-technical issues. This will dominate future urban water decisions and in this context, there would be better chances to address a range of concerns related to water supply, wastewater generation, environmental impact associated with effluent disposal, emissions and community long term benefits that are often regarded as too complex to be addressed and resolved.

References

Falconer, G., Mitchell,S.,(2012). Smart City Framework A Systematic Process for Enabling Smart, Connected Communities . Cisco Internet Business Solutions Group (IBSG). September 2012. www.cisco.com/go/smartconnectedcommunities

Listowski, A., Recycled water system and water sensitive urban design and management at Sydney Olympic Park. IWA 3rd World Water Congress, Melbourne, Australia, 7-12 April 2002.

Listowski, A. (2011) Development of a Novel Assessment Framework and Methodology for Sustainable Water Reuse Scheme and Technology. PhD Thesis, UTS. Sydney.

Economic viability of recycled water schemes. Australian Water Recycling Centre of Excellence. Marsden Jacob Associates (2013). ISBN 66 663 324 657

Figures and Tables

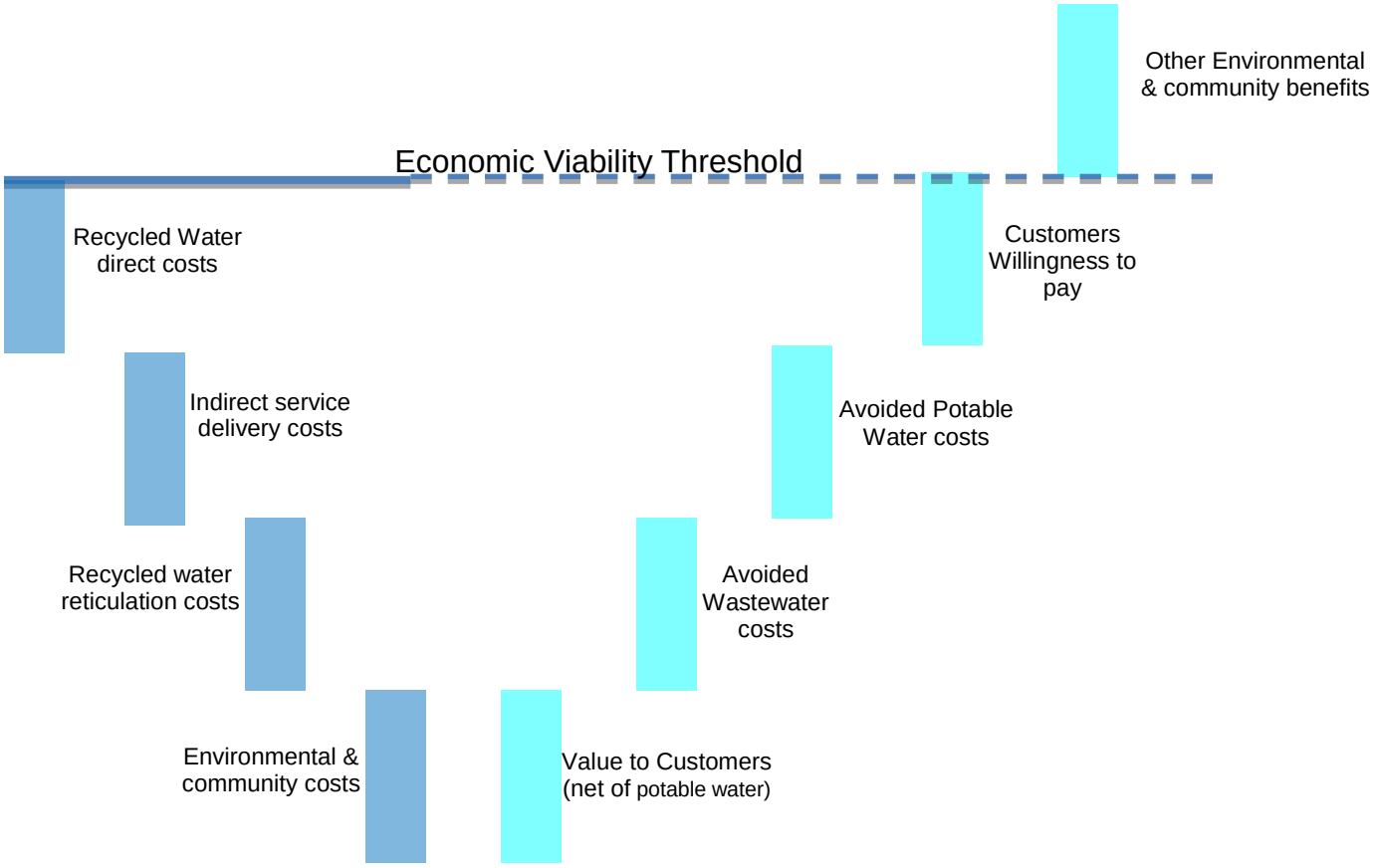


Figure 1: Economic framework showing primary costs and benefits

Source: Australian Water Recycling Centre of Excellence - Commercial and Institutional Barriers (2013)

Table 1 Cost Benefits Analysis - Model Structure for a typical water reuse scheme.

A - Project analysis	**Project Input**	**Input Parameter**
ate	Current year	2018
Time	Selected Analysis Period	35
%	Discount Factor / Rate	4%
%	Escalation Rate (= CPI)	2.50%
%	Profit / Rick Margin	25.00%
Q_{in}	Design Capacity (kL/y)	850,000
	Efficiency Rate (%)	90
Q_{out}	Actual Recycled Water Production (kL/Y)	765,000
$QSEW_{in}$	Annual Wastewater Treament (ML/Y)	670,000
$QSTW_{in}$	Annual Stormwater Treament (ML/Y)	485,000
Pe	Energy Consumption (kWh/Y)	1,260,000
Pac	Average Electricity rate ($/kWh)	0.18
	Potable Water Base Price ($/kL)	2.02
	Recycled Water Price ($/kL)	1.87
B - LCC	**Financial Analysis**	**TOTAL (PV)**
C_o	Capital costs	39,000,000
Cd	Capital Costs - Recycled Water Network	15,000,000
M_f	Fixed O & M cost	84,452,119
M_v	Variable O & M costs	30,965,777
M_{vd}	Distribution System O & M	1,689,042
E	Energy Cost	12,769,160
M_c	Miscellaneous Cost	9,852,747
C - LCC	**Periodic Costs**	
R	Capital Costs - Periodic Major Repairs	2,500,000
C_u	Capital Costs - Major Process Upgrade	2,000,000
S - D	Net Salvage Value (less Disposal)	2,000,000
G	Capital Assets Depreciation (straight line)	-56,500,000
D - LCCA	**Economic Analysis**	
Co	Total capital costs (less salvage value)	-56,500,000
∑O&M	Total O & M costs	144,228,846
∑C = ∑Co+∑O&M	Total costs (less salvage value)	196,228,846
∑O&M+G	Cash Flow (Net O&M Cost+Depreciation)	83,228,846
(1/(1+i)^n)	Discount Factor	
NPV	Life Cycle Costs (NPV)	95,967,251
E - LCCA	**Operating Revenue**	
R_w	Recycled Water Production Cost	37,467,251
F - LCCA	**Income and Savings Analysis**	
Mr	Meter reading revenue (Mr)	48,325,192
Mc	Meter charges revenue (Mc)	2,074,008
PWs (Potable -Rec)	Potable water sawing Cost($)	4,116,656
SEWs	Wastewater disposal saving costs	41,494,141
SWTs	Stormwater pollution savings	13,653,093
GHG treat	GHG savings from process ($20/Ton CO2)	4,426,867
GHG energy	GHG savings from energy ($20/Ton CO2)	1,477,236
INFR	Infrastructure, transportation savings	29,055,920
Cin	Total Net Cash Inflow (Cin)	114,089,957
F - LCCA	**Cash Flow Analysis**	
C_{out} - G	Net Cash Outflow - depreciation (discounted)	67,597,269
$N_{cs} = C_{in} - C_{out}$	Net Cash surplus (N_{cs})	46,492,687

Economic benefits of indirect potable reuse in Reno, Nevada

Laura Haak, University of Nevada, Reno, USA; Lydia Peri, PE, Washoe County CSD, Reno, USA; Rick Warner, Warner and Associates, LLC, Reno, USA; Krishna Pagilla, PhD, PE, BCEE, University of Nevada, Reno, USA; lhaak@nevada.unr.edu

Abstract:

Indirect potable reuse (IPR) has allowed cities to address water scarcity and enhance management of conventional and non-conventional water resources. These attributes contribute to the potential importance of IPR in providing an efficient strategy to manage reclaimed water in urbanized closed basins and other inland communities. In these communities there are limited options to discharge reclaimed water resources and population growth may increase this non-conventional resource beyond the disposal capacity of the region. The current study evaluates if IPR is an economically feasible strategy to manage reclaimed water in a closed basin that has exhausted its local capacity to utilize non-potable water resources and would benefit from the creation of an additional potable water resource. The methodological approach employs a cost-benefit assessment to examine the feasibility of IPR by determining the economic outcomes of IPR on water and reclaimed water management within the basin. The study identifies that IPR is likely to produce a net benefit for the region by producing a new potable water resource and averting significant effluent management costs that would be incurred if reclaimed water must be exported out of the region.

Keywords: Indirect potable reuse; Cost-benefit analysis; Economic feasibility; Urban water management; Urban water reuse; Water planning

Introduction

Urbanization has increased water stress across the western United States, which encompasses many arid and semi-arid cities. Closed basins, which are areas with no hydrologic outlet except through evaporation to the atmosphere, are found throughout this region including most of Nevada, Utah, and parts of California, Idaho, and Oregon. This study focuses on a closed basin within the metropolitan area of Reno-Sparks. Water supplies to the area include natural groundwater and imported surface and groundwater resources. The study area has two water reclamation

facilities (WRFs) that service the basin. Reclaimed water is utilized within the closed basin for purposes such as wetland ecosystems, non-potable reuse, or evaporation. This basin is one of the fastest growing in the metropolitan area and future wastewater generation is expected to exceed the capacity of local discharge options. As the region approaches the capacity of its non-potable reuse system and wetlands it is likely to either pursue a strategy to export surplus effluent across the watershed to a creek. This option would reduce the total water resources available to the study area and would require enhanced nutrient removal prior to discharge as well as a costly distribution system. Alternatively, indirect potable reuse (IPR) would allow the region to retain these water resources and direct them to higher value use through advanced treatment processes that produce water that meets or exceeds drinking water standards.

Cost-benefit analysis is an economic analytical technique that is widely used to evaluate water and wastewater management strategies. This approach is intended to evaluate if the scenarios examined produce an increased level of welfare for a community based on economic, social, and environmental objectives. These external impacts can be significant when considering water recycling projects, such as the use of non-potable water for park irrigation (Garcia and Pargament 2015). However, environmental benefits of wastewater management are often not associated with market values that can be incorporated into a cost-benefit analysis (Molinos-Senante et al. 2010).

This study examines if IPR presents an economically feasible strategy to manage water resources in a closed basin, where the impacts may be driven by the costs associated with treatment and distribution systems for reclaimed water and benefits include generating new water rights and averting the costs associated with exporting reclaimed water.

Materials and Methods

The economic feasibility of IPR was determined following a conventional cost-benefit analysis, which requires identifying internal costs (e.g. capital costs, operating and maintenance costs), internal benefits (e.g. costs averted), and externalities (Hernández et al. 2006). Externalities included costs or benefits that occur when the internal decisions of the decision maker (e.g. water utility) impact other stakeholders. Several

external benefits were identified in a previous study (Haak et al. 2018), including decreasing regional water stress and the timing of discharge to wetlands for enhanced management. However, data was not available to estimate a monetary value for these external benefits. A summary of the cost and benefit components that were included in the analysis is illustrated in Figure 1.

Financial costs included capital and annual components. Capital costs included as construction materials, equipment, borrowing costs, and project planning and design services. Annual costs included pumping costs, power, media replacement for components of the AWTF, cooling, equipment maintenance, and replacement costs for AWTF components like UV lamps. The cost estimates used in this study were adapted from several regional reports that have been commissioned to evaluate effluent management scenarios for the study area. These reports have included estimates for the costs of developing a treatment and distribution system to export surplus effluent (Eco:Logic 2010), and for an advanced water treatment facility, conveyance, injection, and monitoring wells for IPR (Farr West Engineering 2019; Stantec 2018). These reports identify an ozone-biological activated carbon based system for an advanced water treatment facility (AWTF) prior to injection into an aquifer (Figure 1).

IPR would also result in several financial benefits by averting the costs associated with exporting the reclaimed water and generating new water rights, which were assessed based on their potential market value. The design flow for the IPR system was estimated to produce 2.76 Mm^3 of water resources for augmenting a selected aquifer annually. The study assumed that 80% of this resource could then be recovered, which produced an estimated 2.21 Mm^3 of water rights that could be sold to support municipal and industrial uses in the study area. The financial benefits of producing water rights through IPR were uncertain; local groundwater resources are fully allocated and alternative sources included imported groundwater or imported surface water from different water providers. Thus, the net present value (NPV) equation, shown below, was used to determine a minimum price for water rights that would ensure a positive NPV. This price was then compared to alternative water rights available in the region to determine the feasibility of IPR as an economically feasible water management strategy. A discount rate (i) of 3% and project life (t_f) of 20 years were assumed.

$$NPV = P_{WR}\left[\frac{1-(1+i)^{-t_f}}{i}\right] + P_{averted}\left[\frac{1-(1+i)^{t_f}}{i}\right] - P_{IPR}\left[\frac{1-(1+i)^{t_f}}{i}\right]$$

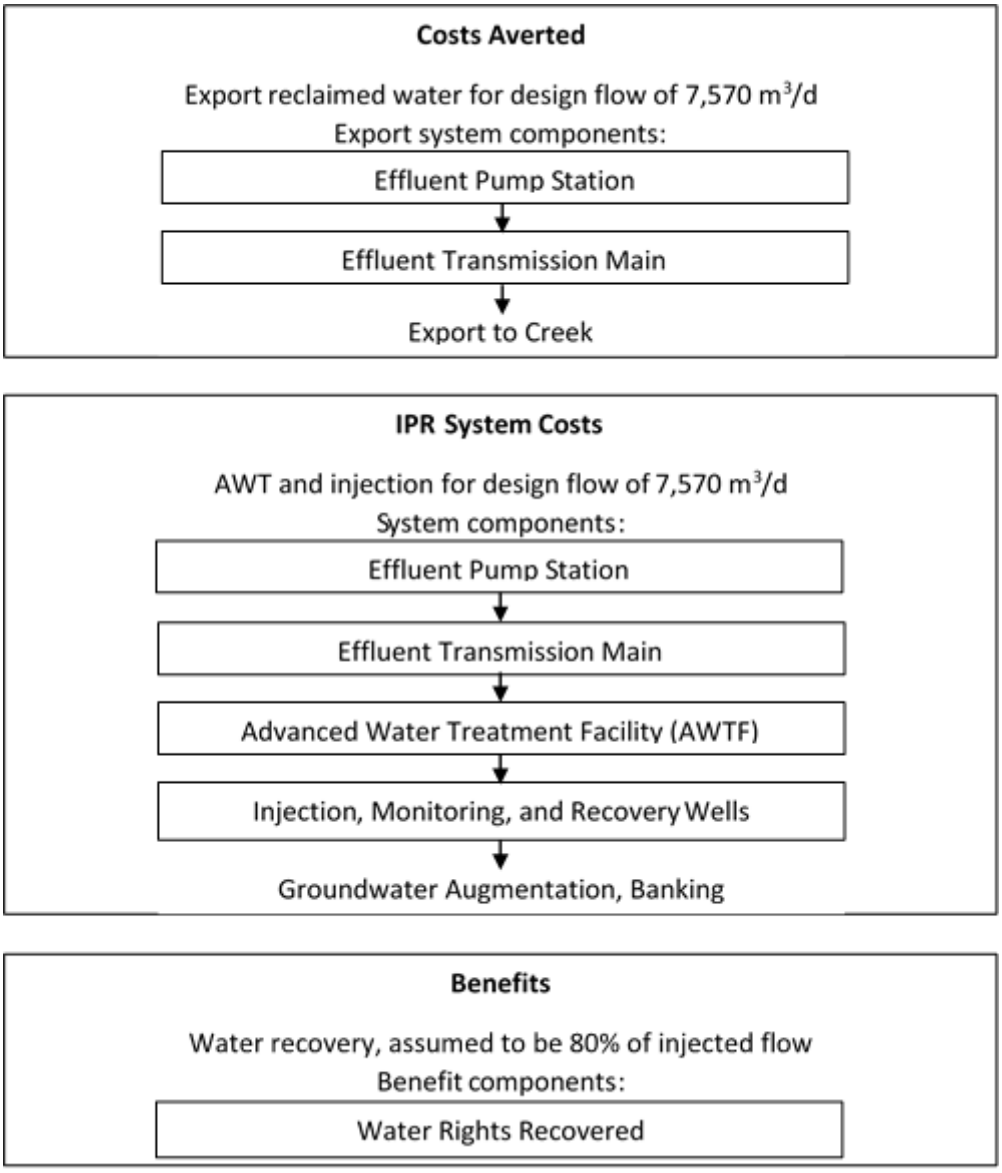


Figure 1. Components considered for financial cost and benefit parameters of IPR

Results and Discussion

IPR was estimated to avert significant capital costs associated with constructing a distribution system to export reclaimed water. As Table 1 illustrates, the capital costs of the IPR system were only 30% larger than those that would be incurred if the region pursued exporting of reclaimed water. However, annual costs associated with operation and maintenance of the IPR system were expected to be large due to high power requirements for the ozone-biological activated carbon AWTF, maintenance,

labor, and chemical costs. These costs were more than four times larger than the averted pumping and power costs for exporting reclaimed water. However, in the case of IPR these costs come at the benefit of generating a new potable water resource.

Table 1. Summary of costs and benefits for IPR effluent management

Cost/benefit parameters	One-time benefits (costs)	Annual benefits (costs)
Averted costs of export system ($)	28,800,000	596,000
IPR system costs ($)	(37,500,000)	(2,542,000)
Water rights recovery (Mm^3)	2.21	

The potable water resources generated through IPR would directly benefit the region through the creation of water rights, as shown in Table 1. Although the economic value of these water rights was uncertain, it was estimated that the water rights would need to be sold at a minimum value of $18 per m^3 to generate positive net benefits for the region. Water rights in the study area currently sell for as much as $28.38 per m^3. Thus, the cost-benefit assessment identified that IPR is likely to produce a positive net value for the region based on the financial parameters. Generating the potable water resource was estimated to generate numerous benefits to the region. Water resources within the Reno-Sparks metropolitan area were found to produce $266 of GDP (in US Dollars) per m^3 of water produced. Additionally, the increased local supply of potable water resources would ensure that water demand within the study area can be met by available water supplies, without the need to identify additional resources that can be imported. One of the most significant non-financial benefits to the region is likely to be enhanced management of reclaimed water resources. Reclaimed water plays a critical role in sustaining a wetland ecosystem in the study area, particularly during summer months. During the high-precipitation winter months the region has limited demand for non-potable water resources and utilizes the wetlands for discharge. IPR may be managed to ensure that environmental flows are met sufficiently during the dry season while providing a more beneficial use for wet winter season production of reclaimed water.

Conclusions

The value of water rights generated through IPR and the costs to export reclaimed water were likely to exceed the capital, operating and maintenance costs. Thus, this

study identified that IPR was likely to provide an economically beneficial water management strategy in a closed basin with costly effluent management alternatives. Non-financial parameters were likely to enhance these benefits but information was not available to evaluate the potential economic benefits of these non-market values. Although the results are specific to a region with limited high-cost options to manage reclaimed water resources, it does identify the importance of including effluent management costs when evaluating IPR in a decision making process. Closed basins, such as the study area, are more likely to have internalized the costs associated with effluent management. For example other regions may be more likely to export the costs of health risk, environmental degradation, and water quality. Thus, closed basins such as the study area may provide a simplified perspective into the potential impacts of IPR on reclaimed water management.

References

Eco:Logic (2010) The North Valleys Initiative: Advancing Solutions to Regional Water Issues. Western Regional Water Commission

Farr West Engineering. (2019). Technical Memorandum #4: Lemmon Valley-Stead Wastewater Facility Plan

Garcia X, Pargament D (2015) Reusing Wastewater to Cope with Water Scarcity: Economic, Social and Environmental Considerations for Decision-Making. Resources, Conservation and Recycling 101:154–166. doi: 10.1016/j.resconrec.2015.05.015

Haak L, Sundaram V, Pagilla K (2018) Sustainability Assessment for Indirect Potable Reuse: A Case Study from Reno, Nevada. Water Environment Research 748–760. doi: doi/10.2175/106143017X15131012153185

Hernández F, Urkiaga A, De las Fuentes L, et al (2006) Feasibility studies for water reuse projects: an economical approach. Desalination 187:253–261. doi: 10.1016/j.desal.2005.04.084

Molinos-Senante M, Hernández-Sancho F, Sala-Garrido R (2010) Economic feasibility study for wastewater treatment: A cost–benefit analysis. Science of The Total Environment 408:4396–4402. doi: 10.1016/j.scitotenv.2010.07.014

Stantec. (2018). LVWRF Conceptual Study Life-Cycle Cost Memo.

Using cost-benefit analysis to assess economic interests of integrated and multi-purposes reuse scenarios: Cannes basin case-study

Rémi DECLERCQ, Ecofilae, Montpellier
Nicolas CONDOM, Ecofilae, Montpellier
Sébastien LOUBIER, IRSTEA, Montpellier

Abstract:

Unlike many structuring projects, water reuse projects are rarely subjected to economic analysis. And when they are, social and environmental benefits and costs are often not accounted for or are not properly quantified. Studies carried out in Mediterranean countries showed that when external benefits are properly quantified and integrated into the economic analysis the number of economically viable water reuse projects increases.

Cannes is a water stessed area with a planned increase of population in the upcoming years. Here we assess the profitablity of integrated and multi-purposes water reuse scenarios by using the cost-benefit analysis methodology. Specific indicators have been tailored to quantify and to monetize major social, economic and environmental impacts. Results highlight profitability for the territory and enable decision-making by local stakeholders.

Keywords: Water reuse; cost-benefit analysis; territorial assessment; integrated water reuse; risks and uncertainties

Introduction

Treated or untreated water reuse is a particularly appealing solution in water-stressed areas and can be used to tackle water scarcity but also to recover surface water quality (Asano, 1998; Lazarova et al., 2001). Nevertheless projects need to be sustainable. Economic considerations become of high importance when assessing the potential of water reuse projects (Asano, 1998; Jimenez and Asano, 2008). Studies carried out in Mediterranean countries (Molinos-Senante et al., 2011; Condom et al., 2012; Xu et al., 2001) showed that when external benefits are properly quantified and integrated into the economic analysis the number of economically viable water reuse projects increases. Cost-Benefits Analyses (CBA) for water reuse projects are therefore of growing interest, but the methodology has

scarcely been applied in France as well as in the Mediterranean area on water reuse projects.

The CBA method has then been carried out on Cannes case study. The objectives are (1) to assess the CBA methodology's applicability without specific difficulties to water reuse projects and to highlight its limitations; (2) to assess the economic profitability of water reuse Scenarios for territories.

Material and Methods

Method: Cost-Benefit Analysis

The Cost-Benefit Analysi (CBA) is a technique used for analyzing projects to determine whether or not they are in the public's and private sector's interest thanks to the assignment of monetary value to each input and output resulting from the project (Verlicci et al., 2012; Kihila et al., 2014; Chen and Wang, 2009).

Once they have been estimated, all future costs and benefits need to be assessed in present value before being summed. The discounting principle is used to integrate the preference for the present into the analysis. The Net Present Value calculated is then equal to the sum of differences of discounted costs and benefits between the 2 compared scenarios (e.g. reuse and business-as-usual scenarios).

Many of the costs and benefits are easy to identify and to monetize (added value, investments, expenses, etc.) but some are particularly difficult to monetize like the environmental externalities, the employment evolution in downstream chains or even the individual satisfaction. Specific, complex and time-consuming economic methods are developed to assess in detail these costs and benefits. This requires a good knowledge of economic concepts and time to carry out these analyses. Carrying out only a single economic analysis, i.e. from the community's point of view, highlights potential advantages (NPV>0) or disadvantages (NPV<0). Sensitivity analyses are carried out to assess the robustness of the deterministic calculated results. A Monte-Carlo method can therefore be used: it consists in carrying out a succession of thousands of random draws for the values of some key but uncertain parameters and then in analyzing the related results dispersion.

Site, context and studied scenarios

The Siagne Low Valley (SLV) in the Cannes area is a water stressed one with many constraints related to intensive urbanization and a planned increase in permanent

and seasonal population in the upcoming years. The Aquaviva Wastewater Treatment Plant treatment process includes a biological reactor and membrane ultrafiltration. The plant treats Mandelieu-la-Napoule, Cannes, and 6 other cities' domestic effluents. More than 16 Mm^3 of treated wastewater are discharged every year into the Mediterranean with very low impact on bathing areas and sea biodiversity (Ecofilae, Tecurbis, Espelia, 2015). The Siagne River is subjected to major water uptakes in the SLV area including from upstream to downstream: (1) agricultural uptakes for irrigation; and (2) the Mandelieu-la-Napoule city's 2 water uptakes for potable water production and the Golf course irrigation. Groundwater is used for: (1) potable water production that distributes water to Cannes' urban area with 3 wells located upstream; and (2) for irrigation and private domestic uses with an unknown number of wells and pumped volume. We consider that there is no additional local water resource available in the SLV, nor in the Siagne River and Beal Canal or in the groundwater, to face increasing demand for potable water related to the planned population increase.

More than 10 short, medium and long terms water reuse scenarios that integrate different end-uses have been designed and analyzed through juridical, regulatory, administrative, social and technical aspects (Ecofilae, 2015). Finally, and considering the above-mentioned aspects, economic and financial analysis, has been carried out on 5 water reuse scenarios selected by local stakeholders. The Cannes city Mayor, specified that economic profitability would be a major decision criterion (Berard, 2015). The objectives are therefore: (1) to assess water reuse profitability and sustainability for the 'community' and for each stakeholder; (2) to compare Scenarios to select the most profitable one for the 'community'. So far no final decision has been taken by stakeholders but results shall support local decision-makers in their choice. The main stakeholders involved are Cannes and Mandelieu-la-Napoule cities as they both produce potable water.

The water reuse scenarios consist in: irrigating a golf course that currently uptake water in the Siagne river (Scenario 1); deliver water to several urban uses including green areas irrigation and urban washing through a dual pipe water network (Scenario 2); mutualizing Scenarios 1 and 2 into a Scenario 3; recharge surface and groundwater to enable indirect potable reuse and to limit salt water intrusion (Scenario 4); mutualizing Scenario 4 and Scenario 3, and adding agriculture irrigation

into a Scenario 5 (Figure 1). Indirectly, water reuse will then enable to meet part of the expected increased demand in potable water in the upcoming years for both producers Cannes and Mandelieu-la-Napoule. Recharge of the Beal Canal will also enable farmers to return to this historically dedicated water resource and abandon well drilling, therefore releasing the pressure on groundwater resources and limiting salty intrusion close to the sea.

Results and Discussion

All costs (OPEX and CAPEX) have been considered. The main expected benefit of the water reuse Scenarios is an increase of available water to face the planned summer increase in demand for potable water in the cities of Mandelieu-la-Napoule and Cannes: we consider that costs in the business-as-usual scenario (that turn to be benefits for the water reuse Scenarios) are at least equal to present local production costs for potable water. Benefits related to the limitation of salt intrusions could be integrated and monetized by using the value of agricultural lands that could be preserved within the water reuse Scenarios. Improvement of surface and groundwater quality and quantity can also be integrated and monetized by considering the fees that the cities would pay for the non-respect of environmental standards.

Calculated economic NPV over a period of 30 years is then positive for 4 Scenarios (Scenario 1 : 4€M ; Scenario 3 : 2,8 €M ; Scenario 11.9 €M ; and Scenario 5 : 7.8 €M) and negative for Scenario 2 : -2.5 €M. Project profitability can nevertheless hardly be considered as certain for the 4 Scenarios since the NPV result does not seem significant if we take into account the 30 years' analysis timeline. A sensitivity analysis of the NPV regarding the main parameters is relevant to deepen the analysis and better interpret the results. Sensitivity analysis on 15 parameters has been performed on Scenarios 3, 4 and 5 (preselected by local authorities). Results show (Figure 3) that uncertainty on NPV is very high but that the 3 Scenarios are economically profitable for all the 1 000 simulations carried out.

Conclusions

Cost-Benefits analysis methodology enables us to make a value judgement on the economic profitability of water reuse projects and to seek for opportunities to increase development of water reuse projects. Economic profitability has been demonstrated with Siagne Low Valley. Some benefits and costs are difficult to

quantify such as the socio-economic benefits of increasing potable water or the advantages for the community and for farmers to maintain agriculture on the territory. The sensitivity analysis is necessary. It demonstrates here the robustness of the deterministic results calculated during the CBA.

References

Asano T. 1998. Wastewater reclamation and reuse, Technomic Publishing Co., Singapore.

Berard C. 2015. De l'eau dans les mains, AE RMC, Opossum Production : Lyon, France (in French).

Chen R., and Wang C., 2009. Cost-benefit evaluation of a decentralized water system for wastewater reuse and environmental protection, Water Sci Technol. 59(8): 1515-22 doi: 10.2166/wst.2009.156

Condom N, Lefebvre M, Vandome L. 2012. Treated Wastewater reuse in the Mediterranean: Lessons Learned and Tools for Project Development. Blue Plan Papers 11. Plan Bleu, Valbonne, France.

Condom N, Declercq R. 2017. Wastewater reuse for peri-urban agriculture irrigation in developing countries: practices, challenges and operational solutions. COSTEA. Montpellier, France. 63 pp.

Ecofilae, Tecurbis, Espelia. 2015. Prospective and Feasibility study of wastewater reuse in Siagne Low Valley – Phases 1 and 2. SIAUBC: Cannes, France (in French)

Jimenez B., Asano T., 2008, Water reuse : an international survey of current practice, issues and needs. Scientific and Technical report No.20, IWA Publishing, London, UK, 602 pp

Kihila, Jacob & Mtei, Kelvin & Njau, Karoli. (2014). Development of a cost-benefit analysis approach for water reuse in irrigation. International Journal of Environmental Protection and Policy. 2. 179-184.

Loubier S., Declercq R., 2014, Cost-Benefit Analysis of treated wastewater reuse projects – Application to 3 french case studies. ONEMA, Vincennes (in French)

Molinos-Senante M, Hernandez-Sancho F, Sala-Garrido R. 2011. Cost-benefit analysis of water-reuse projects for environmental purposes: a case study for Spanish wastewater treatment plants. Journal of Environment Management, 92 3091-3097

Xu, Pei & Valette, François & Brissaud, F & Fazio, A & Lazarova, V. (2001). Technical-economic modelling of integrated water management: Wastewater reuse in a French island. Water science and technology : a journal of the International Association on Water Pollution Research. 43. 67-74. 10.2166/wst.2001.0583.

Figures

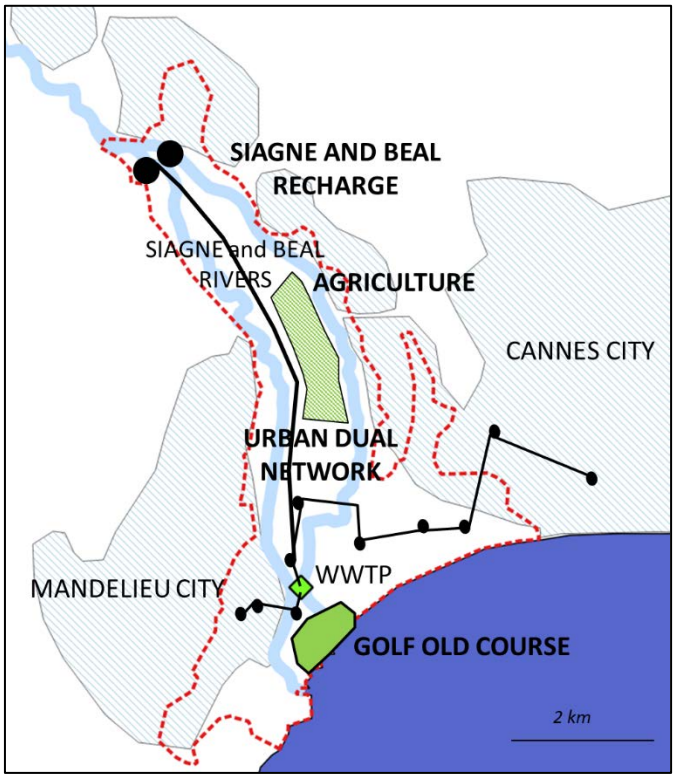


Figure 1: Water reuse Scenario 5 in the Siagne Low Valley

Figure 2: NPV values for 5 water reuse Scenarios

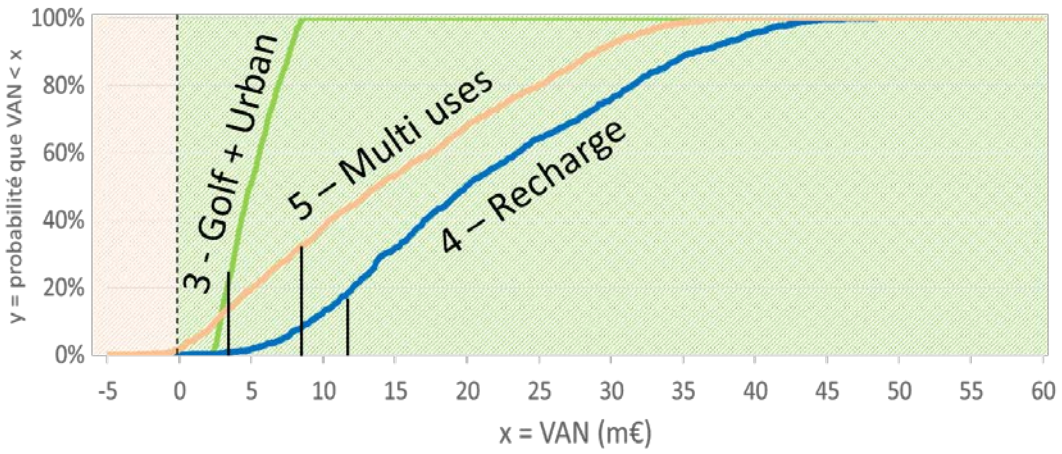


Figure 3: Sensitivity analysis – 3 water reuse Scenarios

Sustainability Assessment of Water Reuse Technologies – Application of a Decision Support Tool in International Case Studies

Kristina Wencki, Verena Thöne, IWW Water Centre, Mülheim an der Ruhr, Germany; Dennis Becker, DECHEMA, Frankfurt am Main, Germany; Kerstin Krömer, Isabelle Sattig, OOWV, Brake, Germany; Gunnar Lischeid, ZALF, Müncheberg, Germany; Martin Zimmermann, ISOE, Frankfurt am Main, Germany

k.wencki@iww-online.de

Abstract:

The decision on the implementation of water recycling measures always depends on local conditions. To support decision makers in assessing the technical feasibility, economic viability, ecological compatibility and social acceptance of alternative water supply solutions, the MULTI-ReUse project has developed a tool with specific focus on industrial and agricultural applications. Testing and validation was successfully carried out in two case study settings in Germany and Namibia. Results, implications and limitations of the structured evaluation approach are presented and discussed.

Keywords: water reuse; assessment framework; practical implementation; multi-criteria decision analysis; water management

Introduction

In many countries the effluent of wastewater treatment plants (WWTPs) is discharged into receiving waters without further use. On the long run, it is expected that treated wastewater will, as an additional water resource in water-scarce and/or densely populated regions, constitute an essential part of the urban water cycle, also in Germany. The German research project MULTI-ReUse[1] develops and implements modular treatment processes to reuse treated wastewater for industrial and agricultural purposes, groundwater recharge and domestic uses. Currently, treatment of wastewater in most countries primarily aims at reducing the organic carbon and nutrient (nitrogen, phosphorus) load that would impair ecological functions of the receiving streams. Alternative use of treated wastewater, however, sets different

[1] The project MULTI-ReUse (Modular Water Treatment and Monitoring for Wastewater Reuse, 2016-2019) has received funding from the German Federal Ministry of Education and Research as part of the funding measure “Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)”, https://water-multi-reuse.org/en/.

requirements. E.g., for industrial purposes salinity, corrosiveness and microbial contamination are of the utmost importance, water for domestic use has to fulfill high hygienic standards, and a high nutrient content would even be beneficial for agricultural use. Thus, wastewater treatment has to be adapted to these purposes because providing highest quality standards (i.e., drinking water quality) for universal use would not pay off in most cases. Hence, pros and cons of different options need to be balanced accounting for the respective local conditions. In addition, technological, economic, ecological and social aspects need to be considered and to be weighted. To that end a multi-criteria decision analysis (MCDA) tool has been developed and tested for various case studies. It is intended to be used by WTP and WWTP managers, municipal decision makers, operators of industrial plants and consulting engineers in an initial phase of the planning process.

Material and Methods

MCDA Approach. In order to select a scientifically sound and practicable assessment methodology for the sustainability assessment tool, widely used MCDA approaches for the inclusion of quantitative and qualitative data were examined in a focused literature review. Within the 47 peer reviewed articles from the years 1998 to 2017 found in the Web of Science or Scopus databases, 25 different evaluation procedures have been distinguished. For the MULTI-ReUse decision support tool, a large part of these procedures had to be excluded due to the one-dimensionality of assessment, exceeding level of complexity and/or the expectation of insufficient data availability. Based on this considerations, value measurement models (c.f. Kiker et al., 2005; Chowdhury/ Al-Zahrani, 2013) were found to be best suitable for the assessment purposes of the MULTI-ReUse tool.

The MCDA approach that was finally developed within the project, is based on 23 evaluation criteria in four dimensions covering environmental impacts (e. g. net energy consumption, space requirement, volume of residual substances), social factors (e. g. compliance with national strategies, increasing environmental awareness, health risks), technical feasibility (e. g. anticipated expense for implementation, flexibility, adaptability, expandability), and economic viability (annual costs, potential for innovation leadership, competitiveness) of water supply alternatives. All criteria should be assessed individually to identify advantages and

disadvantages of the observed water supply variants. In order to facilitate decision-making the criteria assessments can be further combined to an overall assessment of each alternative based on the preference set by the decision makers. The final result is ranking of the different alternatives.

Based on this evaluation approach, sustainability assessments for two case studies were being carried out. Data was taken from measurements in existing and pilot plants, structured interviews and experts estimate.

Case Study 1: Nordenham, Germany. In North Germany, the water company Oldenburgisch-Ostfriesischer Wasserverband (OOWV) ensures water supply for municipal and industrial customers. In a pilot plant, OOWV already demonstrated water reclamation and reuse from the WWTP Nordenham with improved process technologies such as ultrafiltration and reverse osmosis. In the medium term, the company intends to substitute drinking water consumption in an industrial park in Nordenham by reuse water with low electrical conductivity and low chlorine contents supplied from a separate pipeline network. The demand for industrial service water is expected to increase by 800.000 m^3 per year. By using the sustainability assessment tool developed within the MULTI-ReUse project, OOWV aimed at performing a sound cost-effectiveness consideration for the planned water recycling project (Option 1-B) by comparing it to the current water supply system (Option 1-A) (Fig. 1).

Case Study 2: Outapi, Namibia. In the northern Namibian town of Outapi, a sanitation and reuse system for domestic wastewater of three settlements comprising approx. 1,000 inhabitants has been successfully in operation for more than six years. The plant is designed to supply a drip irrigation scheme with reused water for the production of vegetables and fruits for human consumption. Due to the semi-arid climate, water reuse is a reasonable alternative for the cultivation of crops in the region. However, it can be questioned which kind of reuse technology is the most sustainable one. Based on the developed sustainability assessment approach, the potential positive and negative impacts of three different water reuse options were evaluated (Fig. 2). Option 2-A is the above mentioned system which consists of an upflow anaerobic sludge blanket (UASB), rotating biological contactors (RBC), a micro sieve and UV radiation for final disinfection before the irrigation water is stored in a pond. In option 2-B, the micro sieve and UV radiation of option 2-A are replaced

by an ultrafiltration (UF) membrane as it is tested in the Multi-ReUse project. The rest of this hypothetical option is identical to the first option. Option 2-C makes use of existing wastewater ponds as they are already in use for a large part of Outapi's sewage disposal. These wastewater ponds are enhanced by a pre-treatment step using either UASB reactors or a micro sieve, a stone filter for post-treatment after the wastewater ponds and an additional UF membrane to produce irrigation water.

Results and Discussion

Decision Support Tool. The MULTI-ReUse assessment tool is an excel-based application that allows decision makers to evaluate and compare the sustainability of conventional water supply and innovative process chains for water reclamation and reuse. Furthermore, the tool can assist the user in an early planning phase to identify the most suitable site for a modular treatment plant and to select the most sustainable process in reference to the local water demand and quality requirements. To run the assessment, the user has to insert data into six different spreadsheets:

- a checklist with exclusion criteria (e. g. water demand, social acceptance, disposal of residues), that should be fulfilled in any case;
- the four data entry tables containing 23 evaluation criteria to be assessed by the user either quantitatively or qualitatively, referring to five-point Likert scales;
- a table to add weighting factors based on the user´s own preferences in addition to the set of default values for sensitivity analysis with different focal points.

Inserted data is processed automatically within the tool using a value measurement model approach, in which partial utility values are calculated based on a scale derived from the minimum/maximum input values for a single indicator. In the end, a total utility value of each alternative supply system is determined via aggregation of the weighted partial utility values. Input parameters as well as the final assessment results are presented graphically in a `management cockpit` and spider charts, allowing for a direct comparison of the individual options. Sensitivity analyses of the assessment results can be viewed in ranking tables (Fig. 3).

Results Case Study 1: Nordenham, Germany. Applying the decision support tool for the assessment of the German case study confirms that from a technical, social and economic perspective the current water supply system shall be preferred (Fig. 3 left).

But focusing on ecological factors water reuse should be considered further as accompanying water supply since it is expected to reduce the pressure on scarce regional groundwater resources by covering the increased industrial demand for water with fit for purpose water quality. Considerably lower chlorine and salt contents of the reuse water furthermore allow for a multiple water recirculation within industrial processes, so that fresh water consumption for production can be even reduced. Besides, using the MULTI-ReUse approach (Option 1-B) induces a minimized use of purification chemicals (e.g. flocculants, precipitating agents) within the different process steps.

Results Case Study 2: Outapi, Namibia. The sustainability assessment of the Namibian case study's three options results in option 2-A being the most sustainable water reuse system (Fig. 3 right). This is mainly due to option 2-A's good social, economic and environmental performance. It is for instance more water and energy efficient, needs less chemicals for operation, has lower specific annual costs and shows capacity for innovation leadership. Furthermore, it is said to be more accepted and has smaller personnel requirements. Only from a more technology oriented perspective, option 2-B proves to be the most sustainable option, since it is easier to integrate into existing infrastructure, less technically complex and expected to be less prone to errors. Options 2-A and 2-B are also said to have lower follow-up costs in case of a system failure. Throughout all weighting scenarios, option 2-C ends up on the last rank since it seems to combine all the disadvantages of the two other options.

Conclusions

The application of the developed decision support in two international case studies proved that it is applicable in different environmental and societal settings with widely differing organizational, technical und structural conditions. Due to its user-friendly design, a transparent valuation approach as well as the clear and comprehensible presentation of results, the local users became more aware of the strengths and weaknesses of the considered option and were able to identify the most sustainable supply system or strategy for their decision case.

References

Chowdhury S. and Al-Zahrani M. (2013). Reuse of treated wastewater in Saudi Arabia: an assessment framework. Journal of Water Reuse and Desalination, 3 (3), 297-314.

Kiker G. A., Bridges T. S., Varghese A, Seager T. P. and Linkov I. (2005). Application of Multicriteria Decision Analysis in Environmental Decision Making. Integrated Environmental Assessment and Management, 1 (2), 95–108.

Figures and Tables

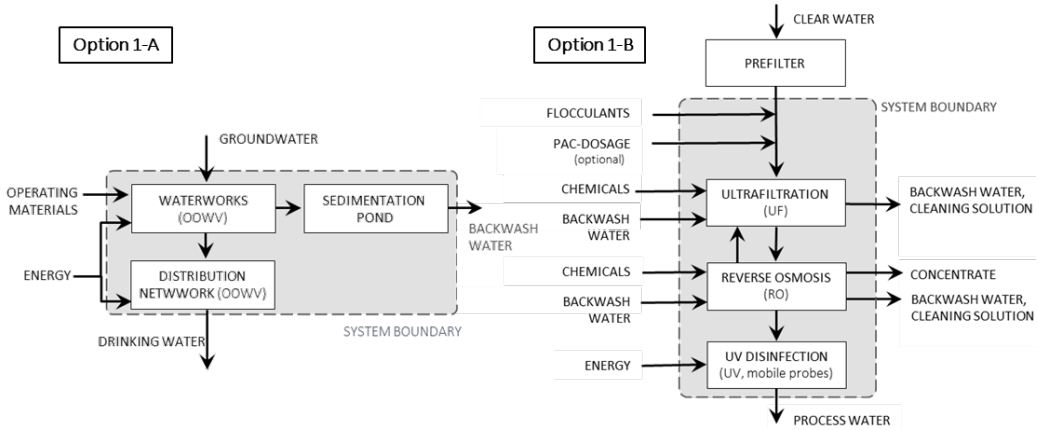


Figure 1: Process schemes for water supply options 1-A and 1-B in Nordenham, Germany.

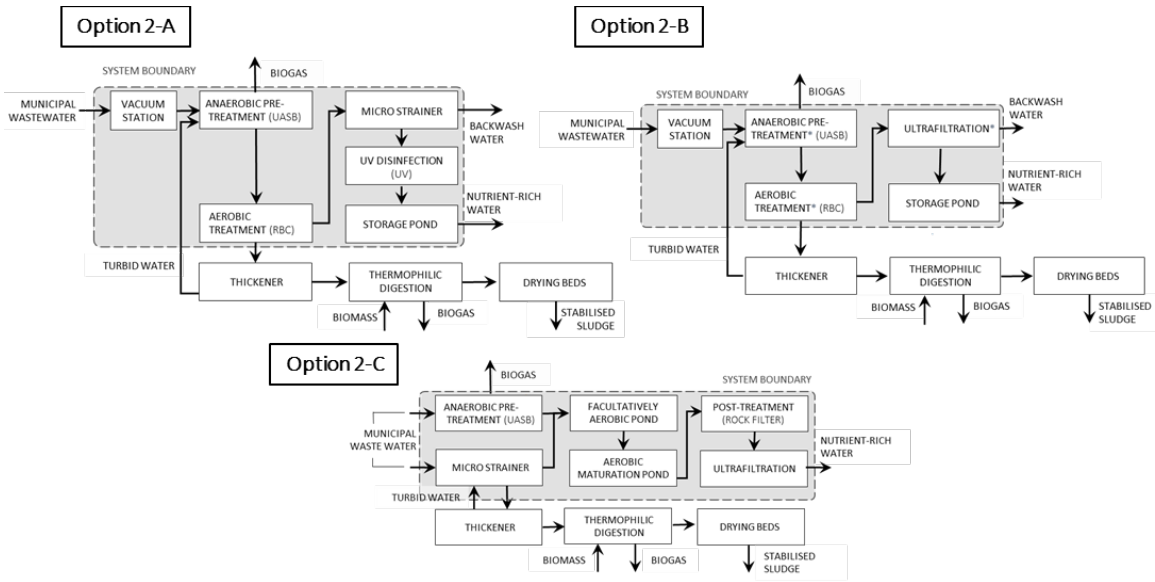


Figure 2: Process schemes for water supply options 2-A, 2-B and 2-C in Outapi, Namibia.

No.	Weighting variants		Option 1-A	Option 1-B	Option 2-A	Option 2-B	Option 2-C
1	**User**´s own focus		0,787	0,683	0,524	0,489	0,326
			1	2	**1**	2	3
2	Example from **MULTI ReUse**		0,652	0,600	0,518	0,481	0,340
			1	2	**1**	2	3
3	Focus **Environment**		0,605	0,622	0,564	0,470	0,322
			2	**1**	**1**	2	3
4	Focus **Social Issues**		0,714	0,670	0,504	0,475	0,342
			1	2	**1**	2	3
5	Focus **Technology**		0,691	0,622	0,486	0,506	0,336
			1	2	2	**1**	3
6	Focus **Economics**		0,659	0,588	0,517	0,472	0,359
			1	2	**1**	2	3
7	Focus **Environment + Social Issues**		0,659	0,646	0,534	0,473	0,332
			1	2	**1**	2	3
8	Main focus **Envrionment + Technology**		0,610	0,622	0,525	0,488	0,329
			2	**1**	**1**	2	3
9	Main focus **Technology + Economics**		0,675	0,605	0,502	0,489	0,348
			1	2	**1**	2	3
10	**Equal weighting** of all dimensions		0,667	0,625	0,518	0,481	0,340
			1	2	**1**	2	3

Figure 3: Ranking lists for the case studies in Nordenham (Options 1-A, 1-B) and Outapi (Options 2-A, 2-B, 2-C) from the excel-based sustainability assessment tool.

Designing transdisciplinary research – A comparative case study of wastewater management in Latin America and the Caribbean

Angela Hahn, UNU-FLORES, Dresden Germany, Sabrina Kirschke, UNU-FLORES, Dresden Germany, Tamara Avellán, UNU-FLORES, Dresden Germany, Serena Caucci, UNU-FLORES, Dresden Germany, Lucia Benavides TU Dresden, Dresden Germany*

*United Nations University – Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES)

Key words: transdisciplinarity, co-design, participatory approach, stakeholder involvement

Abstract:

This study presents and assesses results of a transdisciplinary research process carried out in two pilot sites in Latin America, where the aim was for stakeholders and experts to co-design waste water management solutions. The study developed and applied a conceptual framework for systematically designing and implementing transdisciplinary research. A comparative case study on the application of this design highlights the challenges and opportunities of this framework. Results may help to clarify the design of effective transdisciplinary research processes for complex wastewater management processes in small to medium-sized cities in Latin America. This may also contribute to efforts in the "International Decade for Action – Water for Sustainable Development", 2018–2028 and to the achievement of the Sustainable Development Goals (SDGs).

Introduction

New connections and interrelations make problem definitions and the finding of solution strategies increasingly complex. This increasing complexity and the accompanying everyday transformation processes can only be pursued in a transdisciplinary manner. In this way, the area of integrated resource management as well faces new challenges. Unsustainable resource management, or rather the slow process towards sustainable resource management, is one problem which is being described as a very complex or `super wicked` problem (Bunders et al., 2015, Kirschke, 2017). Especially, when it comes to Nexus problems, where sectors or resources (e.g. water, soil and waste) are involved in a strongly interlinked manner, the management becomes quite complex (Roidt and Avellán, 2019). Transferred to the field of wastewater management, the involvement of practitioners in the design of infrastructures in addition to the involvement of different scientific disciplines may enable an ecologically, economically, environmentally and socially, sustainable treatment of wastewater. So far, however, it is widely unclear how this paradigm of transdisciplinary research can be implemented in practice.

This study presents and assesses results of a transdisciplinary research process carried out in two pilot sites in Latin America in a one-year project, which was completed by the end of February 2019. The overarching objective of designing and implementing this transdisciplinary research process was for international experts and local stakeholder to co-design sustainable wastewater management solution options for the two pilot sites.

Material and Methods

The transdisciplinary research process is examined from two different levels (see Figure 1). On the one hand the overarching framework of systematically designing, implementing and evaluating a transdisciplinary research will be conceptualized (macro level). On the other hand, the application phase of the actual project implementation will be analysed in more detail (micro level).

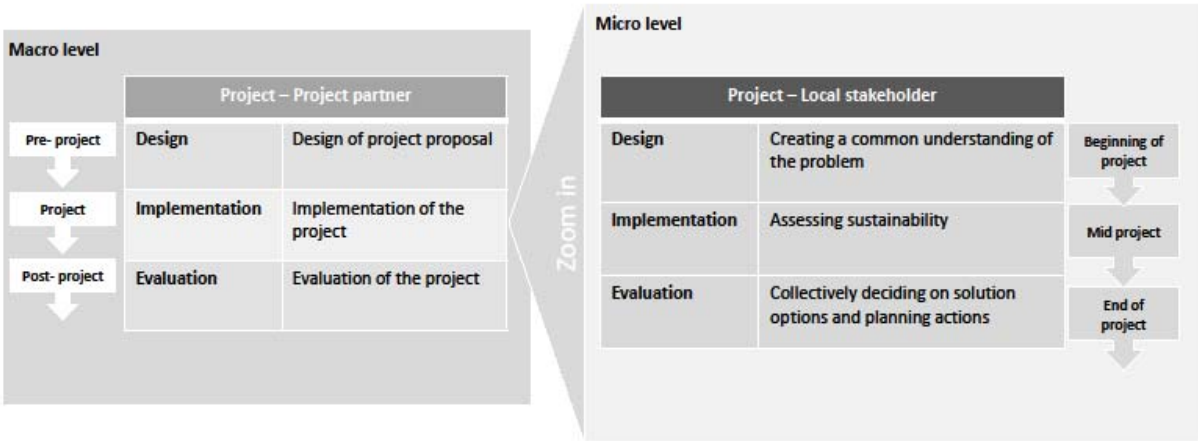


Figure 1 Macro- and Micro level of the transdiciplinarity research process

To determine the degree of transdisciplinarity of the research process, both levels will be analysed in terms of two criteria: 1. Number of actors involved, 2. Degree of involvement (from low to high: Information sharing, Consultation, Co- production and -decision (Arnstein, 1969, Mostert, 2003)). Both the macro level and the micro level of all three phases of the project (design, implementation and evaluation) are taken into consideration. On the one hand the degree of transdisciplinarity on the project partner level is the subject of the analysis, on the other hand the degree of transdisciplinarity by involving local stakeholders will be analysed. Figure 2 shows how the results will be reflected.

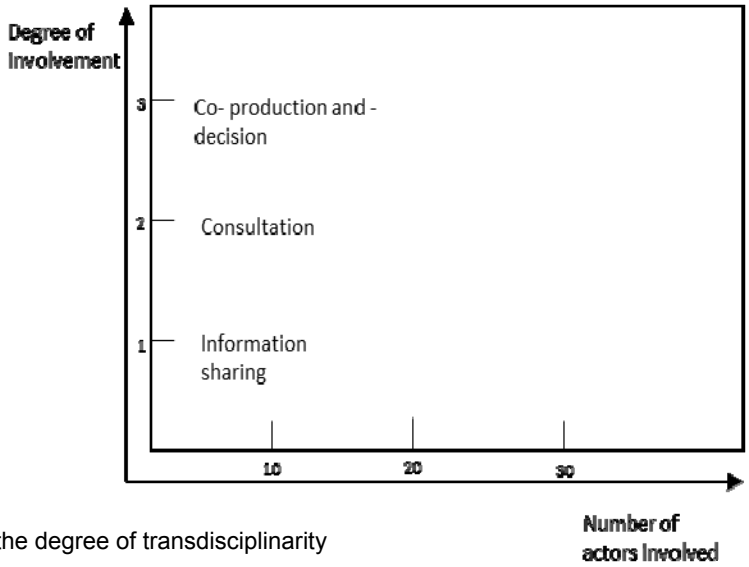


Figure 2 Determining the degree of transdisciplinarity

The dataset to analyse the degree of transdisciplinarity at the macro level in the design, and implementation phase, consists of a wide variety of project documents

such as e-mails, meeting minutes, letters etc. The data for the analysis of the evaluation are based on interviews with the project partners. Data on the micro level is mainly based on gathered data at three multi-stakeholder assessment workshops (Caucci and Hettiarachchi, 2017, UNU-FLORES, 2018, UNU-FLORES, 2019). Within the design phase, interactive and participative workshop sessions were used to create a common understanding of the problem, and to design an assessment framework by involving local stakeholders. Furthermore, a wickedness analysis was applied to define the degree of complexity of the problem, and a stakeholder analysis helped to understand who is affected by it. Within the implementation phase, the assessment framework was applied, and data was gathered by sampling, conducting qualitative interviews, and holding data meetings. Based on the gathered data a sustainability assessment was undertaken by determining the distance to target and by applying the traffic light method (Balkema et al., 2002). Within the evaluation phase a multi-stakeholder workshop was carried out to share and discuss the results of the analysis with the local stakeholders. Furthermore, pathways toward sustainable solutions were identified and further actions were planned.

However, since the project was recently completed, the final phase of the evaluation has not taken place yet but is still on-going. Final results can therefore not yet be presented. For this reason, the results and discussion section describe the challenges and opportunities of the actual implementation of the project on the micro level.

Results and Discussion

Although scientist and policy makers managing social- ecological systems are increasingly encouraged to use transdisciplinary approaches, there is only few literature on how this paradigm of transdisciplinary research can be implemented in practice. However, there are many challenges and methodological obstacles in implementing a transdisciplinary research process. Some of these are outlined below, following the three steps on the micro level of the transdisciplinary research process: 1. Creating a common understanding of the problem, 2. Assessing sustainability, 3. Collectively deciding on solution options and planning actions.

Challenges and opportunities of creating a common understanding of problem

The knowledge of the problem related to the wastewater treatment management is highly fragmented in both cases. Existing information are owned by only a few stakeholders, who seldom share it with others. Given that only 77% in Guatemala, and 76% in Mexico of all data for the sustainability assessment could be gathered, it can be stated that the information availability is poor (Avellán et al., 2019). Nevertheless, "[…] transdisciplinary research can contribute to sustainability cultures, because it can be applied in the absence of a clear and agreed problem definition and provides a comprehensive set of tools to overcome communication problems" (Bunders et al., 2015: 19). The participatory and interactive multi-stakeholder workshops allow to develop a broad picture of the problem, as both practitioners and experts exposed their different perspectives. The results of the workshop evaluation reflect the highly positive effect of the implementation of the transdisciplinary activities. Stakeholders indicated that the project activities helped to better understand the complexity of the problem. Furthermore, they highlighted a high level of usefulness of the new generated knowledge in their work (Caucci, 2017; UNU-FLORES, 2018; UNU-FLORES, 2019).

Challenges and opportunities of assessing sustainability

One of the most challenging obstacles of the sustainability assessment was the question of defining the scales and system boundaries, taking into account the technical, environmental, economic and social dimensions of sustainability. A multi-layer system model was built up in a transdisciplinary manner, to assess sustainability of the wastewater management systems in the two pilot sites. The biophysical layer was used as a basis to build the social, and the policy layer on it (see

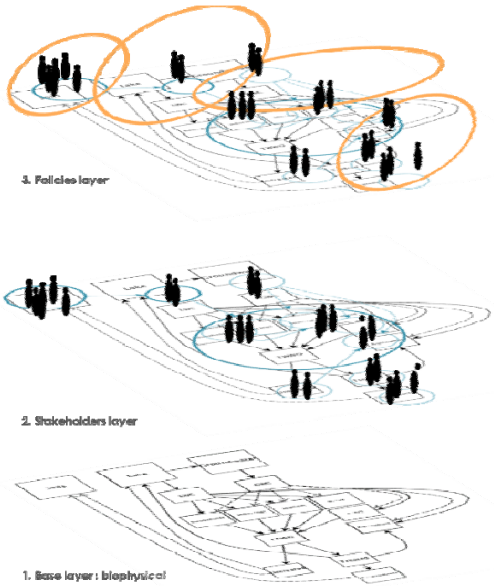


Figure 3 *Multi- layer System Model (graphic by Lucia Benavides*

Figure 3).

When applying the snowball- sampling in the field, it became clear that the geographical area is not sufficient to represent the landscape of the stakeholders. The social networks analysis in both cases showed that the relations among stakeholders go beyond the biophysical scale, as defined in the system model of the assessment framework. The dilemma of incompatibility of the disciplinary boundaries arose by trying to identify the interlinkages between the different layers presented in the same system. While resource management problems are mostly stated as spatial problems (Werlen, 2015), socio-cultural problems go beyond biophysical realities, and should be stated from a social space perspective (Kessel & Reutlinger, 2007). Consequently, the definition of a common starting point for comprehensive problem-solving strategies is one of the main obstacles that transdisciplinary research has to overcome.

Challenges and opportunities of collectively deciding on solution options

The presentation and latter discussion of the main findings of the transdisciplinary research process took place at the multi-stakeholder workshop. Various participative and interactive workshops sessions were aiming to collectively define solution options and to come to a consensus on defining concrete actions (UNU-FLORES, 2019). In order to conclude the transdisciplinary research process, local stakeholder in both pilot sites should now implement the collectively defined actions to further re-assess the same situation at a later point in time (Avellán et al., 2019). This would also allow to measure the impact of the implemented transdisciplinary research process.

Conclusions

Overall, the study shows that an inter- and transdisciplinary approach is needed to assess complex problems related to wastewater management to find comprehensive problem-solving strategies which go beyond technical solutions. It further shows that the implementation of a transdisciplinary research process entails a variety of

dilemmas of incompatible perspectives and methodological challenges, that need to be overcome to address complex environmental problems as well as social problems.

References

Avellán, T., Benavides, L., Caucci, S., Hahn, A., Kirschke, S., and Müller, A. (2019). Towards Sustainable Wastewater Treatment Systems: Implementing a Nexus Approach in Two Cases in Latin America. Case Study Report. United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES). Dresden.

Arnstein, S. R. (1969). A ladder of citizen participation. Journal of the American Institute of planners, 35(4), 216-224.

Balkema, A., J, Preisig, H., Otterpohl, R., and Lambert, F. (2002). Indicators for the Sustainability Assessment of Wastewater Treatment Systems. Urban Water, 4 (2), 153–61. https://doi. org/10.1016/S1462-0758(02)00014-6.

Bunders, J., Bunders, A. and Zweekhorst (2015). In: Global Sustainability. Cultural Perspectives and Challenges for Transdisciplinary Integrated Research. B. Werlen. Springer, Heidelberg.

Caucci, S., and Hettiarachchi, H. (2017). Wastewater Irrigation in the Mezquital Valley, Mexico: Solving a Century-Old Problem with the Nexus Approach. Proceedings of the International Capacity Development Workshop on Sustainable Management Options for Wastewater and Sludge, Tepeji, Mexico, 15−17 March 2017. UNU-FLORES. Dresden. http://collections.unu.edu/ view/UNU:6216

Kessel, F. and Reutlinger, C., (2007). Sozialraum. Eine Einführung. VS Verlag für Sozialwissenschaften, Wiesbaden.

Kirschke, S., and Newig J. (2017). Addressing Complexity in Environmental Management and Governance. Sustainability, 9 (6): 983. https://doi.org/10.3390/su9060983.

Mostert, E. (2003). The challenge of public participation. Water policy, 5(2), 179-197.

Pries, L. (2008). Die Transnationalisierung der sozialen Welt. Suhrkamp, Frankfurt am Main.

Roidt & Avellán (2019). Learning from integrated management approaches to implement the Nexus. Journal of Environmental Management, 237, 609–616.

UNU-FLORES (2019). Sustainability of Wastewater Treatment Plants – Validation and Options. Proceedings of the SludgeTec Project closing workshop in Tepeji del Rio Ocampo, México, 12 - 16 November 2018. UNU-FLORES, Dresden. http://collections.unu.edu/view/UNU:7287

UNU-FLORES (2018). Sustainability of Wastewater Systems: Current and Future Perspectives - an Assessment Workshop. Proceedings of the SludgeTec Project closing workshop in Panajachel, Guatemala, 20-23 March 2018. Dresden, Germany: UNU-FLORES. http://collections.unu.edu/view/ UNU:6648

Werlen, W. (2015). Global Sustainability. Cultural Perspectives and Challenges for Transdisciplinary Integrated Research. Springer, Heidelberg.

Alternative Drivers for Potable and Nonpotable Reuse

Justin Mattingly, The Water Research Foundation, Alexandria VA, United States;
Julie Minton, The Water Research Foundation, Alexandria VA, United States;
jmattingly@waterrf.org

Abstract:

The practice of water reuse is well established in many water stressed regions throughout the world including the west coast and much of the southern United States. This is largely due to the traditional drivers for water reuse of persistent drought and reducing the need for potable water for nonpotable purposes. While communities in the eastern United States and other less water stressed regions are not typically susceptible to such persistent droughts, there are alternative drivers that are leading many such communities to consider water reuse as part of a broader integrated water management strategy.

Introduction

Traditionally, the drivers for water reuse have largely been limited to issues surrounding drought and water scarcity. Recently, the 2011-2017 California drought from has catalyzed significant developments in water reuse – including potable reuse. However, these developments in the United States are not limited to California. For example, the first Direct Potable Reuse facility in the United States was the Raw Water Production Facility in Big Spring Texas that was largely developed in the face of extreme drought (Steinle-Darling et al., 2016).

In addition to locations that traditionally face issues of water scarcity, other regions in the United States are also seeing increased interest in water reuse. In these cases, there are other drivers taken into consideration when the decision is made to pursue water reuse – both potable and nonpotable. In Florida, water reuse is a well-established practice, not just to augment existing water supplies to but to also reduce wastewater discharges into sensitive coastal ecosystems (National Research Council, 2012). This has largely been done through the use of nonpotable reuse, but potable reuse is also of significant interest to many communities in Florida. Managing discharges for a variety of reasons (e.g., nutrients) is one several alternative drivers

that is catalyzing the practice of reuse in many regions that do not face persistent water scarcity

Discussion

Among the utilities advancing water reuse to manage discharges is the Hampton Roads Sanitation District (HRSD) in southeastern Virginia. HRSD is currently planning and implementing their Sustainable Water Initiative for Tomorrow (SWIFT) program to inject advanced treated effluent into the coastal Potomac Aquifer (Nading et al., 2017). While this program will augment local potable water supplies, it will also eliminate most wastewater discharges and reduce the flow of nutrients into the Chesapeake Bay, an iconic and economically important waterbody for the region. By reducing nutrient discharges, surrounding communities will be able to better coordinate water infrastructure investments, potentially avoid stormwater management upgrades, and ensure that investments provide the largest possible benefit. In this case, water reuse is created multiple benefits aside from water supply augmentation in an integrated approach.

In addition to the work at HRSD, a Water Research Foundation research project is ongoing in the Potomac River watershed in the Washington DC region to investigate the impact of potable reuse on discharges of nutrients and endocrine disrupting compounds (Kaushal et al., 2020). Preliminary results indicate that waterbodies under the influence of potable reuse show a lower concentration of estrogenic compounds, although additional sampling is being conducted to better characterize impacts. The impact on nutrient concentrations is also being investigated. This project, funded by the U.S. Environmental Protection Agency, is also looking at stormwater management and agricultural best management practices to determine their impact and how water reuse can fit into the broader concept of integrated water management. As this research and other efforts better characterize benefits, water reuse will not be viewed as just a water supply option but as a potential management strategy for nutrients and other pollutants.

Aside from reducing nutrient discharges, HRSD is implementing SWIFT to halt and potentially reverse land subsidence due to aquifer depletion and slow the pace of sea level rise by replenishing the coastal aquifer. The Hampton Roads region is not alone on the east coast in regards to depletion of aquifers (Masterson, et al., 2016), but

they are acutely susceptible to sea level rise due to geography. The planning and implementation of the SWIFT project has had resulted in increased interest in groundwater augmentation, as several other communities in the region and elsewhere that are considering similar projects to combat sea level rise, protect existing groundwater supplies, and reduce nutrient discharges.

In addition, coastal communities in states like New Jersey and New York are grappling with saltwater intrusion (Barlow and Reichard, 2010) and may need to consider management strategies including groundwater injection to properly replenish diminished aquifers and create a seawater intrusion barrier to protect water supplies. Such communities may not be considered to be water stressed, but may still need to protect their current supplies. While the implementation of groundwater injection may not be implemented or even considered for some time, it is not out of the question that it will be considered in the future.

Conclusions

Communities in the west coast and the southern United States along with other water stressed regions will continue to lead the development of water reuse, but the above described drivers will likely gain importance and drive decision-making among some communities for water reuse. The issue of nutrients management is a significant problem for many communities and water reuse offers the potential to reduce nutrient discharges in a manner that may be more cost effective than other means. When combined with the need to protect threatened groundwater supplies, water reuse may become a more common practice due to reasons beyond diminishing drinking water supplies.

References

Barlow, P. and Reichard, E. Saltwater intrusion in coastal regions of North America. Hydrogeology Journal, 18: 2247-260.

Kaushal, S., Duan S., Godrej, A., Iwanowicz, L., Aga, D., and Rosenfeldt, E. (2020 expected publication) Improving Water Reuse for a Healthier Potomac Watershed. The Water Research Foundation.

Masterson, J.P., Pope, J.P., Fienen, M.N., Monti, J., Nardi, M.R., and Finkelstein, J.S. (2016) Assessment of groundwater availability in the Northern Atlantic Coastal Plain aquifer system from Long Island, New York, to North Carolina. U.S. Geological Survey Professional Paper.

Nading, T., Schimmoller, L., Salazar-Benites, G., Bott, C., Mitchell J., Wilson, C., Zuravnsky, L., Dano, J., Henifin, T., Snyder, and E., Holloway, D. (2017). Sustainable Water Initiative For Tomorrow: A Look at HRSD's Innovative Approach to Water Reuse. Proceedings of the Water Environment Federation.

National Research Council (2012) Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater. Washington, DC: The National Academies Press. https://doi.org/10.17226/13303.

Steinle-Darling, E., Salveson, A., Sutherland, J., Dickenson, E., Hokanson, D., Trussell, S., and Stanford, B. (2016). Direct Potable Reuse Monitoring: Testing Water Quality in a Municipal Wastewater Effluent Treated to Drinking Water Standards. Water Environment and Reuse Foundation.

The reuse, as a reinvention of wastewater?

Anne-Laure Collard[1], Nassim Ait Mouheb[1], Remi Barbier[2] ;
University of Montpellier, G-EAU[1], France[1],
ENGEES[2], Strasbourg[2], France[2] ; anne-laure.collard@irstea.fr; nassim.ait-mouheb@irstea.fr; remi.barbier@engees.unistra.fr

Abstract

In 1989, a water reuse project was developed in the Saint Mathieu de Tréviers municipality (South France). Today, the territory actors seem to be totally rediscovering this practice. The aim of this article is to understand this oversight by resocializing treated wastewater. The results show, over time, a different partnership of actors and interests, which can explain the omission of this original TWW reuse project as well as the requalification of this practice.

Key words: wastewater reuse, socio-technical, local, requalification, France

Introduction

In the Pic Saint Loup region (PSL), TWW reuse has been quietly talked about since 2016 as a potential for territorial development. The originality of this practice raises questions. Since 30 years, a technical device installed in the municipality of Saint Mathieu de Tréviers (SMT) has been based on the principle of wastewater reuse. Nevertheless, this water reuse project is rarely mentioned, indeed forgotten. The local actors give the impression to rediscover this practice. Why does Saint Mathieu's project appear "naturalized" and no longer received attention? Our reflection is based on this observation and on the hypothesis that the past water reuse device - similar to every technical devices (Akrich, 1993, Aubriot, 2018) - is not according with the current definition.

The practice of water reuse is not new practices around the world (Barles, 2005, Cirelli, 2006). In the literature, this long history is used either to justify the relevance of using the wastewater (Angelakis et al., 2018, Hamlin, 1980), or to draw lessons about project success or failure (Po, Nancarrow et al. 2003, Lazarova et al., 2007). In agreement with Russell and Lux (2009), these mainly descriptive approaches contribute to make this practice as socially disembodied practice in the territory scale,

or even the "hydrosocial contract" (Farrelly and Brown, 2014). Wastewater seems to pass through the time or places without changing. The aim of this article is to provide a "narrative" of the experience conducted at SMT by resocializing treated wastewater and then to compare it with the project imagined since 2016 on the PSL territory. By socialization, we mean the identification of the actor partnerships involved in the reflections about TWW reuse and the identification of their interests.

To answer these questions, a qualitative survey (2016 to 2019) was carried out with the stakeholders of old SMT project (engineers, municipal agents, researchers, elected officials) (n=10) and those who are currently concerned by the water reuse perspective (n=27). The analysis of old technical reports was cross-referenced with stakeholders' declarations. The aim was to identify the development in the water reuse practices over time (actor coalition, interests, and materiality).

Wastewater device trajectory at Saint Mathieu de Tréviers

In 1977, an infiltration analysis were carried out by the hydrogeology laboratory and the Center of geological and hydrological studies and research (CERGH) in the University of Montpellier. The measurements showed that the discharges of SMT wastewater treatment plant into the Terrieu stream pollute the drink water source (called Lez) that supplies the current Montpellier agglomeration. In 1981, a Declaration of Public Utility defined a protected drinking water area. The elected representatives of SMT municipality are invited by the Regional Health Agency to achieve the "Zero Discharge" objective in the Terrieu stream. In 1989, the project entitled "Reuse of treated effluent at SMT: experimental forest irrigation" was proposed as a solution by a group of researchers, led by Professor Brissaud (recognized a few years later as a "Reuse expert"). The project was planned that the treated wastewater from activated sludge plant will be diverted to irrigate 5 ha pine forest. SMT Reuse project was defined as an "experimental" project. This demonstrator aims to provide answers about the treatment effects of soil (Figure 1). The system is cheap and quickly installed (the links between the actors involved facilitate arrangements).

Soon, the demonstrator aspect of this project disappears. The researchers at the University of Montpellier are withdrawing from the project. In 1997, the state authorities highlight many dysfunctions (irrigation schedule, water flow rate) which

raises the question about the technical device effectiveness to achieve the "Zero Discharge" objective. The engineering company is forced to redesign the irrigation system and to enhance the irrigated area. Since, the reuse system has many damages and maintenance problems. Indeed, the administrative agreement does not clarify the responsibilities of each. For 20 years, the system was managed on basis of oral arrangements between the sanitation company and the private owner, and later with the municipal agent. They distribute with each other the maintenances to be carried out according to their size (of the leak for example). Nevertheless, the treatment effectiveness remains uncertain as said one of our interlocutor: "*We don't know, we don't know where this water goes, we don't know what happens to it in the end*" (Engineer). Since 2018, SMT's treatment plant has been renovated. A baffle channel will replace the old device forest irrigation system.

Shifting interests: a requalification of the wastewater reuse

Over the past 30 years, the Reuse definition of the SMT project has gradually changed, as have the interests attached to it. Initially, a partnership of actors was formed to solve the environmental problem related to the drinking water source pollution used by Montpellier population. In this context, the researchers used the SMT experiment to broad their investigation issues on real condition. For engineering experts, TWW was a technological challenge, to design a hydraulic and irrigation device for this singular water. The SMT mayor was content with by this an innovative, reasonable budget and rapid installation solution. At the end of 1990s, this coalition disintegrated with actors' disinterest. Indeed, the experimental framework loses its meaning and researchers shift their cognitive investment to other sites. The private owner of the pine forest is comforted to see his plot protected from property pressure because it is necessary for treatment process. The elected officials of SMT and Montpellier are satisfied by the principle of diverting wastewater from the watercourse. Therefore, after the first moments of project installation, it is no longer the subject of attention. The care on it disappears. The prime contractor and the municipal agent then inherit a technical device in which they have not participated in the beginning and simply tinker with it to ensure its functioning. An installation of a modern UV device make the previous one obsolete. It should be noted that the SMT wastewater reuse system is similar to another called the «Vegetative Treatment

System". Nevertheless, it never has not been qualified with this term, which probably could have rehabilitated the interest.

Currently, the Reuse is being promoted by an "epistemic community" (Haas, 1992) of experts as a solution to climate change and water resource reduction (water stress, drought, maintenance of biodiversity, agricultural activities). Presented as a promising solution, the Reuse would be working for a rational water management. Regularly compared to other devices (desalination or water transfer process), the promise is based on environmental and social benefits (Lazarova, and al. 2001). As such, the principles of the circular economy are used to give treated wastewater the image of recyclable resources and no longer that of "taboo" waste (Jeanjean, 2000).

This qualification of the Reuse reinforces the omission and disinterest in the SMT project by two aspects: in terms of the problem identified and the coalition of actors. In 2016, wastewater reuse is imagined as a solution to water scarcity for the irrigated viticulture development, the main local economic activity. In this perspective, the Reuse solution interests the local elected officials who are concerned to answer the local demand from winegrowers. It is also an opportunity to promote an innovative and modern territory where the challenges of climate change are being considered. They are accompanied by a consulting company (REUSE expert) in charge on manage the community projects and whose reputation partly depend on the concrete achievement of TWW design. Waiting a water sustainable transfer, the local winegrowers are interested by the Reuse as an alternative from their demand. Thus, wastewater is considered as a potential to perpetuate the high value-added crops and participate in the development of fast-growing sectors. The issues are more focused on economic than environmental concerns. However, the Montpellier agglomeration maintains a definition of the Reuse as a guarantee to improve the quality of the wastewater treatment, which infiltrates to the Lez source.

Depending to the moment, the wastewater reuse has been shape within two coalitions of actors. Indeed, the reuse solution was adopted for very differently problem (environmental, then economic). In this way, the wastewater reuse practice was requalified. Indeed, if it is still a question of irrigating with treated wastewater, the expected promise behind the technical solution is no longer the same. In 1989, it was

applied an ingenious, effective and inexpensive treatment device. Since 2016, the practice is considered as a sustainable technique to promote a responsible development of irrigation. This reinvention of wastewater partly explains this kind of rediscovery of their reusing by the current local actors.

Conclusion

The water reuse is not a standard practice. Based on the aim to resocializing local wastewaters, this study shows that it is now a completely different Reuse from the one discussed in 1989. Questioning actors and interests allows us to extract ourselves from a purely technical conception of this practice and to avoid adopting a definition of a "plastic word" (Cirelli, 2006) that would only make sense in a specific situation. This study invites us to continue the reflection about the socio-technical broader in order to understand the plurality of translations of wastewater reuse practice (TWW reuse, RDW, NEWater, water reuse...).

Acknowledgements

The authors gratefully acknowledge the financial support of Water RMC Agency (France). Project SoPoLo, coordination: Sébastien Loubier.

References

Akrich M. (1991). L'analyse socio-technique. In : *Gestion de la recherche: nouveaux problèmes, nouveaux outils, D. Vinck, M. Akrich (eds.)* De Boeck Professional Publication, Paris, France, *pp.* 339-353.

Angelakis A. N., Asano T., Bahri A., Jimenez B. and Tchobanoglous G. (2018). Water reuse: from ancient to modern times and the future. Frontiers in Environmental Science 6(26).

Aubriot, O., Fernandez S., Trottier J., and Fustec K. (2018). Water technology, knowledge and power. Addressing them simultaneously. Wiley Interdisciplinary Reviews: Water, 5(1).

Barles S. (2005). L'invention des déchets urbains: France, 1790-1970, Editions Champ Vallon, Paris, France.

Cirelli C. (2006). Environnement et usages de l'eau. Pratiques agricoles à risque aux marges des villes mexicaines. PhD thesis, University Paris VIII Vincennes-Saint Denis, France.

Denis J. and Pontille D. (2015). Material ordering and the care of things. Science, Technology, & Human Values, 40(3), 338-367.

Farrelly M. A., and Brown R. R. (2014). Making the implicit, explicit: time for renegotiating the urban water supply hydrosocial contract? Urban Water Journal, 11(5), 392-404.

Fressoz J. B. and Bonneuil C. (2016). L'Événement anthropocène. La Terre, l'histoire et nous: La Terre, l'histoire et nous, 2nd edn, Editions du Seuil, Paris, France.

Haas P. M. (1992). Introduction: epistemic communities and international policy coordination. International organization, 46(1), 1-35.

Hamlin C. (1980). Sewage: Waste or resource? A historical perspective. Environment: Science and Policy for Sustainable Development, 22(8), 16-42.

Lazarova V., Levine B., Sack J., Cirelli G., Jeffrey P., Muntau H., Salgot M., and Brissaud F. (2001). Role of water reuse for enhancing integrated water management in Europe and Mediterranean countries. Water Science and Technology, 43(10), 25-33.

Lazarova V., and Brissaud F. (2007). Intérêt, bénéfices et contraintes de la réutilisation des eaux usées en France. *L'eau, l'industrie, les nuisances*, (299), p. 29-39.

Po M., Kaercher J. D. and Nancarrow B. E. (2003). Literature review of factors influencing public perceptions of water reuse, Technical report 54/03, CSIRO Land and water, Australia

Russell S. and Lux C. (2009). Getting over yuck: moving from psychological to cultural and sociotechnical analyses of responses to water recycling. Water Policy, 11(1), 21-35.

Rolling literature review on pathogen reduction by water treatment processes

Patrick W.M.H. Smeets, KWR Watercycle Research Institute, Nieuwegein, The Netherlands; Karl Linden, University of Colorado, Boulder, USA; Ulf Miehe, Kompetenzzentrum Wasser Berlin (KWB), Berlin, Germany

Water treatment to manage risks of water reuse

Water that is contaminated with pathogenic microorganisms can lead to spreading of contagious diseases. Reuse of municipal wastewater for drinking water production or irrigation and reuse of water in the food industry are clear examples of such risks. Water treatment is generally required to provide safe, fit for purpose water. To design adequate treatment, often a quantitative microbial risk assessment (QMRA) is carried out with the aim to meet health based targets expressed as risk of infection or disability adjusted life years (DALY). Based on the level of pathogenic microorganisms in the water source and their reduction by treatment, the concentration in the treated water can be calculated. Then the exposure and health effects of various applications and exposed persons can be simulated. The presented work focuses on providing state of the art knowledge on pathogen reduction by treatment in this context.

Rolling literature review

There are many scientific studies on the effect of water treatment on pathogens. Each focuses on a different microbial pathogen, treatment process or water matrix. Incidentally a review study is carried out that combines results from various of these studies to reach more generic conclusions. These may lead to concise overview tables such as the Table 7.7 in the WHO Guidelines for Drinking Water Quality (WHO 2017). However such reviews are rapidly outdated, as new scientific studies are published. Also a lot of information is lost when reducing all the data into a basic table. Therefore a rolling literature review was initiated that allows continuous updating of the underlying data and provides access through a web tool that allows selection and interpretation of the data. This allows users to quickly select the data that is most relevant for their situation. Since the original publications are all listed with the selected data, the information source is transparent and users can refer back to the original publications. Figure 1 shows the web tool for UV disinfection.

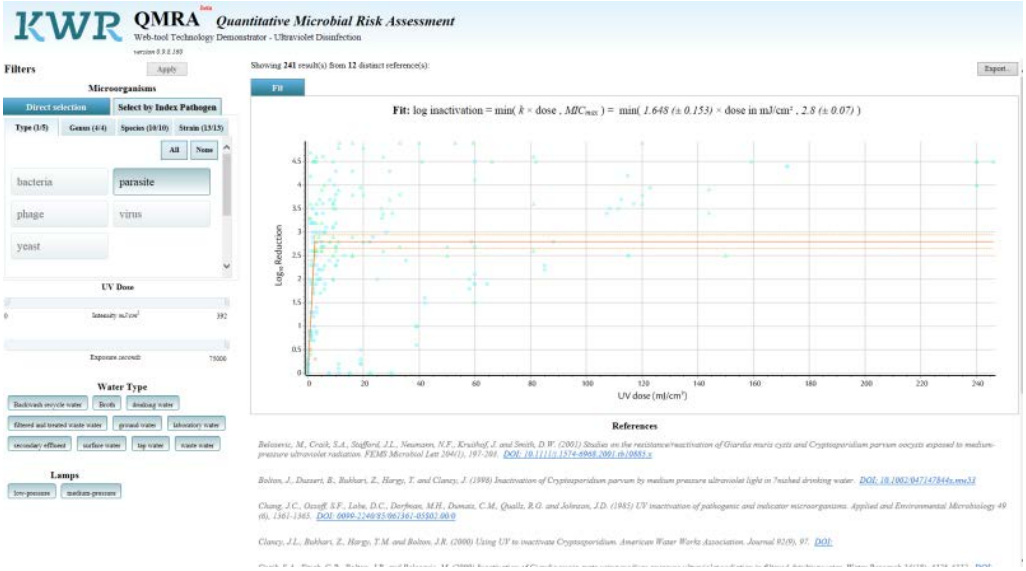


Figure 1 Screenshot of the web tool that provides access to the data from the rolling literature review

Joint efforts for data collection

The data collection starts with a systematic literature review using standardized keywords and several literature databases. The selected publications then undergo a series of quality checks based on title, abstract, provided details and quality of the data provided. Data is extracted from the publication by hand, which requires a joint effort. Currently efforts from various projects and partners are joined. KWR reviews drinking water treatment processes for the joint research of the Dutch drinking water companies. University of Colorado does the same for the update of Tables 7.7 and 7.8 in the WHO GDWQ. In the AquaNES project, KWB focuses on treatment processes which combine nature-based and engineered treatments steps,. By joining forces the work load is shared, knowledge is exchanged and quality is checked.

Outlook and discussion with the audience

It is expected that the databases will be up to date for all treatment processes by mid 2019, which will be followed by the gradual completion of the web tools per treatment process. Meanwhile, a QMRA web tool is being developed in the AquaNES project that incorporates the treatment tools. In addition a similar tool for pathogen concentrations in water sources of different qualities is being developed. At the IWA reuse conference we will present the status of the online QMRA tool and its specific functions (e.g. as oral presentation and live demonstration at a booth) and hope to initiate further cooperation with partners to continue this development into the future. We are also open for other formats such as a workshop on risk management and QMRA during the conference.

Application of a model for supporting risk assessment of emerging contaminants in the context of wastewater reuse for irrigation

Riccardo Delli Compagni[1], Fabio Polesel[2], Kerstin J.F. von Borries[2], Zhen Zhang[2], Marco Gabrielli[1,2], Andrea Turolla[1], Stefan Trapp[2], Luca Vezzaro[2], Manuela Antonelli[1]*

[1] *Politecnico di Milano, Dep. of Civil and Environmental Engineering, Milano, Italy*

[2] *Technical University of Denmark, Dep. of Environmental Engineering, Kongens Lyngby, Denmark*

Introduction

About 17% of the European territories suffer from water scarcity. The situation is expected to worsen over the next years due to climate change, with potentially severe socio-economic implications. Recently, EU member states agreed that agricultural reuse of reclaimed urban wastewater should be enhanced whenever safe and proposed minimum requirements for safe reuse [1]. The proposal recognized the need of assessing the risk (where relevant) associated to contaminants of emerging concern, whose threat for environment and human health is well recognized. Given the lack of measurements and the challenges inherent to field monitoring, integrated chemical fate models represent valuable tools to (i) predict exposure concentrations (for assessing the current risk) and (ii) to evaluate alternative scenarios (to identify risk minimization strategies). However, these models are usually applied within the boundaries of urban areas or for hypothetical wastewater reuse scenarios [2], lacking significant validation for real cases. In this study, an integrated dynamic model was developed and tested for a highly urbanized area in northern Italy, where treated municipal wastewater is used for irrigation. Calibration and validation were performed at different locations and risk indicators were calculated to assess environmental and human health safety associated to the exposure to several emerging contaminants.

Material and Methods

The IUWS-MP model library [3] was coupled with a dynamic plant-uptake model [4] and calibration/validation was performed at different locations (wastewater treatment plant inlet/outlet, along the irrigation canal) for conventional (COD, TSS, N, P) and emerging contaminants (e.g., pharmaceuticals, biocides). Site-specific input data (consumption, inhabitants, irrigation periods, type of soil and crops) were collected, while chemical properties (partitioning coefficients, biodegradation rates) and toxicity data were obtained from literature. Long-term (≥ 1 year) predictions of exposure

concentrations were obtained in different sensitive recipients (irrigation water, edible crop tissues) and risk indicators were calculated.

Results and Conclusions

Figure 1a shows mass fluxes of carbamazepine (CBZ), ibuprofen (IBU) and diclofenac (DCF) along the integrated system, while Figure 1b presents the predicted bioconcentration factors for CBZ in different crop compartments. While IBU and DCF showed removal along the system, CBZ persisted (with limited removal during irrigation periods). For the river compartment, predicted environmental concentrations never exceeded no effect concentration (e.g., risk quotient=0.023 for CBZ), suggesting no risk. The expected daily dietary intake was estimated from predicted concentrations [5] in edible crop tissues, being <1000 times lower than the acceptable daily intake for substances.

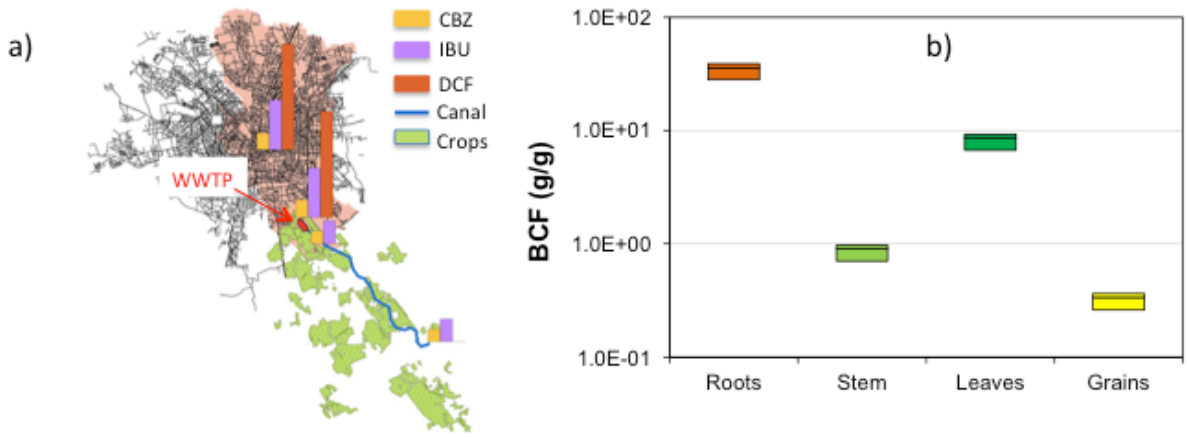


Figure 1 (a) Catchment and substance flow analysis; (b) Bioconcentration factors for CBZ.

An integrated fate model was tested for an existing case of urban wastewater reuse for irrigation. The presented approach can be useful in predicting environmental and human risk associated to the exposure to a wide array of emerging contaminants.

References

[1] European Commission, Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse COM/2018/337 final - 2018/0169 (COD) 28 May 2018, Brussels, Belgium.

[2] Polesel, F., Plósz, B.G., Trapp, S. (2015). From consumption to harvest: Environmental fate prediction of excreted ionizable trace organic chemicals. Water Res.84, 85–98.

[3] Vezzaro, L., Benedetti, L., et al. (2014). A model library for dynamic transport and fate of micropollutants in integrated urban waste-water and stormwater systems. Environ. Model. Softw. 53, 98–111.

[4] Trapp, S. (2017). New release dynamic (numeric) coupled soil-plant uptake model for monovalent ionics.

[5] Prosser, R.S., Sibley, P. (2015). Human health risk assessment of pharmaceuticals and personal care products in plant tissue due to biosolids and manure amendments, and wastewater irrigation. Environ. Int. 75, 223–233.

Virus Detection Methods for Water Reuse Applications

Krista Wigginton, University of Michigan, Ann Arbor, United States; Nicole Rockey, University of Michigan, Ann Arbor

Introduction

Pathogenic virus removal is a major driver in the guidelines and design of planned wastewater reuse for potable water. Depending on the location, reuse regulations and guidelines for virus removal range from 8- to 13-logs or more from untreated wastewater to finished drinking water. Potable water reuse treatment trains are frequently overengineered for virus removal because utilities cannot demonstrate the true virus log reductions for certain common unit processes (e.g., biofiltration, ultrafiltration, R.O.). Ideally, we could monitor viruses directly in finished drinking water to demonstrate the water is safe; however, due to the extremely low virus concentrations in finished water that correspond to a 1 in 10,000 risk of infection (e.g., 10^{-7} enteric viruses/L), this is not possible. Viruses are incredibly small (~20-200 nm) and this makes them challenging to concentrate, purify, and count. Detection typically relies on culture-based or PCR-based methods; however, most viruses are not readily cultured, and their lack of conserved genes and rapid evolution complicates PCR primer development and sequencing efforts.

Objective

The purpose of this presentation will be to summarize recent advances in virus detection techniques and applications. We will start with a review of approaches employed to concentrate and recover small numbers of virus particles in large volumes of water. We will then discuss advancements in the more traditional virus detection methods, including culture-based methods and PCR-based methods. For example, we will review the status of recent developments related to human norovirus culturing. We will also discuss several up-and-coming virus detection methods that we believe will be increasingly applied in water reuse applications. For example, we will introduce quantitative viral metagenomics methods and its application for better characterizing the pathogenic virus strains and concentrations in untreated wastewater. We will also discuss flow virometry, which is increasingly applied to measure the concentration of virus particles in water samples. With respect to this last technique, we will describe our group's recent work on the

application of virus like particles with green fluorescent proteins (GFP) for tracking virus reduction credits across physical and biological unit processes in water treatment trains.

Flow Cytometric Monitoring of a German Pilot Study for Treating Municipal Wastewater to Different Water Quality Standards

Andreas Nocker, Barbara Zimmermann, Andreas Nahrstedt, IWW Zentrum Wasser, Mülheim an der Ruhr, Germany;
Kerstin Krömer, Yannick Tiemann, OOWV, Brake, Germany;

The dry summer 2018 and resulting local water stresses have confirmed the importance of water reuse in Europe also for areas that traditionally have not suffered from water shortage. In collaboration with the water supplier Oldenburgisch-Ostfriesischer Wasserverband (OOWV) in Lower Saxony, a German research consortium assessed the suitability of a combination of different water treatment technologies to treat municipal wastewater treatment plant effluent to different quality levels meeting standards mainly for agricultural irrigation and industrial applications. Among other technologies, the pilot water treatment train included coagulation, ultrafiltration (UF), reverse osmosis, sand filtration, granular activated carbon filtration and disinfection. Different combinations of these treatment steps were combined in a modular fashion.

Absence of traditional microbiological indicator organisms after ultrafiltration confirmed an efficient removal of hygienically relevant microorganims at an early point in the treatment process. Traditional microbiology was supported by flow cytometry to rapidly monitor the effect of different treatment steps on bacterial concentrations. Flow cytometric results were in good agreement with colony counts with both methods showing similar relative changes of bacterial numbers over the treatment train although only between 0.2 and 1.5 percent of bacteria were culturable. In addition to quantifying bacterial numbers at the time point of sampling, flow cytometry allowed for assessment of the regrowth potential of the treated water. Although bacterial concentrations were substantially reduced especially after membrane filtration processes, the greatest challenge consisted in reducing the regrowth potential to achieve sustainability of treatment. In the absence of disinfection, regrowth typically occurred within 5 days at 22 °C. Alternatively to nutrient removal, regrowth could be efficiently suppressed by addition of hypochlorite. Chlorine concentrations of 1 or 2 ppm could suppress regrowth in UF permeate for at least 5 or 14 days, respectively.

The project MULTI-ReUse (Modular Water Treatment and Monitoring for Wastewater Reuse, 2016-2019) has received funding from the German Federal Ministry of Education and Research as part of the funding measure “Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)”, https://water-multi-reuse.org/en/.

Quantitative exposure and risk assessments of sequential biofiltration within a potable reuse treatment train

Veronika Zhiteneva[1], *Juan Rodriguez*[1], *Max Ehre*[2], *Uwe Hübner*[1], *Jörg E. Drewes*[1]

[1]*Technical University of Munich, Garching, Germany*

[2]*Technical University of Munich, Munich, Germany*

Abstract:

A probabilistic network capable of modeling concentrations at the effluent of a potable reuse treatment train was constructed. By including additional water quality parameters known to influence removal of trace organic chemicals in the network, the created model became more complex when discretization thresholds for nodes in the system were increased. The final model requires a wider range of experimental data, as well as additional external data for validation, but demonstrates that such a framework can predict whether effluent trace organic chemical concentrations are above or below health-relevant thresholds.

Keywords: Trace organic chemicals; modeling; Bayesian network; potable reuse

Introduction

The status quo of current urban water management approaches is for conventional wastewater treatment plants (WWTP) to discharge treated wastewater into surface waters. WWTPs employ physical (filtration, adsorption), biological (degradation), and chemical (advanced oxidation) removal processes, but achieving an efficient removal of the majority of trace organic chemicals (TOrCs), treatment comes at higher operational costs (Wang & Wang, 2016). Potable water reuse, where WWTP effluent undergoes advanced water treatment (AWT), then is either released into an environmental buffer in indirect potable reuse (IPR) or directly sent to a drinking water treatment plant when practicing direct potable reuse (DPR), can augment drinking water supplies (National Research Council, 2012). Multiple treatment barriers are required to ensure proper water quality and minimize chemical and microbial risk for consumers.

Laboratory-scale column studies have shown that oxic and oligotrophic redox conditions foster microbial communities capable of improved TOrC removal (Alidina,

Li, Ouf, & Drewes, 2014; Li et al., 2012; Rauch-Williams, Hoppe-Jones, & Drewes, 2010), which prompted the development of the sequential biofiltration (SBF) concept. Here, biodegradable dissolved organic carbon (BDOC) present in WWTP effluent is removed in a first biofilter, followed by aeration and a second filter where elevated dissolved oxygen (DO) concentrations are maintained to foster the establishment of specialized microbial communities, resulting in improved cometabolic TOrC removal (Rauch-Williams et al., 2010).

The aim of this study is to quantitatively assess the microbial and chemical risks to human health of alternative treatment concepts for indirect potable reuse based on the novel SBF concept. Therefore, a chemical risk assessment for two reuse trains currently under investigation was conducted (Figure 1).

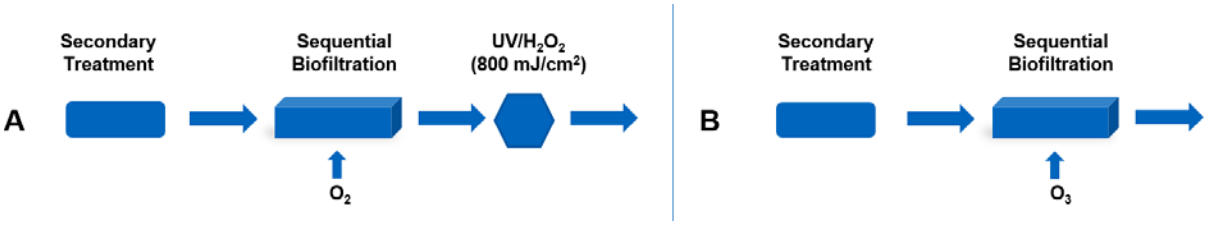


Figure 1: Proposed water reuse treatment trains adopting the SBF concept employing A) intermediate aeration or B) ozonation.

Material and Methods

The first step in conducting a health risk assessment is to construct a model capable of predicting chemical and/or pathogen removal. While the entire pathway from raw sewage to the point of exposure is usually considered for quantitative microbial risk assessment, the presented QCRA approach focuses on the advanced treatment processes until the point of compliance (at the UV/H_2O_2 effluent in Figure 1A, and at the SBF effluent in Figure 1B) as no additional removal in subsequent treatment processes is expected.

Health-relevant and process performance-based chemicals were identified by the ratio of the 90th percentile of the measured effluent concentration (MEC) in secondary effluent divided by the monitoring trigger level (MTL), defined by toxicological no effect levels as compiled by the Science Advisory Panel of the CA Division of Drinking Water (Drewes et al., 2018). If MEC(90)/MTL > 1, the chemical is deemed suitable for conducting a risk assessment.

Data from different treatment steps was combined in a stochastic network capable of determining relationships between TOrC and bulk water quality parameters to predict final effluent TOrC concentrations. Bulk water quality (DOC, DO, UVA) and TOrC grab samples, collected over two years from WWTP effluent and a pilot-scale SBF (with and without employing ozonation, Müller et al., 2017 and Müller et al., under review) were combined with TOrC and water quality parameter removals observed in UV/H_2O_2 treatment (Miklos et al., 2018). By describing parameters using probability distribution functions, a Bayesian network capable of determining whether and which TOrCs exceed MTLs after treatment can be established, which allows characterization of variability and uncertainty inherent to environmental treatment systems.

Probabilites were determined by fitting 9 PDFs to experimental data using Matlab's probplot function to visually select the best fitting distribution. Once selected, relationships between the parent and child nodes could be described by populating conditional probabilities tables (CPTs) to discretize the occurrences into bins or defined ranges. Occurrences in each bin were divided by the total amount of occurrences for a particular condition to obtain the probability of that condition occurring.

Results and Discussion

Constructing the Bayesian network from baseline data revealed that the amount of data available was inadequate. As Bayesian networks are based on causal relationships between parent and child nodes, which are both discretized into bin ranges, the data available could not successfully fill every condition in the CPTs. This was compensated by running a Nataf transformation (Engineering Risk Analysis Group, 2018) to generate a greater quantity of random samples using the joint PDF of child and parent nodes. This is done using the original data, the marginal distribution fittings (estimated in Matlab), and the correlation matrix of the parent and child node data for the treatment step in question.

Results from experimental data show that for benzotriazole (MEC(90)/MTL = 2.3), the subsequent treatment steps shown in Figure 1 successfully reduce the concentrations below MTL levels in >95% of cases (Figure 2). Additionally, a preliminary Bayesian network which can be easily modified to include expert opinion and more experimental information was created. As data used for the model came

from only baseline operational conditions, conducting a challenge test to observe how the SBF system responds to higher DOC, DO, and TOrC concentrations is recommended. Further remaining work includes modeling such a wider-ranging data set, and validating the preliminary model with external data from another system operated under similar conditions. A similar network will also be constructed for pathogen removal.

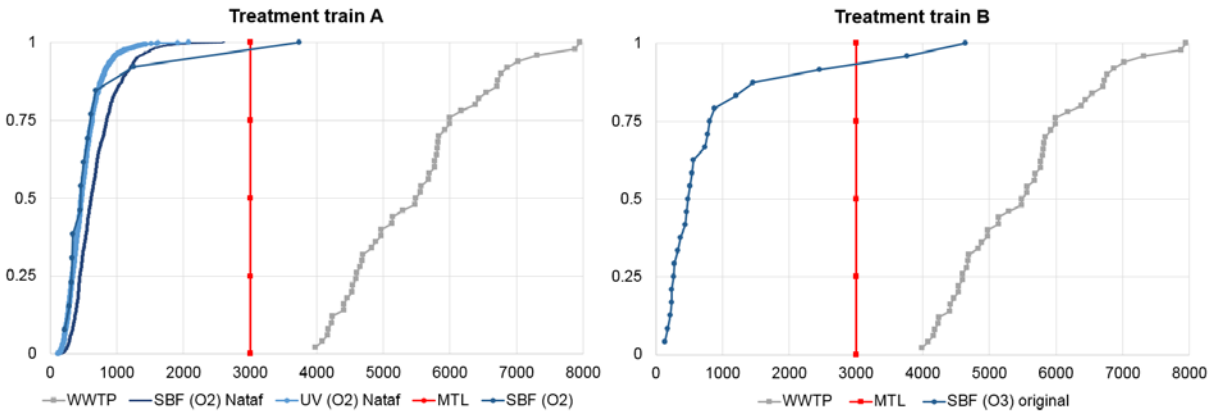


Figure 2: Cumulative distribution functions showing benzotriazole concentrations in every treatment step effluent compared to MTL levels, for WWTP (n=50), SBF(O_2) (n=13, left) and SBF(O_3) original (n=24, right). 'Nataf' denotes simulated data (n=1000), mathematically calculated from the WWTP and SBF(O_2) original data.

Conclusions

A Bayesian network was used to model TOrC concentrations at the end of an advanced treatment train intended for indirect potable reuse, using probabilistic and mechanistic modeling approaches. Data availability shortcomings limited the validation of the network, but the test network demonstrated an attempt at modeling the complicated dependencies in biological-based systems to quantify the risk at the effluent of the treatment trains. Bayesian networks are powerful prediction tools which should be further explored to simulate potable reuse treatment train performances, and can be particularly useful for communicating risk (or lack thereof) to legislators.

References

Alidina, M., Li, D., Ouf, M., & Drewes, J. E. (2014). Role of primary substrate composition and concentration on attenuation of trace organic chemicals in

managed aquifer recharge systems. *Journal of Environmental Management*, *144*, 58–66. https://doi.org/10.1016/j.jenvman.2014.04.032

Drewes, J. E., Anderson, P., Denslow, N., Jakubowski, W., Olivieri, A., Schlenk, D., & Snyder, S. (2018). *Monitoring Strategies for Constituents of Emerging Concern (CECs) in Recycled Water*.

Engineering Risk Analysis Group. (2018). *ERADist and ERANataf classes: Documentation and Examples*.

Li, D., Sharp, J. O., Saikaly, P. E., Ali, S., Alidina, M., Alarawi, M. S., … Drewes, J. E. (2012). Dissolved organic carbon influences microbial community composition and diversity in managed aquifer recharge systems. *Applied and Environmental Microbiology*, *78*(19), 6819–6828. https://doi.org/10.1128/AEM.01223-12

Miklos, D. B., Hartl, R., Michel, P., Linden, K. G., Drewes, J. E., & Hübner, U. (2018). UV/H2O2 process stability and pilot-scale validation for trace organic chemical removal from wastewater treatment plant effluents. *Water Research*, *136*, 169–179. https://doi.org/10.1016/j.watres.2018.02.044

Müller, J., Drewes, J. E., & Hübner, U. (2017). Sequential biofiltration – A novel approach for enhanced biological removal of trace organic chemicals from wastewater treatment plant effluent. *Water Research*, *127*, 127–138. https://doi.org/10.1016/j.watres.2017.10.009

Müller, J., Drewes, J.E., & Hübner, U. (under review). Investigating synergies in sequential biofiltration-based hybrid systems for the enhanced removal of trace organic chemicals from wastewater treatment plant effluents.

National Research Council. (2012). *Water Reuse: Potential for Expanding the Nation's Water Supply Through Reuse of Municipal Wastewater*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13303

Rauch-Williams, T., Hoppe-Jones, C., & Drewes, J. E. (2010). The role of organic matter in the removal of emerging trace organic chemicals during managed aquifer recharge. *Water Research*, *44*(2), 449–460. https://doi.org/10.1016/j.watres.2009.08.027

Wang, J., & Wang, S. (2016). Removal of pharmaceuticals and personal care products (PPCPs) from wastewater: A review. *Journal of Environmental Management*, *182*, 620–640. https://doi.org/10.1016/j.jenvman.2016.07.049

Reduction of viruses using a semi-industrial and near-natural system for advanced wastewater treatment

Rien, Christian, German Environment Agency, Berlin, Germany;
Karakurt, Sema, Technical University of Munich, Munich;
Szewzyk, Regine, German Environment Agency, Berlin, Germany;
Drewes, Jörg, Technical University of Munich, Munich;
Selinka, Hans-Christoph, German Environment Agency, Berlin, Germany

According to UNICEF, currently 2.1 billion people do not have access to clean drinking water whereas for 884 million people there is not even a basic water supply available. UNICEF pointed out that water has to be freely available and also has to be “safe”. This safety is guaranteed if the water is free from hazardous substances and pathogens.

As part of the BMBF project „TrinkWave“, the German Environment Agency (UBA) is involved in the design of a semi-industrial and near-natural system (SMART Plus) which is intended for advanced wastewater treatment. An important objective of “TrinkWave” is the removal of trace substances (e. g. drug residues) and pathogens (e. g. bacteria, viruses, parasites) from wastewater via a multiple barrier system. Key elements of SMART Plus are i) sand filtration of the pre-cleaned waste water in a defined system and ii) the addition of electron acceptors to regulate the redox conditions.

In this context, we studied the potential of SMART Plus to eliminate viruses. Many different human viruses may be present in waste water e.g. noroviruses, enteroviruses, Hepatitis A viruses and adenoviruses. They are able to cause a variety of diseases in humans like gastroenteritis, diarrhea and inflammation of different organ systems. Therefore, the reduction of human viruses must be a key element of advanced wastewater treatment.

For our experiments the following indicator viruses were used:

Somatic phages (PhiX174 in spiking experiments) , F+ phages (MS2 in spiking experiments), human noroviruses, murine noroviruses (for spiking experiments), adenoviruses and pepper mild mottle virus.

Indicator viruses were either naturally occurring in the wastewater or spiked into the inflowing pre-treated wastewater of the SMART Plus in concentrations of about 10^8 viruses/ L. Reduction of virus concentration was followed by taking samples at nine different sample ports of the SMART Plus. Samples were analyzes by plaque assay for phages and q(RT)PCR for other viruses.

Results showed, that spiked phages were reduced by about 4 to 5 log units in the SMART Plus.

Conventional waste water treatment plants remove viruses by about 2 – 3 log units. The so far achieved additional removal of phages by about 4 – 5 log units indicates the high potential of this innovative process for advanced treatment of contaminated water. The SMART Plus model could provide a near-natural and energy efficient solution to water supply in areas with water shortage.

Overcoming Water Stress by Water Reclamation and Reuse

Emmanuel Van Houtte, IWVA, Belgium

Abstract:

Keywords: indirect potable reuse (IPR), managed aquifer recharge (MAR)

Introduction

As the drinking-water demand increased from 3.8 million m³/year in 1980 to 5.5 m³/year in 1990 exceeding the capacity of the dune water catchments of the Intermunicipal Water Company of the Veurne area (IWVA), it was decided that alternatives should be developed. *Artificial recharge* of the unconfined aquifer of the dunes of St-André (Koksijde) was the selected solution; effluent from a nearby wastewater treatment plant was selected as the source for the production of infiltration water (Van Houtte and Verbauwhede, 2005).

The scheme, based on the multiple barrier approach, became operational in 2002. At WPC Torreele, the effluent is treated using ultrafiltration and reverse osmosis. In St-André, this water is infiltrated in a pond of 500 m length and abstracted using wells with filters between 8 and 12 m depth. The average residence time in the aquifer amounts 55 days and this groundwater is treated using aeration and sand filtration iron being the only parameter not complying with drinking-water standards.

Groundwater extraction decreased from 3.87 million m³/year in 1990 to 1.78 m³/year in 2018 resulting in rise of groundwater levels. This enhanced the natural values and will prevent on the longer term the rise of sea level enhanced by climate change. The volume of infiltration water in 2018 amounted 2.11 million m³/year.

Indirect Potable Reuse (IPR)

This kind of Indirect Potable Reuse (IPR) is possible because reverse osmosis (RO) membranes were used. It is the best available technology when drinking-water is at stake. In general the resulting water is of better quality compared to conventional treatment regarding the total dissolved solids (TDS), total organic carbon (TOC) (Le Corré et al., 2012) and trace elements and contaminants (Ernst et al.,2012). The

criteria of all regulated microbiological and chemical constituents are met (Le Corré et al., 2012) and pathogens are removed (Levantesi et al., 2010).
Ultrafiltration (UF) is used prior to RO as it removes bacteria and suspended solids from the water and thus being a good pretreatment for RO. UF, RO and managed aquifer recharge (MAR) result in multiple barriers ensuring the final quality of the produced drinking-water.
The concentrate of UF and RO treatment is drained, together with the effluent that has not been reused, into the adjacent canal that drains into the sea.

IWVA have always been very open to the public and this securing of public trust in the reuse scheme through information provision is widely recognised as a major success of the Torreele scheme (Frijns et al., 2016). Being transparent gains public trust preventing negative public perception.

Results and Discussion

Since the start-up of infiltration there have been no quality issues. In general the resulting water is of better quality compared to conventional treatment regarding the total dissolved solids (TDS), total organic carbon (TOC) (Le Corré et al., 2012) and trace elements and contaminants (Ernst et al., 2012). The criteria of all regulated microbiological and chemical constituents are met (Le Corré et al., 2012) and pathogens are removed (Levantesi et al., 2010).

The UF membranes had to be replaced on average after 8 years; the average replacement time for the RO membranes was over 6.5 years. Replacement was decided based on increased number of cleaning cycles, both for UF and RO, and decreased salt removal for RO. For the UF filtrate, a small increase of Silt Density Index (SDI_{15}) is observed with aging memrbanes.
In August 2016 a DynaSand filter was started reusing the backwash water of the UF process. The filter media (12 m^3) used was calibrated quartz sand (0,8 – 1,2 mm). The effluent from the DynaSand filter is discharged in the buffer reservoir prior to UF treatment. It resulted in an overall recovery increase for WPC Torreele from 70.1 % in 2015 to 73.9% in 2018. This increase is needed as from June to October there are periods that the amount of wastewater effluent from WWTP Wulpen, operated by Aquafin, is not sufficient.

The biofouling and scaling prevention of the RO membranes is based respectively on dosing of monochloramines and the combination of dosing of antiscalant and pH reduction.
Since a small amount of ammonia is present in the WWTP effluent of Wulpen, operated by Aquafin, only hypochlorite need to be dosed. This is done immediately after UF treatment and has not caused any damage of the RO membranes.
The recovery of RO is based on conductivity. Lower salinity means less scaling risk and thus higher recovery. Additionally, since September 2016 the dosing of antiscalant has also been varied with salinity reducing consumption of chemicals.
In 2018 the energy consumption for the production of 1 m^3 of UF filtrate was 0.139 kWh (92.9 % recovery) and 0.559 kWh/m^3 for RO (78.6% recovery)

Concerning MAR, a seasonal variation of recharge rate from the infiltration ponds was observed. Two major factors impacting this variation are variation in hydraulic gradient and hydraulic conductivity (Sayantan, 2018). In November 2014, IWVA introduced a novel infiltration technique in an area 60 m south of the existing wells. A well battery was present there until 2002. Infiltration boxes of the type that are used to store rain water, were placed at a depth of approximately 1,6 m under ground level and covered with 1 m of dune sand. A first experiment expanded 50 m length, the system being 4,8 m wide. It was called ‘subterranean infiltration’ and the feed water for the system was the infiltration water of WPC Torreele. The system offered several advantages compared to the existing infiltration system. There is no recontamination due to wildlife or leaf fall and temperatures remain constant compared to the infiltration water leaving WPC Torreele: no cooling down in winter and no heating up in summer. This meant that during the colder periods the infiltration capacity of ‘subterranean infiltration’ exceeds the conventional infiltration. Based on the positive results the system was expanded in February 2016 to 300 m length. This resulted in higher yearly infiltration capacity and better ratio.

In December 2018 the western part of the infiltration pond was extended in length (100 m). This resulted in an increased infiltration and ratio of approximately 10% in January and February 2019. In 2019 infiltration was expanded to the eastern part of St-André. In this area the existing canal formerly used to infiltrate the flushing water from the sand filters was converted to an infiltration canal. This extra infiltration

capacity of 400.000 m³/year compensated for a decrease of groundwater extraction by 200.000 m³/year.

The total investment cost amounted 7 M€. Currently the production cost for infiltration water is around 0.50 €/m³ as the investment was amortized and IWVA is still using the same equipment. Comparison of drinking-water price for the customer is difficult as the price structure was changed according to Flemish legislation. However IWVA has a competitive price compared to its colleagues.
The recent investments amounted 0.18 M euros for implementing the 'subterranean infiltration (2014 – 2019), 0.17 M euros for extension of the infiltration pond and eastward expansion of infiltration (2018-2019) and 0.1 M euros for extra (2013) and renewed extraction wells (2019).

Future developments

Based on a small pilot test (2010 – 2012) treating RO filtrate with granular activated carbon (GAC), beginning of April 2017, a DynaSand filter was used treating RO filtrate. The medium used (12 m³) was virgin **FILTRASORB**® granular SUPER 830 activated carbon. The flow was increased stepwise and the minimum contact time is currently around 20 minutes. Since start-up the treated water remained bacteriological stable. After over 2 years of operation no regrowth has been observed. The end-use of the GAC filtrate could be mixing with 'other' drinking-water to reduce hardness. This Direct Potable Reuse (DPR) scheme would be equivalent to the existing water reuse scheme as the multiple barrier approach remains intact. In the case of DPR the dune passage would be replaced by GAC assuring a back-up for the RO.

To increase the overall recovery of WPC Torreele IWVA intends to do tests treating the UF BW water directly with UF, replacing the DynaSand filter in the near future. This filtrate should then be treated directly with RO without going back to UF. One of the options could be the use of ceramic membranes.

As the volume of UF BW water would be further reduced RO concentrate would remain the major part of the water to be discharged. Since 2007 tests were

performed using willows. After selection of salt resistant species from 2011 until 2016 a test field with a surface area of 3 m wide, 9,5 m long and 70 cm deep was filled with calibrated quartz sand (0,7 to 1,25 mm) from an old sand filter was used (Van Houtte, 2015). The grains had iron oxides on the outside. The feed of concentrate was at surface level on one side of the field and the effluent was gathered at the bottom of the sands at the other end of the test field. This means that the concentrate flowed horizontally from one side to the other; no 'dead' zones were present. The set-up of the test is based on the principles of short rotation coppice (SRC). The feed flow was 250 l/h.

The nitrogen and phosphorous removal was 35% on average. IWVA plans to implement this treatment full-scale. Approximately 1 hectare would be needed. It would mitigate the effects of discharging this water into the environment, save annually around 30.000 euros of discharge fees and by harvesting of the biomass a CO_2 neutral way of producing energy could be introduced mitigating the effects of climate change.

Conclusions

Indirect Potable Reuse based on multiple barrier approach with the combination of water reuse and MAR enabled sustainable groundwater management of the dune aquifer and safe drinking-water production fort he IWVA area.

IPR showed a lot of benefits for the area :

- the groundwater levels increased resulting in enhanced natural values and declining risk of saline intrusion;
- the drinking-water production was secured in the region;
- the quality of the produced drinking-water is excellent but the use of reverse osmosis is mandatory for Indirect Potable Reuse (IPR) practices;
- novel infiltration techniques, e.g. 'subterranean infiltration' restored infiltration capacity.

In the near future IWVA plans to increase overall recovery by implementing additional UF treatment of UF BW water, implement willows for the treatment of RO c oncentrate and DPR for reducing hardness.

Acknowledgments

The willow research was made possible by grants from the European Commission within the FP7-programme as this test was part of the DEMOWARE project (FP7-ENV-2013-WATER-INNO-DEMO). The full-scale willow treatment will be developed within the *2S06-028* FRESH4Cs project (Interrreg, 2 Seas Programma).

Off course this successful water reuse scheme would not be possible without the dedication of all colleagues of IWVA.

References

Ernst, M., Hein, A., Asmin, J., Krauss, M., Fink, G., Hollender, J., Ternes, T., Jørgensen, C., Jekel, M. and McArdell, C. (2012). Water quality analysis : detection, fate and behavior of selected trace organic pollutants at managed aquifer recharge sites. In: C. Kazner, T. Wintgens and P. Dillon (eds.) Water Reclamation Technologies for Safe Managed Aquifer Recharge. IWA Publishing, London, UK, ISBN: 9781843393443.

Frijns, J., Heather M. Smith, Stijn Brouwer, Kenisha Garnett, Richard Elelman and Paul Jeffrey (2016). How Governance Regimes Shape the Implementation of Water Reuse Schemes. *Water* 2016, *8*(12), 605; doi:10.3390/w8120605

Le Corre, K., Aharoni, A., Cauwenberghs, J., Chavez, A., Cikurel, H., Neus Ayuso Gabella, M., Genthe, B., Gibson, R., Jefferson, B., Jeffrey, P., Jimenez, B., Kazner, C., Masciopinto, C., Page, D., Regel, R., Rinck-Pfeiffer, S., Salgot, M., Steyn, M., Van Houtte, E., Tredoux, G., Wintgens, T., Xuzhou, C., Yu, L. and Zhao, X.. (2012). Water reclamation for aquifer recharge in eight case study sites : a cross case analysis. In: C. Kazner, T. Wintgens and P. Dillon (eds.) *Water Reclamation Technologies for Safe Managed Aquifer Recharge*. IWA Publishing, London, UK, ISBN: 9781843393443.

Levantesi, C., La Mantia, R., Masciopinto, C., Böckelmann, U., Ayuso-Gabella, M., Salgot, M., Tandoi, V., Van Houtte, E., Wintgens, T. & Grohmann, E. (2010). Quantification of pathogenic microorganisms and microbial indicators in three wastewater reclamation and managed aquifer recharge facilities in Europe. *Science of the Total Environment* **408**, 4923–4930

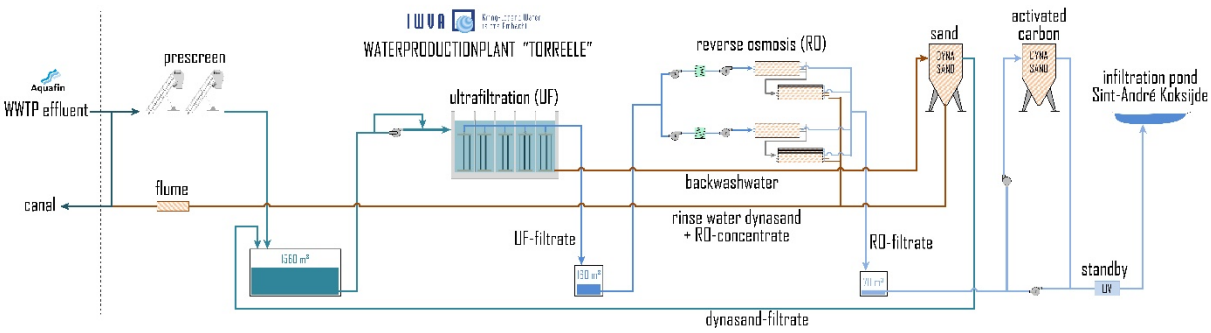
Sayantan Samanta (2018). Seasonal variation of infiltration rates through pond bed in a managed aquifer recharge system. Texas A&M University. Thesis submitted of the requirements for the degree of Master of Science. 55p.

Van Houtte, E. and J. Verbauwhede (2005). Artificial recharge of treated wastewater effluent enables sustainable groundwater management of a dune aquifer in Flanders, Belgium. In: Unesco (2006), Recharge systems for protecting and enhancing groundwater resources. Proceedings of the 5th International Symposium on Management of Aquifer Recharge ISMAR5, Berlin, Germany, 11–16 June 2005. IHP-VI, Series on Groundwater No. 13: 236-243.

Van Houtte, E. (2015). Combining treatment of reverse osmosis concentrate and biomass production at the Torreele reuse facility. Conference proceedings 5th International Symposium 'RE-WATER Braunschweig'. Veröffentlichungen – Institut für Siedlungswasserwirtschaft – TU Braunschweig. Heft 87, p. 175-189.

Figures and Tables

"Figure 1. Scheme of WPC Torreele



The Swiss approach in reducing trace organic chemicals in the aquatic environment

Christa S. McArdell, Eawag, Swiss Federal Institute of Aquatic Science and Technology, CH-8600 Dübendorf, Switzerland;
christa.mcardell@eawag.ch

Abstract:
Switzerland is the first country that has implemented legal measures to ensure a reduction of trace organic chemicals (TOCs) from wastewater in the aquatic environment. In selected wastewater treatment plants (WWTPs), advanced treatment has to be installed by 2040 to reach an abatement of TOCs by 80%. To evaluate the performance of the upgraded plant, twelve indicator substance have to be measured. Today, several full-scale WWTPs are upgraded with an additional treatment with ozone or by applying powdered activated carbon (PAC). Several key points helped the implementation of the new water protection act, e.g. the involvement of stakeholders from the beginning, the simplicity of the approach, and the clear national financial plan. The Swiss approach can so far be considered as successful.

Keywords: wastewater treatment; ozonation; activated carbon treatment; legislation; micropollutants

Introduction

In Switzerland, a new water protection act entered into force as from January 2016 which requires to upgrade selected wastewater treatment facilities by 2040 to reduce TOC discharge and enhance surface water quality (FOEN law 2017, Eggen et al. 2014). To date, several full-scale WWTPs are upgraded with an additional treatment with ozonation or with applying powdered activated carbon (PAC) with sedimentation and filtration, while more plants are under construction or in planning (www.micropoll.ch). Ozonation and treatment with PAC were shown to be economic and can easily be implemented at existing WWTPs. However, the Swiss law does not ask for a specific treatment, but lets the option for other technologies. Current research aims to evaluate the competitiveness of treatment with granular activated carbon (GAC) and the combination of ozone with GAC treatment.

In this keynote presentation, the driving forces that helped the implementation of the new Swiss law will be discussed. It will be explained how the twelve indicator substances to evaluate the performance of the advanced wastewater treatment were chosen, and the current state and success of upgraded WWTPs as examples will be shown.

Material and Methods

To evaluate the performance of the upgraded wastewater treatment plant, twelve indicator substances need to be measured (Table 1). On average, their abatement over the whole plant, *i.e.* including the conventional biological treatment, must reach 80%.

Table 1 The twelve indicator substances defined in the Swiss approach to evaluate the performance of a WWTP.

Substance	class	Abatement during ozone or PAC treatment
Amisulpride	Pharmaceutical (antipsychotic)	Very good (>80%)
Carbamazepine	Pharmaceutical (antiepileptic)	Very good
Citalopram	Pharmaceutical (antidepressant)	Very good
Clarithromycin	Pharmaceutical (macrolide antibacterial)	Very good
Diclofenac	Pharmaceutical (antiinflammatory / antirheumatic)	Very good
Hydrochlorothiazide	Pharmaceutical (diuretic)	Very good
Metoprolol	Pharmaceutical (beta blocking agent)	Very good
Benzotriazole	corrosion inhibitor	good (50-80%)
Methylbenzotriazole	corrosion inhibitor	good
Candesartan	Pharmaceutical (antihypertensive agent)	good
Irbesartan	Pharmaceutical (antihypertensive agent)	good

The selection of WWTP that need to be upgraded include large WWTPs to significantly reduce the load of TOCs (>80’000 connected inhabitants), WWTPs with a high fraction of wastewater to protect the aquatic ecosystem (>8’000 connected inhabitants), and WWTPs that influence drinking water resources.

Results and Discussion

Despite the fact that Switzerland has comparably more diluted surface water, concentrations of selected TOCs still exceed environmental quality standards at which adverse effects to aquatic organisms cannot be excluded (Ort et al. 2009). In 2006, the Swiss Federal Office for the Environment (FOEN) decided to launch the project “strategy MicroPoll” to investigate the pollution situation of Swiss surface waters and to assess potential measure to reduce the load of TOCs from urban areas. Within ten years, pilot tests were run, public consultations done, and a financial plan elaborated. During this time, researchers, authorities and all important stakeholders worked strongly together to come up with a common strategy. A Swiss fund was established, in which wastewater treatment plants need to pay 9 CHF per year and Swiss inhabitant connected to the WWTP. As soon as a WWTP is upgraded, it is exempted from the payment, however, has to cover operational costs and part of the investment costs for the advanced treatment. 75% of the investment costs is paid with the established fund. Specific capital annual costs for TOCs abatement strongly depend on the size of the WWTP (Rizzo et al. 2019). For mid-scale plants (~50.000 PE) the costs are in the range of 0.10 to 0.15 €/m^3 treated wastewater, decreasing further with increasing plant size even below 0.05 €/m^3. The overall investment cost for the plants that need to be upgraded in Switzerland was estimated to be in the order of 1200 Mio. CHF (Abegglen et al. 2012). The increase in annual costs for wastewater treatment was estimated at 130 Mio CHF, which is equivalent to about 10-15% increase of current costs of wastewater treatment, or 15 CHF per person per year (Eggen et al. 2014). The energy consumption is expected to increase by 10-20% in a WWTP, and nationally by 0.1%. This additional energy demand should be compensated by energy optimization and recovery at the WWTP.

According to the requirements of the New Swiss water protection act (GSchV), the Swiss cantons have to select the WWTPs that need to be upgraded, in total around 120 plants. At each location the involved stakeholders (authorities, operators, and experts) need to decide what is the optimal technology to abate micropollutants. Local boundary conditions include the wastewater composition, the existing biological treatment process, the effluent quality and the recipient conditions. Ozonation is economic and easily implemented with a small footprint, however, is not suitable for every type of wastewater. Especially when a high fraction of wastewater results from

industrial discharges, problematic by-products may form. Tools are available to evaluate if ozonation is suitable (Schindler Wildhaber et al. 2015). Research is ongoing on the formation of ozonation transformation products and by-products and their fate in biological post-treatment (Bourgin et al. 2018; von Gunten 2018). For PAC treatment, process variety is much higher, especially with respect to PAC separation and the dosage point. In comparison to ozonation, a higher DOC removal can be obtained. Treatment with granular activated carbon (GAC) has many benefits as it is easier to be operated, can be filled into existing deep bed filters (sand filters), and can be reactivated and reused, therefore having a smaller CO_2 footprint (Benstoem et al. 2017). However, according to earlier studies, more carbon is required with GAC than with PAC, and best practice is not available yet.

To evaluate the performance of a plant, twelve indicator substances must be measured and be abated on average by 80% over the whole plant. These substances are representative for TOCs, and were not selected for their effect to the ecosystem. They are continuously discharged into WWTPs at relatively high concentrations and are easily to be measured. They only include substances that are not well degradable in wastewater treatment. A study has shown that at the conditions selected to reach an abatement of 80% of the twelve indicator substances in ozonation, an exhaustive list of 550 TOCs also showed an average abatement higher than 80% (Bourgin et al. 2018). After the upgrade of the selected WWTP in Switzerland, concentrations expected in the Swiss surface water should much less exceed environmental quality standards (Logar et al. 2014), and surface water quality should be improved (EcoImpact project).

Conclusions

Several key points helped the implementation of the new water protection act, e.g. the interplay between researchers, authorities and stakeholders from the beginning, the simplicity of the approach, and the clear national financial plan. The Swiss approach can so far be considered as successful.

References

Abegglen C. and Siegrist H. (2012). Mikroverunreinigungen aus kommunalem Abwasser,Verfahren zur weitergehenden Elimination auf Kläranlagen, Bundesamt für

Umwelt (BAFU), Bern, Umweltwissen No. 1214: http://www.bafu.admin.ch/publikationen/publikation/01661/index.html

Benstoem, F., Nahrstedt, A., Böhler, M., Knopp, G., Montag, D., Siegrist, H., Pinnekamp, J. (2017). Performance of granular activated carbon to remove micropollutants from municipal wastewater - A meta-analysis of pilot- and large-scale studies. Chemosphere 185, 105-118.

Bourgin, M., Beck, B., Boehler, M., Borowska, E., Fleiner, J., Salhi, E., Teichler, R., von Gunten, U., Siegrist, H., McArdell, C.S. (2018). Evaluation of a full-scale wastewater treatment plant upgraded with ozonation and biological post-treatments: Abatement of micropollutants, formation of transformation products and oxidation by-products. Water Research 129, 486-498.

Ecoimpact project at Eawag: http://www.eawag.ch/forschung/fsp/osf/ecoimpact/index_EN.

Eggen, R. I. L., Hollender, J., Joss, A., Schärer, M., Stamm, C. (2014). Reducing the discharge of micropollutants in the aquatic environment: The benefits of upgrading wastewater treatment plants. Environ. Sci. Technol. 48 (14), 7683-7689.

FOEN law (2017), www.bafu.admin.ch/bafu/de/home/themen/bildung/medienmitteilungen.msg-id-59323.html and www.micropoll.ch.

Gewässerschutzverordnung (GSchV) 814.201: https://www.admin.ch/opc/de/classified-compilation/19983281/201806010000/814.201.pdf

Logar, I., Brouwer, R., Maurer, M., Ort, C. (2014). Cost-benefit analysis of the Swiss National Policy on reducing micropollutants in treated wastewater. Env. Sci. Technol. 48(21), 12500−12508.

Ort, C., Hollender, J., Schaerer, M., Siegrist, H. (2009). Model-based evaluation of reduction strategies for micropollutants from wastewater treatment plants in complex river networks. Environ. Sci. Technol. 43 (9), 3214−3220.

Rizzo, L., Malato, S., Antakyali, D., Beretsou, V.G., Đolić M.B., Gernjak, W., Heath, E., Ivancev-Tumbas, I., ,Karaolia, P., Lado Ribeiro, A.R., Mascolo, G., McArdell, C.S., Schaar, H., Silva A.M.T., Fatta-Kassinos D. (2019). Consolidated vs new advanced treatment methods for the removal of contaminants of emerging concern from urban wastewater. Sci. Tot. Env. 655, 986-1008

Schindler Wildhaber, Y., Mestankova, H., Schärer, M., Schirmer, K., Salhi, E., von Gunten, U. (2015). Novel test procedure to evaluate the treatability of wastewater with ozone. Wat. Res. 75, 324–335.

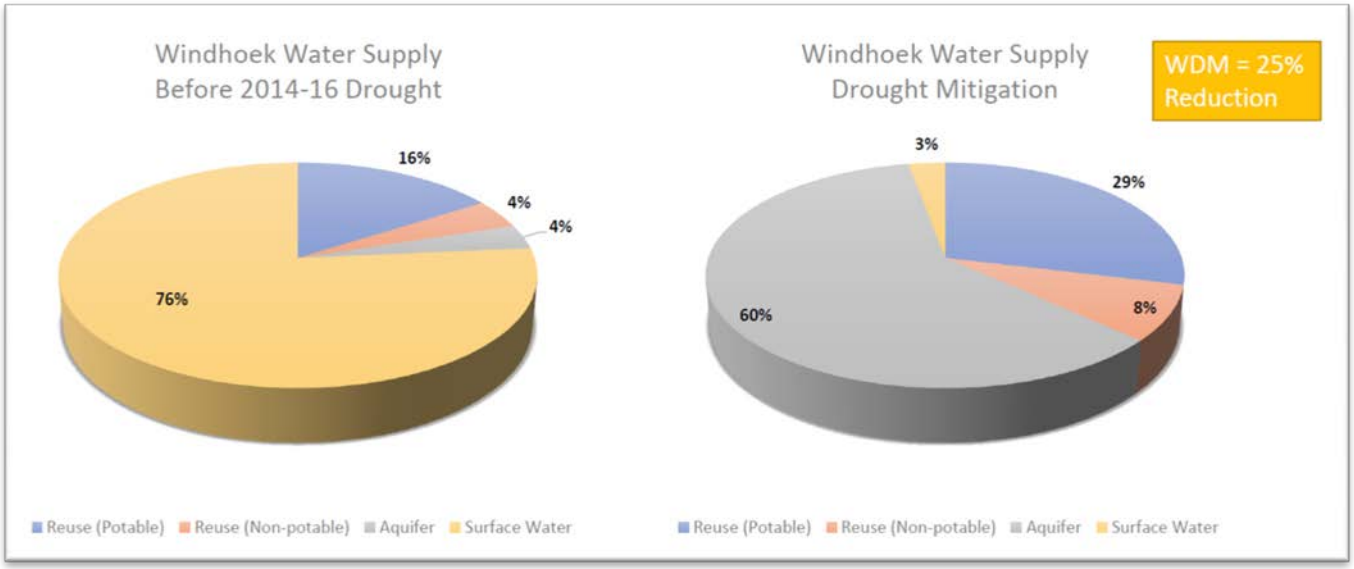
von Gunten, U. (2018). Oxidation processes in water treatment: are we on track? Env. Sci. Technol. 52(9), 5062-5075.

EXTENSION OF WATER REUSE IN WINDHOEK

Author 1: Karl Ulrich Rudolph[1]
Author 2: Jens Hilbig[2]*; Author 3: Keno Strömer*[3]*; Author 4: Sebastian Weil*[4]

INTRODUCTION: Even among water experts, most people are unaware that Windhoek is the "*cradle of potable water reuse*", being the very first city in the world to process drinking water from wastewater already in 1968 (long before Singapore, Australia, California, South Africa et al.). The thrilling story of DPR (*direct potable water reuse*) in Windhoek is how it was done within reasonable budget under a pragmatic approach in Africa. The driving motivation was: They just had to go for DPR, earlier than all others.

WATER BALANCE: Windhoek's annual precipitation is between 10 and 700 mm, in average 250 mm, coupled with an evaporation between 2600 and 3700 mm (B. v. d. Merwe, 2018). During drought periods, there is extreme water scarcity. The water deficit is growing due to increasing water demand and decreasing availability of raw water. During normal supply periods 75 % of raw water is abstracted from surface water. Yet, during the heavy drought period in 2017, less than 3 % of the water demand could be supplied from surface water. Industries had to shut down and private consumers were forced to cut their water consumption by > 50 % (**Chart 1).**



[1] Chairman of the Panel of Contract Advisors WWP Ujams and Consultant for the City of Windhoek WWTP Gammams; Email: rudolph@professor-rudolph.de
[2] COO of IEEM gGmbH, Institute of Environmental Engineering and Management at Witten/Herdecke University, Germany; Tel.: +49 2302 914 01 0; Email: jens.hilbig@uni-wh-ieem.de
[3] GWFA - Global Water Franchise Agency GmbH, Germany; Email: keno.stroemer@waterfranchise.com
[4] REMONDIS (Aqua) Australia Pty Ltd., sebastian.weil@remondis.com.au

Chart 1: Importance of DPR in Windhoek Water Supply (source: P. V. Rensburg, 2018)

Under the BMBF research project "**IWRM South Africa, MOSA**" a new water resources modelling concept has been developed, consisting of three elements: (I) the water resources module, (II) the water utilisation module and (III) the water intervention module. The Windhoek water map was developed to provide a detailed yet comprehensive overview of (I) the data and flows of available water resources, (II) the demand and development of water utilisations with different consumer groups and (III) the existing water infrastructure with a listing of which interventions (= technical as well as institutional measures) are possible to improve and secure water supply, to protect the water resources and the environment (see **Chart 2**).

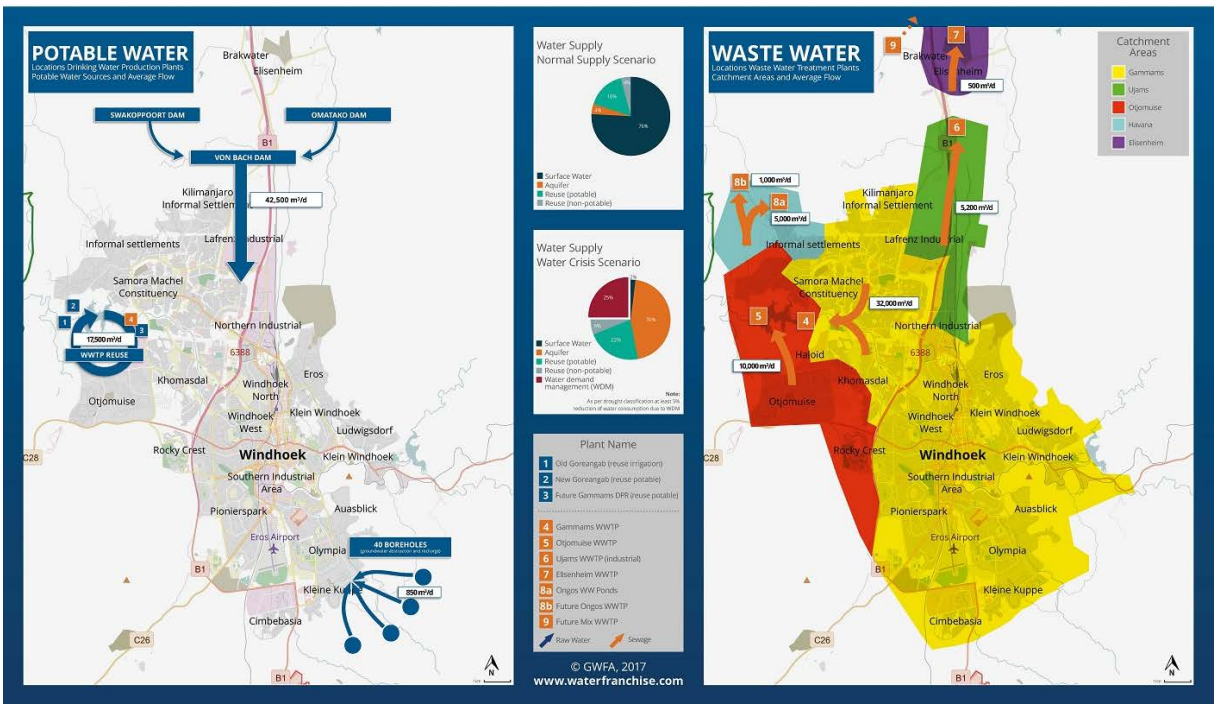


Chart 2: The Windhoek Water Map (source: GWFA, 2018)

Based on the existing capacities (esp. the GOREANGAB potable water production plant, see Lahnsteiner et. al., 2007 and Rensburg, 2018), the **most important intervention measures** to secure and improve the Windhoek water balance are:

a) continuous efforts to further improve the network and reduce water leakage and administrative losses,
b) institutional measures of water demand management, especially peak tariffs and fair, justified rules how to cut consumption during severe drought periods,
c) the development of the local aquifer as seasonal groundwater storage (with additional wells for groundwater recharge during wet periods and groundwater abstraction during dry periods) and technical measures, which are

d) long term investments like the import of water from the Okavango river basin (800 km in the North) and desalinated seawater from the coast (350 km away and 1.700 geodetic pump-meters below).

Possible to realise within short time and financial limits

(A) was the new wastewater plant **UJAMS** to purify contaminated industrial wastewaters for non-potable reuse and

(B) is the rehabilitation, upgrade and extension of the wastewater treatment plant **GAMMAMS** to produce raw water for further processing in the existing potable water production plant GOREANGAB (and, maybe, a new future DPR plant).

The Wastewater Plant UJAMS

Since the surplus costs for a new industrial wastewater treatment plant UJAMS with effluent quality for non-potable water reuse were justified by the surplus benefits compared to purification according to the stringent standards set under the law (Rudolph, 2013), the City decided for the project. To shift technological and operational risks and gain access to financial sources, the City went for a BOT (build, operate, transfer) under private finance. The plant is operating successfully for four years and is one of the very few high-tech plants in Africa well-functioning under sustainable public governance and professional operations. The plant development from design, procurement, contracting, technical pilot tests, plant construction and operations are explained in **Chart 3 which** gives an overview of the project development and implementation. Data are provided for plant components such as fine screen, membrane bioreactor and UV-disinfection. Future needs are for further capacity extension and long term solutions for sludge utilisation.

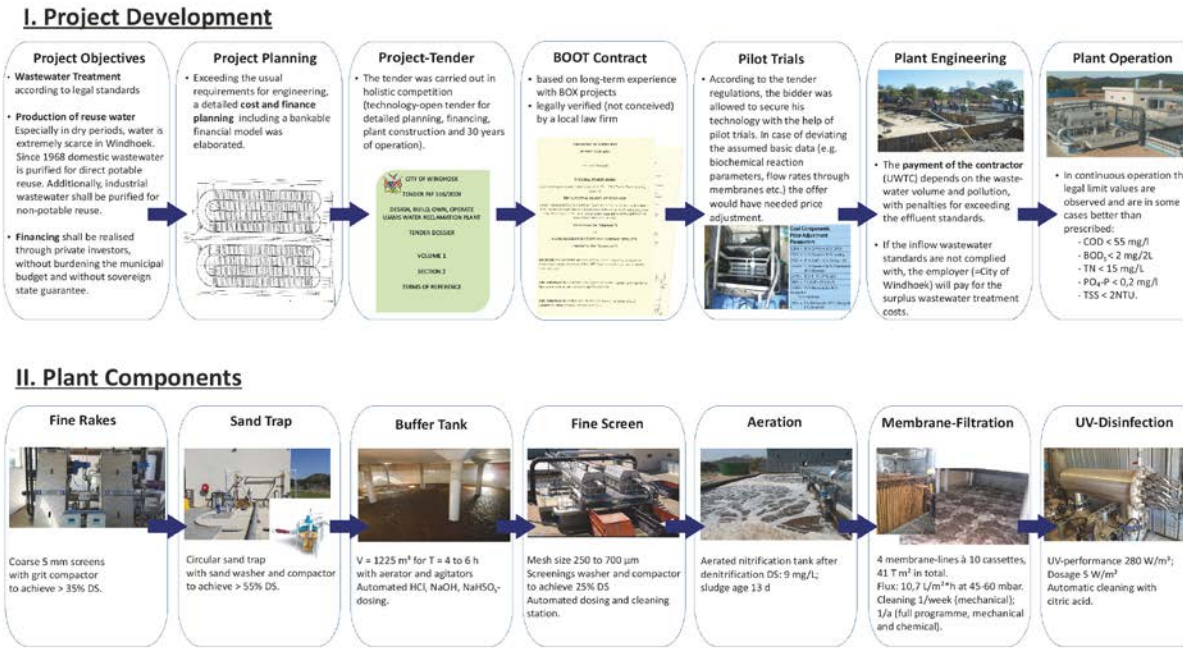


Chart 3: The UJAMS Industrial Wastewater Plant, Windhoek (source: GWFA, 2018)

The Wastewater Plant Gammams

The most urgent investment-project currently under preparation is for the Gammams wastewater plant, to produce raw water for further processing in the existing Goreangab potable-water production plant. Gammams needs to be rehabilitated, extended and modernised with an investment of roughly Mio 40 €.

Initially the project was planned to be realised under an EPC (engineering, procurement, construction) through the municipality. Yet, being aware of the technological and financial risks and eager to create a holistic competition on life-cycle-cost-basis (incl. investment plus operational costs), the City decided to go for a DBO (design, build, operate model).

Strongly recommended by the author was to establish an autonomous, ring-fenced municipal entity (ME) to secure cost transparency and allow for performance incentives on the operational, local level. Alternative solutions for the open-technology tendering and the financial model are:

I. Municipal Entity (ME) for the Gammams WWTP Investment

Chart 4 below shows the tariff forecast for the ME (responsible for Gammas, only) profiting from donor grants and loans, compared to the tariffs which would be needed for commercial financing at a moderate rate:

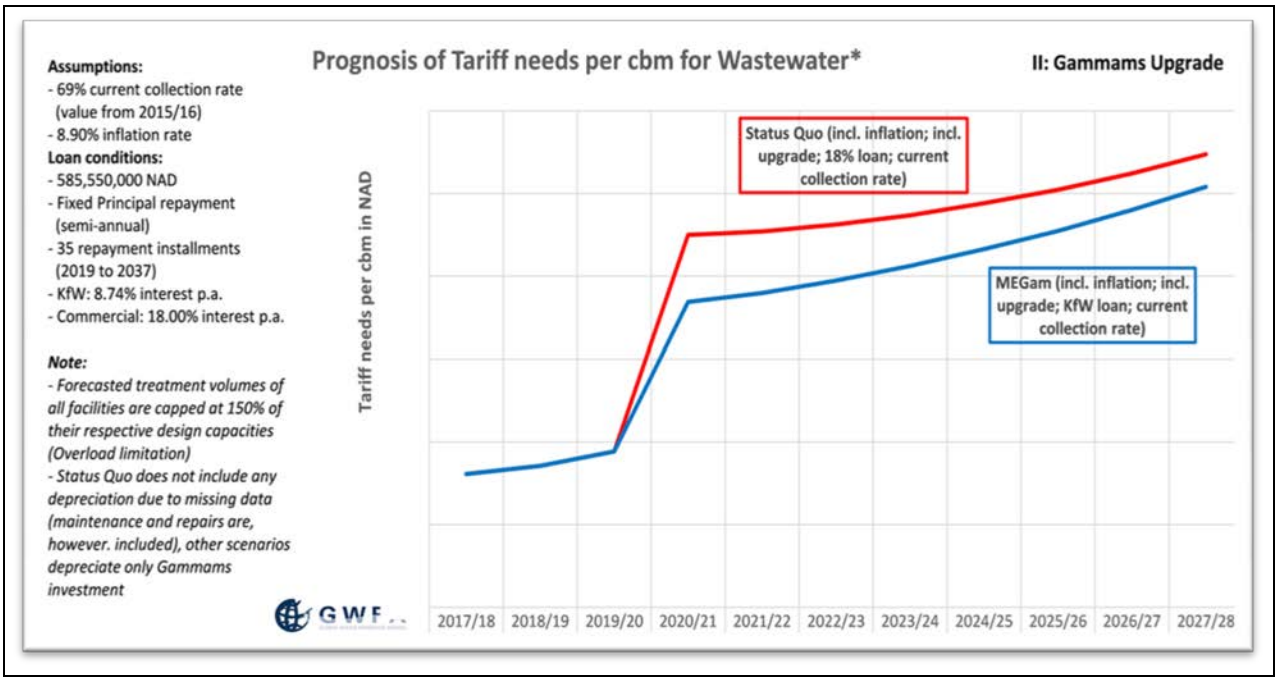


Chart 4: Financial Model for the ME for the Gammams WWP

II. Municipal Entity for all Water and Wastewater Plants in Windhoek

With all plant operations consolidated in one ME, the ME could be developed to become a bankable unit for financing outside the City's balance sheets in the future. The savings created through the consolidation synergies, calculated along cost benchmarks for different positions as a total of 12.5 % of OPEX (CAPEX not considered, even though some synergies could be presented).

III. Municipal Entity for all Water and Wastewater Services

The responsibility of the ME would include all plants plus the reticulation networks (water distribution system and sewerage). A significant change is that the ME would become responsible for billing and collection (in the name of CoW. The main cost advantage results from the improvement of the tariff collection rate (increased to a benchmark of 80 %, as achieved by other water utilities under similar conditions).

IV. Comparison of water tariffs for the different organisational options

Chart 5 summarised the figures forecasted under the financial model developed (and calibrated with the City's' status quo data and calculation principles) by the authors.

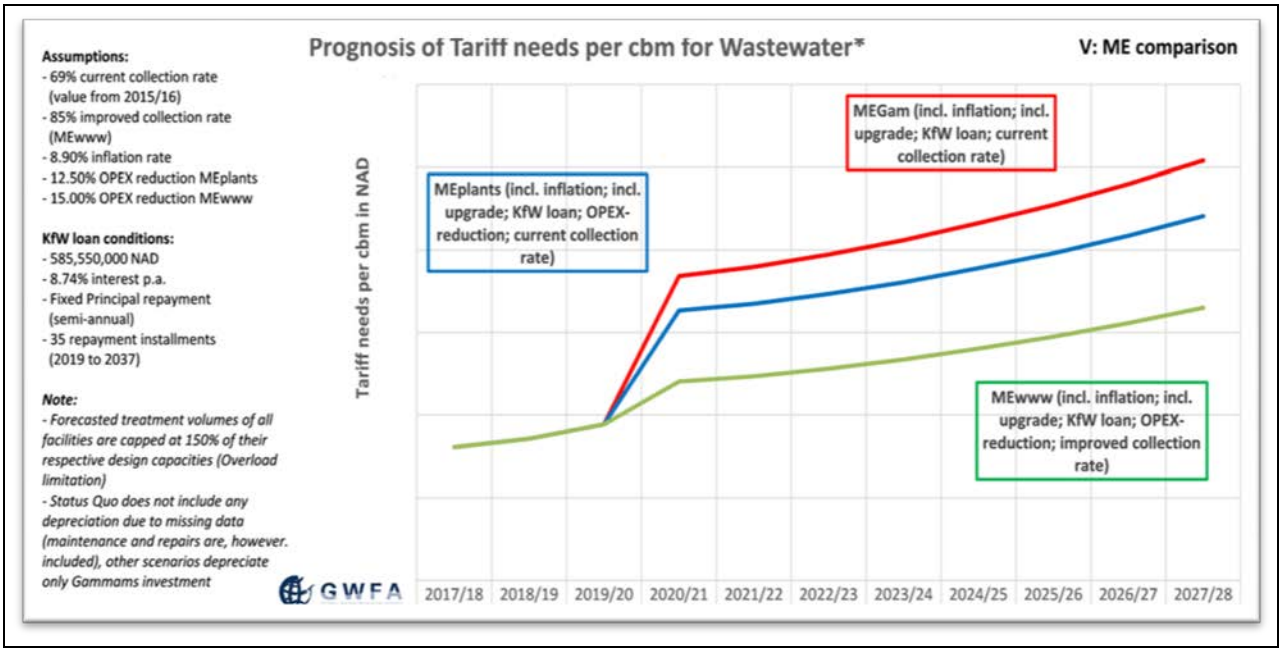


Chart 5: Comparison of MEs for Gammams (red), **for all plants** (blue), **for all water and wastewater services** (green)

Especially for water reuse, appropriate political decisions, sufficient financial sources, reasonable planning, qualified technologies & constructions plus and sustainable operations & maintenance are needed to be successful. For UJAMS, all this has worked out: The surplus costs of commercial finance have been outweighed by technical-economic advantages - thanks to clear responsibilities and risks dedicated to all parties involved (employer, contractor and bank).

For GAMMAMS, the future is open. Since the draught is over, and rain has come back, the political importance of water competing with so many other urgent issues is less than it was before. Due to this and due to political, strategic events (new City Councillors; municipal CEO and Water executive plus leading water officers have changed), the installation of a National Procurement Board plus complexities with donor bank finance and (last not least) because of the economic crisis in Southern Africa, project implementation has come to a halt.

As time goes by, the existing facilities are ageing and the engineering design as well as the financial modelling will be outdated, soon. It might happen, that a different approach will become reasonable. Hybrid Finance with two motors driving things forward (donors with low interest rates subsidised by the tax-payers from wealthy countries and private investors bearing financial responsibility, see Rudolph, 2016) respectively Blended Finance (based on donor bank finance and rules with additional private money, see OECD, 2019) might be the solution to follow.

References:

GWFA – Global Water Franchise Agency (2018): Chart of the Windhoek Water Supply. Elaborated for the Dpt. Of Water and Infrastructure, City of Windhoek.

Hilbig, J.; Kalinowski, A., Rudolph, K. U.: (2016): “MOSA Integrated Water Resources Management in the "Middle Olifants". Schriftenreihe "Wasser und Umwelt" Vol. 34. ISBN 978-3-9818108-0-6

Lahnsteiner, Josef and Lempert, Guenter (2007): “Water management in Windhoek, Namibia". Water Science & Technology Vol 55 No 1–2 pp 441–448 Q IWA Publishing

Merwe, Ben Van der (2019): “The Effect of Global Warming in Safeguarding Water Supply in Arid Africa”. 50th DPR Anniversary Conference Windhoek, 18 Oct 2018

OECD Working Party on Global and Structural Policies (2010): “Innovative financing mechanisms for the water sector” ENV/EPOC/GSP(2009)11/FINAL

Rensburg, Pierre Van (29018): “Fifty years of direct potable reuse – the Windhoek experience”. 50th DPR Anniversary Conference Windhoek, 18 Oct 2018

Rudolph, Karl Ulrich (2013): “Project Economics of Water Reuse in Context to IWRM with Cases from Africa, Asia, Europe”. 9th IWA International Conference on Water Reuse, Windhoek, 27-31 Oct. 2013

Rudolph, Karl Ulrich (2016): “Forfaiting - An Output-Based Component for Sustainable Water Finance”. IWA World Water Congress “Shaping Our Water Future”, Brisbane 9-14 October 2016.

Treatment of Wastewater containing Powdered Activated Carbon with Inside-to-Out Ultrafiltration Membranes

Christian Staaks, inge GmbH, Germany; Denis Vial, inge GmbH, Germany;
Grit Hoffmann, University Duisburg-Essen, Germany;
Patrick Buchta, inge GmbH, Germany; Roland Winkler, inge GmbH, Germany;
Stefan Panglisch, University Duisburg-Essen, Germany;
Peter Berg, inge GmbH, Germany

Abstract

This study presents the results of filtration tests with inside-to-out polyethersulfone ultrafiltration membranes combined with coagulant and powdered activated carbon addition to polish wastewater before discharge. Long-term follow-up of the operation demonstrates that such membranes can be used as a polishing step and that the membranes do not suffer from any performance or integrity loss. Results show that organic content is reduced by approximately 33 % for DOC, 54 % for COD and that an overall reduction of 80% of the micropollutants can be reached with such hybrid process. The study finally presents reductions of the operational expenditures which can be achieved by discontinuous coagulant dosing.

Keywords: Powdered Activated Carbon; Ultrafiltration; Waste Water; Micro Pollutants; Organic Compounds

Introduction

Literature suggests that 10 mg/L of powdered activated carbon (PAC) can remove most micro-pollution from secondary wastewater [2], while the removal efficiency still depends on the micropollutant, the type of PAC [1] [3] [4] [6], as well as mixing conditions and in particular contact time. Alt [1] reports that the addition of PAC has beneficial effects in removing chemical oxygen demand (COD) and total organic carbon (TOC). PAC can be removed with sand filters or low-pressure membranes. Even if some polymeric membranes experienced fouling issues [5], the use of ultrafiltration (UF) membranes results in many advantages over sand filter as among them footprint savings, removal of microorganisms (even viruses) and a constant low filtrate turbidity independent of feed turbidity. Considering that PAC alone also forms

a carrier for bacterial growth, UF is an effective barrier against multi-resistant bacteria and even multi-resistant genes with total elimination rates for selected UF membranes[6].

Material and Methods

Two pilot units have been employed in this research at two waste water treatment plants in Germany (Site A and Site B). Both sites consist of screening, clarification, biological treatment and secondary clarification. On Site A, a contact reactor with 5 to 20 mg/L PAC addition followed by tertiary clarification and sand filtration is installed to remove the PAC. The pilot unit is fed by the effluent of the tertiary clarification and has two identical lines (Line I and Line II) each equipped with a 1 m² module. On Site B the PAC is added into the feed tank of the pilot unit with concentrations up to 240 mg/l simulating a maximum breakthrough. At this site, the pilot unit is equipped with an 80 m² dizzer® type module.

At both locations, tests were conducted with a fully automated UF pilot unit provided by inge GmbH and equipped with several components:

- feed and backwash pumps with frequency-controlled drives to enable constant flow rates,
- feed and filtrate holding tanks,
- chemical dosing pumps for different chemicals (acid, caustic and chlorine),
- instrumentation (pressure sensors, pH and temperature probes, turbidity and flow meters) and
- automatic data logging.

The UF modules used for the study contain inside-to-out Multibore® fibers with seven capillaries (Figure 1). The inner layer of each capillary (internal diameter of 0.9 mm) represents the very thin active filter surface. The pore size of the filtration layer is approx. 20 nanometers. Between the capillaries is the foamy supporting structure which has a permeability approx. 1000 times higher than that of the membrane surface. This ensures an even distribution over the entire cross-section of the fiber. In addition, this unique structure allows a very high stability of the membrane.

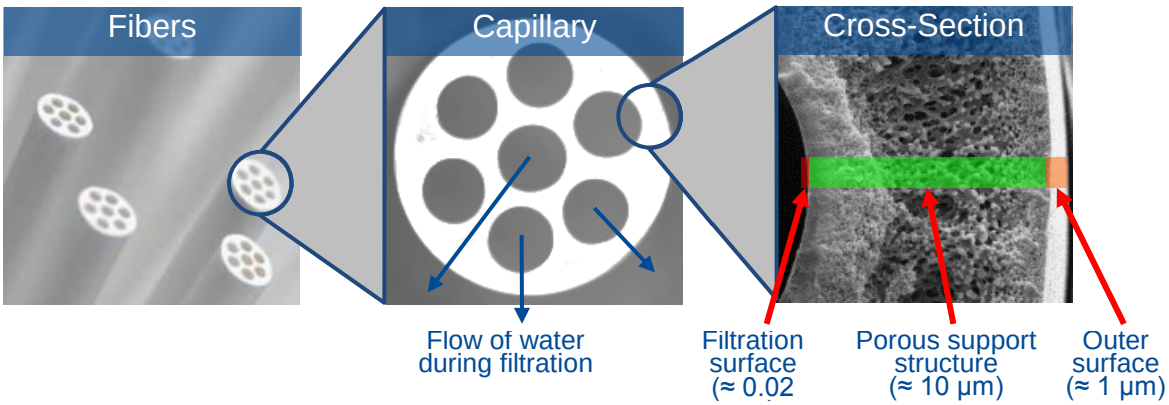


Figure 1: Multibore® Membrane

The material of the Multibore® fibers is modified polyethersulfone (PES) with a high pH tolerance of 1-13, which enables efficient cleanings even under extreme conditions. Thus, changes in membrane properties caused by fouling can often be reversed by e.g. normal backwashes or chemical cleanings [7].

Results and Discussion

On Site A, the two lines were operated with similar conditions: flux rate of 70 L/(m².h), filtration duration of 45 min, injection of polyaluminumchloride (PACl) at 3 mg/l as of Al^{3+} prior to the UF. In Line I, PACl was dosed continuously , while in Line II, PACl was dosed during one-fourth of the total filtration duration at the beginning of the cycle (intermittent dosing also called coating procedure). For Line I, permeability varied from 130 to 200 L/(m².h.bar) at 20°C, while for Line II, permeability was recorded at slightly lower values between 100 to 150 L/(m²·h·bar) at 20°C. Both permeabilities being stable, one can conclude that there is no evidence of any clogging of the capillaries thanks to the effectiveness of the backwash. For both lines, a constantly low turbidity in the filtrate suggests that there is no weathering on the membranes nor integrity issues. COD and phosphate were monitored to evaluate the removal and hence, biological regrowth potential. No significant filtrate quality difference between continuous and intermittent dosing was observed as similar COD and phosphate removal were achieved for both lines, 26 to 46%, and 40 to 87%, respectively. Additionally, qualitative measurements of multi-resistant genes and bacteria in the feed and filtrate of the UF endorsed full elimination of the latter. Considering chemicals for cleaning, coagulants and energy consumption for pumps,

calculations show that operational expenditure (OPEX) is reduced significantly when coating is applied compared to continuous dosing.

On Site B, the filtration flux was set to 60 L/(m²·h) with a filtration duration of 45 min. PAC concentrations from 30 to 240 mg/l were applied at continuous dosing into the feed tank for process stability tests. No adverse effect on membrane fouling had been observed as can be seen from Figure 2.

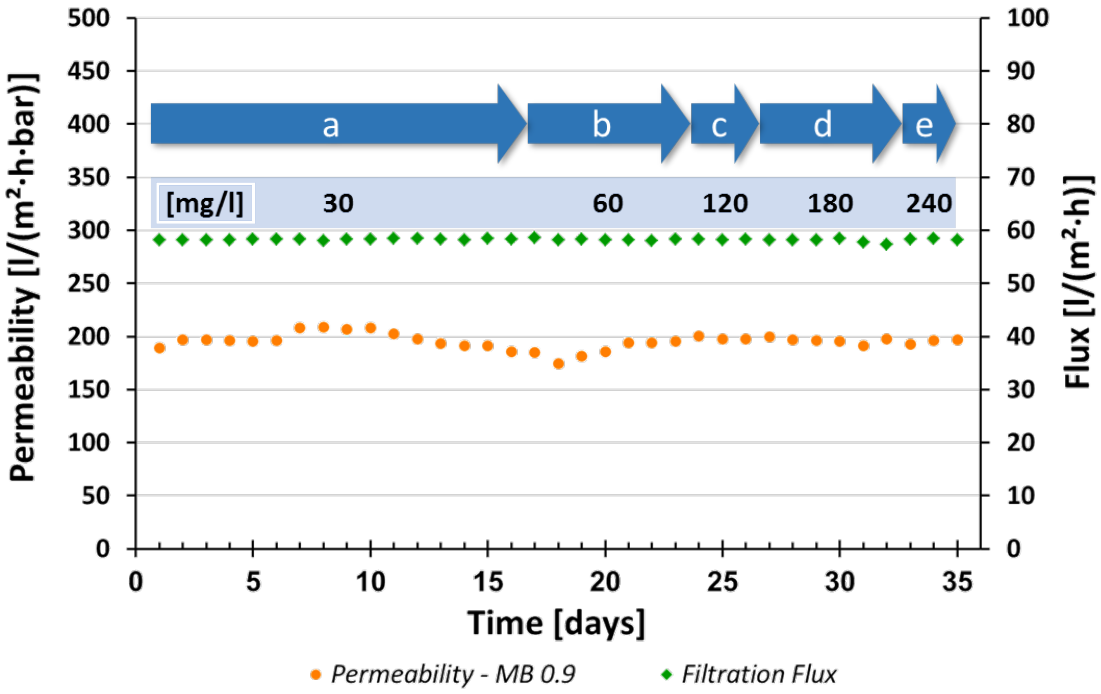


Figure 2 inge ultrafiltration performance at increased PAC concentrations

Subsequent addition of PACl at a concentration of 4 mg/l as of Al^{3+} stabilized the fouling behavior reflected in a permeability level around 200 L/(m²·h·bar) at 20°C. Further tests using 15 mg PAC/L revealed a reduction of 33 % for DOC and 54 % for COD by PAC/coagulation/UF. Concentrations of selected micropollutants have been determined in the influent as well the effluent of the waste water treatment plant and in the filtrate of the UF.

An overall removal of 82% could be achieved for Clarithromycin, Diclofenac, Sulfamethoxazol, Metoprolol, 1H-Benzotriazol, and Carbamazepin as is illustrated in Figure 3 meeting the requirements of the competence centre for micro pollutants of North Rhine Westphalia.

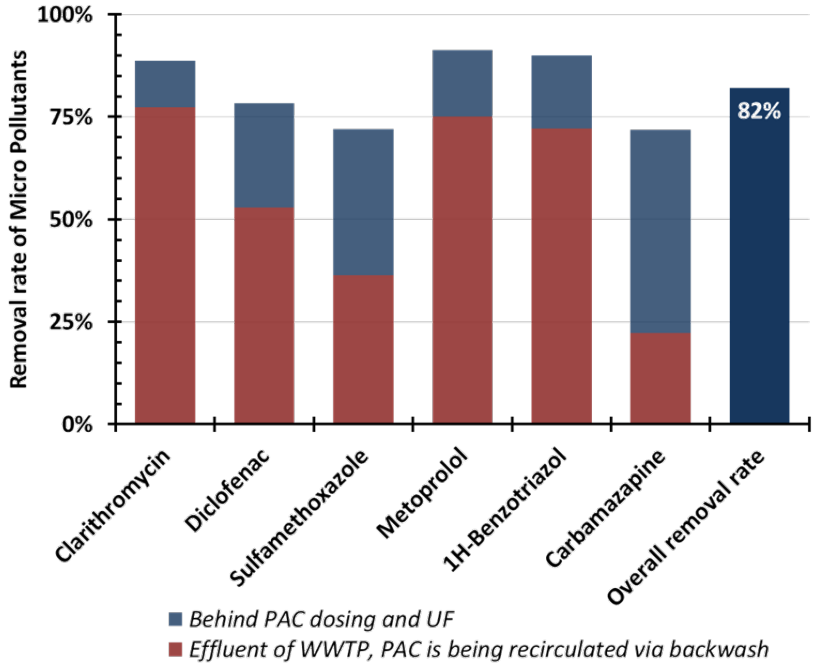


Figure 3 Removal of selected micro pollutants by PAC and UF

Based on adsorption kinetics and physico-chemical properties of the selected micro pollutants, it can be derived from the figure that in particular the recirculation of the PAC with the UF backwash into the biological treatment step has major impact on the overall removal efficiency. Supplementary, the short contact time of PAC (30 sec) prior to the UF adds up significantly to the overall removal.

Conclusions

This study illustrates that inside-to-out polyethersulfone membranes can be operated on wastewater effluents containing powdered activated carbon for long periods of time without experiencing any weathering. Also, concentrations up to 240 mg/l did not have a harmful effect on the overall operating performance. It is proved that stable permeabilities on different levels can be maintained depending on the way coagulant is added (continuous dosing or coating procedure). It is observed that there is no difference in chemical oxygen demand or phosphate removal rates when coating is used compared to a continuous dosage of coagulant. It could be assessed that the dissolved organic carbon could be reduced by 33%, and that an overall removal of micropollutants of more than 80% could be achieved by the waste water treatment plant followed by powdered activated carbon and ultrafiltration. Finally, it is demonstrated that the coating procedure significantly reduces operational expenditure.

References

[1] Alt, K., & Mauritz, A. (2009). Projekt zur Teilstrombehandlung mit Pulveraktivkohle im Klärwerk Mannheim. gwf-Wasser/Abwasser.

[2] Hildebrand, A., Metzger, S., & Prögel-Roy, C. (2013). Mit Aktivkohle gegen Spurenstoffe im Abwasser. *Sonderdruck Aus KA- Korrespondenz Abwasser, Abfall*, (3), 170–174.

[3] Meckes, J., Metzger, S., & Kapp, H. (2014). Untersuchungen zum Spurenstoffbindungsverhalten von Pulveraktivkohle unter anaeroben Bedingungen, 52.

[4] Metzger, S., Kapp, H., Seitz, W., Weber, W. H., Hiller, G., & Süßmuth, W. (2005). Entfernung von iodierten Röntgenkontrastmitteln bei der kommunalen Abwasserbehandlung durch den Einsatz von Pulveraktivkohle. *GWF, Wasser - Abwasser*, *146*(9), 638–645.

[5] Oligny, L., Bérubé, P. R., & Barbeau, B. (2016). Impact of PAC Fines in Fouling of Polymeric and Ceramic Low-Pressure Membranes for Drinking Water Treatment. https://doi.org/10.3390/membranes6030038

[6] Schwartz, T. (2019). Kommunale Kläranlagen, Eliminationsverfahren. Abschlussveranstaltung des BMBF-Verbundvorhabens HyReKA: Antibiotikaresistenz im Wasserkreislauf

[7] Zeman, L.J. and Zydney, A.L. (1996). Microfiltration and Ultrafiltration – Principles and Applications, Marcel Dekker Inc., New York.

Optical coherence tomography (OCT) for the MF fouling investigation under different pretreatment scenarios

Bhaskar Jyoti Deka, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China; Jiaxin Guo, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China; Sanghyun Jeong, Graduate School of Water Resources, Sungkyunkwan University, 2066 Seobu-ro, Jangan-gu, Suwon, Gyeonggi-do, Republic of Korea; Alicia K.J. An, School of Energy and Environment City University of Hong Kong, Hong Kong SAR China

Introduction

Chemical pretreatment can reduce significant fouling issues in microfiltration (MF), a membrane based separation technology. However, during harmful algal bloom (HAB), generation of dissolved algal organic matter (AOM) was responsible for the cause of severe membrane fouling worldwide. The dissolved AOM mainly consist of polysaccharide, protein, humic substances in association with other particles which largely triggered the fouling mechanism. This paper investigates different primary pretreatments such as coagulation/flocculation/sedimentation (CFS) and coagulation/flocculation/dissolved air flotation (CF-DAF) for the removal of AOM. The AOM model compounds: humic acid (HA), sodium alginate (SA), and bovine serum albumin (BSA) dissolved in real seawater were used as feed water. Ferrate (Fe(VI)) was generated by wet chemical oxidation using sodium hypochlorite (NaOCl) and ferric chloride ($FeCl_3$) under alkali conditions. In situ generated Fe(VI) was compared with ferric (Fe(III)) coagulant in different pretreatment scenarios. The optimal removal condition was observed by adopting coagulation/flocculation with in situ Fe(VI) of 1.29±0.05 mg L^{-1}, followed by a DAF process (CF-DAF) for a 10 min period with 8% recycling ratio and a saturation pressure of 500 kPa. In this case, the removal efficiencies of

AOM and turbidity were 81% and 31%, respectively. Flux recovery was also recorded at 65% under constant pressure by CF-DAF with in situ Fe(VI). AOM fouling on microfiltration membrane with different primary pretreatments was investigated using optical coherence tomography and scanning electron microscopic.

Materials and Methods

Under primary pretreatment, coagulation/flocculation/dissolved air flotation (CF-DAF) experiments were carried out in a standard DAF Jar test apparatus (Platypus, Australia) at room temperature (25±2 °C) with 2 L jars as shown in Fig. 1. For CF-DAF conditions, rapid mixing at 120 rpm for 1 min, flocculation at 30 rpm for 20 min and 8 min period of floatation using 8% recycling ratio at saturation pressure of 500kPa.

Results and Discussion

During primary pretreatment, participle destabilization played most significant role to arrest colloidal particles, the coagulation-flocculation produces hydrophobic flocs which further perform efficient removal in successive DAF application [1]. In CF-DAF operation, pressurized air bubbles are used to arrest the colloidal floc particles [2].

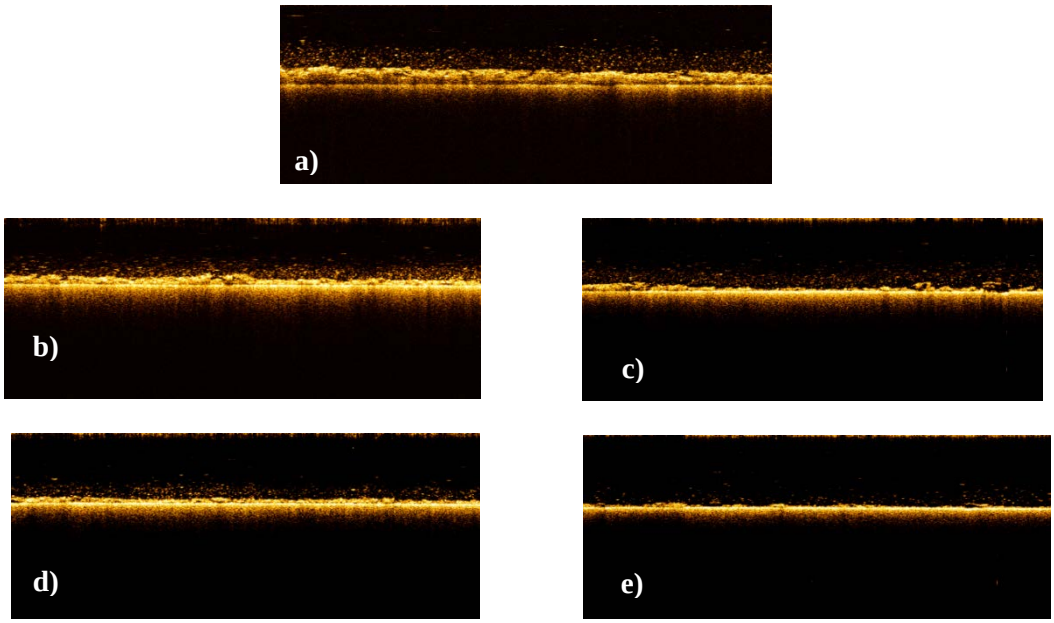


Table 1: MF feed quality in different primary pretreatment scenarios.

Pretreatment scenario	Turbidity removal eff. (%)	pH	DOC removal eff. (%)
CFS by Fe(III): 2.5 mg L^{-1}	9	7.75	43
CFS by in situ Fe(VI): 1.31±0.02 mg L^{-1}	19	7.75	63
CF-DAF by Fe(III): 2.5 mg L^{-1}	17	7.66	53
CF-DAF by in situ Fe(VI): 1.29±0.05 mg L^{-1}	32	7.60	81

Conclusion

During MF study, severe and rapid formation of fouling was observed for the AOM without any pretreatment, however at neutral pH, 67% flux recovery was observed under the CF-DAF pretreatment scenario i.e. peroxidation by NaOCl and CF by Fe(III). In-situ Fe(VI) oxidized the polysaccharide, protein and humic like compounds by forming larger size complex flocs. Further during DAF process, flocs and bubbles interact to form stable floc–bubble aggregates, resulting improvement in fouling. The MF feed quality was observed with 81% DOC removal, 32% turbidity removal as well as decrease in conductivity from 48.3 to 35.8 µS cm^{-1}.

References

(1) Teixeira, M. R.; Rosa, M. J. B. Sep. Purif. Technol. 2007, 53 (1), 126–134.

(2) Fonseca, R. R.; Thompson, J. P.; Franco, I. C.; Flávio, V. Automation and Control of a Dissolved Air Flotation Pilot Plant. IFAC-PapersOnLine 2017, 50 (1), 3972–3977.

Sweden's first beer brewed with recycled water to raise the value of water reuse

Christian Baresel (presenting author); Staffan Filipsson; Jesper Karlsson; Christian Junestedt

IVL Swedish Environmental Research Institute, Stockholm, Sweden;

Highlight

The paper focus on the aspect of adopting society's water reuse and acceptance. It is shown that public perception, engagement and acceptance can be provided by certain activities that cannot be provided by just proven technology efficiency.

Introduction and objectives

For many years and together with several collaboration partners, e.g. Sweden's largest environmental technology company Xylem, IVL Swedish Environmental Institute has been working developing water treatment systems for safe reuse of wastewater for different purposes. The technologies used and the concept allow for a holistic approach to solve several environmental challenges we face around the world but also in Sweden, such as declining groundwater levels, water shortage, saltwater intrusion, poorer quality of raw water sources, etc. For example, treatment systems for the reuse of sewage for industry, irrigation in agriculture or indirect potable reuse (surface water augmentation and groundwater recharge) have been developed.

Our studies show that by using the right combinations of technologies, wastewater can be recycled both cost-effectively and to such quality that it can be returned to groundwater or reused in agriculture and industry at equal or lower cost and environmental impact as today's sewage treatment. However, the strategy of reusing treated wastewater as a natural part of water resource management is relatively new, and is still regarded by many countries, including Sweden, as a solution that is some way off in the future. In order to challenge producers and consumers preconceived notions about wastewater, and to acknowledge that wastewater can be part of the solution in the future, IVL contacted the Carlsberg-backed brewery New Carnegie in Stockholm and asked if they were interested in brewing a beer with recycled water.

Methodology approach

The water used in the beer comes from the unique pilot and demonstration facility Hammarby Sjöstadsverk, where the water has passed through a chain of standard purification stages including a MembranBioReactor (MBR) that is currently installed in Stockholm largest WWTP and that will become one of the world largest MBR-installation. After thorough lab testing, the water was delivered to New Carnegie Brewery and the brewing team took over. Four weeks later, PU:REST – Sweden's first beer brewed on wastewater, saw the light of day. The result is a crystal clear pilsner, brewed on recycled water with organic malt and hops.

Conclusions and recommendation

The difficulties in getting this relatively cost- and energy-efficient method to be used for the production of drinking water is not technical but primarily emotional. The recycled water is as pure and safe as normal tap water, but most people are still skeptical about actual drinking purified wastewater. The initiative seems to fit well into new thinking in generally and also into Carlsberg's new environmental program, 'Together Towards Zero'. Part of the initiative is to cut the company's water use in half by 2030. It highlights the topics that implementing safe, innovative and cost-effective water reuse solution is not enough if public perception, engagement and acceptance is not given.


NYA CARNEGIE
BRYGGERIET
PU:REST
RECYCLED WATER PILSNER

Water reuse in France - Social perception of an unknown practice

Benjamin Noury, SCP Irstea IMSIC, Aix en Provence/France

Patrice Garin, Irstea G-Eau, Montpellier/France

Marielle Montginoul, Irstea G-Eau, Montpellier/France

Myriam Campardon, Irstea G-Eau, Montpellier/France

marielle.montginoul@irstea.fr

Abstract:

In France, wastewater reuse (WWR) is an emerging practice. In light of climate change, French authorities multiply pilot experiments but little data have been collected on public perception of this practice. This study questions French opinions towards WWR and tests variables that influence it.

The most discriminating factors are, in our study, perception, disgust, targeted use and information. The different types of information tested produced contrasting reactions. Our work also shows a strong coherence between attitudes and behavioral intentions. However, the threat of a 20% drop in local customers would not be acceptable in an agricultural and wine-growing area such as Pic Saint Loup.

Keywords: perception; wastewater reuse; information; communication

Introduction

Every second year, half of French departments set up restrictions on use due to water scarcity (CGAAER, 2017). Irrigation is limited or even prohibited for weeks. WWR could be justified in these territories. However, French regulations have long imposed requirements that have limited this practice. Only 0.2% of treated urban wastewater effluents is reused annually in France. In light of climate change, French Water Agencies multiply pilot experiments. Among them, the SOPOLO project focuses specifically on socio-economic issues, sometimes referred to as “social acceptability” (Lazarova & Brissaud 2007). This notion, although "embarrassing" (Barbier & Nadaï 2015), was soon acknowledged as a key element for the development of WWR in the same way as technical issues (Baumann & Kasperson 1974).

In France, national statistics regarding WWR acceptance do exist but few researchers have looked into sociotechnical factors which can slow down the emergence of WWR projects. Cerceau (2015) evokes the lack of awareness of water scarcity and the restrictive regulatory framework. Berry et al. (2016) reveal difficulties related to the rise of controversies. Indeed, water is a controversial subject in France, whether for the justification of irrigation (Granjou & Garin, 2006), or the quality of drinking water (Hervé-Bazin, 2014).

Our study focuses on the representations and the opinions of a representative sample of the Pic Saint Loup territorial community in South of France. This Mediterranean wine-growing territory has undergone several droughts that could intensify in the coming years. WWR is an alternative currently explored on the territory. Our work concentrate on public attitudes towards this emerging alternative.

Material and Methods

For this study, a questionnaire was administered by master students at the University of Montpellier. They conducted their surveys around markets and supermarkets in 10 municipalities. 845 questionnaires have been completed.

This questionnaire combines various methods:

- An associative method (Abric, 2003) to qualify the social representations of the object "treated wastewater".
- In line with the work of the theory of planned behavior (Ajzen, 1991), questions aim to establish relationships between attitude, norm and intention of behavior.
- Finally, in the same survey, we wanted to check if different forms of information could reinforce consumer confidence (Pichon, 2006). In the literature, the influence of information on the attitude towards WWR is not a consensus (Fielding et al., 2018).

Results and Discussion

1/ Associative method

The table below presents the analysis of 3-word associations pronounced and ranked at the beginning of the interview by the participants in response to the statement "treated wastewater". These rankings include the words after

lemmatization. For example, we have grouped the terms "connection", "pipeline", "water tower" and "pipe" under the same term "network".

The rareness indices (word cited only once by one person) and diversity indices (number of different responses) are 0.14 and 0.22 respectively before lemmatization. This reflects the poverty of the lexical field associated with WWR. For comparison, a similar study conducted on water obtained indices of 0.58 and 0.72 (Garin et al., 2018). These figures show that WWR hasn't been much discussed among the population, which is at the origin of social representations (Abric, 2003). It can be explained by the low media coverage of this object in France.

The following table ranks the words statistically according to their frequency and significance (in relation to the average rank, from 1 to 3, given by the interviewees).

Table 1 Social representations via the analysis of words associated with WWR

		Significance	
		High (rank<2)	Low (rank ≥ 2)
Frequency of occurrence	High (≥ 10%)	*CORE* **Wastewater treatment plant** (16%)	*1st PERIPHERY* NONE
	Low (<10%)	*CONTRASTING ELEMENTS* Recycling (9%), environment (7), treated wastewater (6), sanitation (4), pollution (4), dirt (3), clean (3), water (3), water saving (3), positive opinion (2), process (2), cost (2), potable (2), septic tank (1).	*2nd PERIPHERY* Toilet (2%), disgust (1), network (1), organic pollutant (1), chemical process (1), waste (1), etc.

In light of these results, "treated wastewater" seems to be strongly associated with "wastewater treatment plant". The participants therefore relate this type of water to its producing entity. Contrasting elements highlight different and less common ways of thinking. They refer here mainly to people who see WWR as an opportunity (recycling, water saving, etc.). In general, there are very few elements with negative connotations. It corroborates CI Eau national water survey (2018) in which a very large majority of individuals (75%) are in favor of using treated wastewater for fruit and vegetable irrigation.

2/ Attitude

The survey question the attitude of citizens towards nine uses: 3 "recreational" uses (golf, roundabout and green spaces) and 6 "agricultural" uses (shared gardens, market gardening, orchards, olive trees, vine and meadows for livestock).

The results support the patterns identify in the literature (Smith et al., 2018) on the relationship between attitude and uses. People are less likely to use treated wastewater for market gardening (70%) than for watering green spaces (90%). This distinction is also confirmed when consumer intentions are questioned. 83% would continue to frequent green spaces irrigated with treated wastewater while only 69% would continue to buy from grocers who sell fruits and vegetables irrigated with treated wastewater.

A statistical analysis was conducted to identify the sociotechnical variables that may be correlated with these attitudes. We obtain the following results for the irrigation of three uses.

	Parks and gardens	Vine	Market gardening
Disgust	**0.000**	**0.000**	**0.000**
Environmental sensitivity	**0.000**	**0.001**	**0.000**
Risk perception	**0.003**	**0.000**	**0.000**
Information	0.811	**0.007**	**0.001**
Trust in technologies	**0.021**	0.106	0.142
Gender	0.744	0.383	**0.019**
Age	0.409	0.259	0.092
Information habits	0.557	0.418	0.438

Table 2 Chi-Square Test of Independence (p-value<5%)

Disgust, environmental sensitivity and risk perception influence attitudes for all three uses. For instance, people who are reluctant to eat a vegetable that has been irrigated with treated wastewater are less likely (-55 %points) favorable than others to reuse wastewater. For parks and gardens, the more environmentally sensitive participants are, the more likely they are to reuse wastewater (+10pp).

Confidence in technology act on WWR attitudes also, but the probability of independence is less significant between these two variables.

In the literature, the effect of age is different depending on the cultural context. A negative effect is demonstrated in American studies while Australian studies show the opposite (Fielding et al., 2018). Here, age does not seem to have a significant effect. For market gardening, a gender-related effect is confirmed. Men are more favorable to WWR than women (+ 4.57pp).

3/ Effect of information

To analyze the information effect, the sample was divided into four groups, a control group and three groups facing different types of communication: 1/ neutral, presenting WWR with factual elements, 2/ persuasive, emphasizing the benefits of WWR and, 3/ commitment (Bernard &J Joule, 2004), subjecting participants to a preparatory act before delivering the persuasive communication. A flyer was handed out to each participant.

The results presented in Table 3 show an effect of the information on attitudes. This effect does not seem to be homogeneous. It varies according to the type of use and the type of communication.

Table3 Effect of information on attitude towards WWR

	Attitudes	Commitment (N=154)	Neutral (N=309)	Persuasive (N=176)	No Info (N=204)
Agricultural uses	Strongly agree	44%	55%	44%	37%
	Agree	29%	23%	32%	28%
	Disagree	18%	12%	17%	22%
	Strongly disagree	8%	8%	4%	8%
	No opinion	2%	2%	3%	3%
Recreational uses	Strongly agree	61%	72%	62%	64%
	Agree	19%	16%	27%	21%
	Disagree	13%	7%	6%	11%
	Strongly disagree	5%	3%	3%	2%
	No opinion	1%	2%	2%	1%

Information described as neutral significantly strengthens the favorable attitudes for all uses. This impact could be explained by the mention of the health authority's controls exclusively on this communication medium. The so-called persuasive information changes the opinion of the very opposed participants, but only for

agricultural uses. This brochure explicitly mentions agriculture in its slogan "WWR - a resource for our agriculture" and as a local solution to food security. Finally, in the commitment scheme, participants gave their opinion on short food channel, as preparatory act, before being subjected to persuasive information. The results are contrary to scientific hypotheses. There is even a slight decrease in positive opinions compared to the control group. The relevance of the preparatory act is to be questioned.

The effect of information also appears to be influenced by media consumption habits (radio, TV, web, newspapers). Among those who received an information, being well informed by the media increases by 25pp the probability of responding "strongly agree" rather than "agree" (at the 1% threshold). This supports an Australian study (Dolnicar et al., 2010) on WWR. It points out that the cause of heterogeneity in information responses is more the experience of information processing than socio-demographic data.

Finally, the study also found a strong coherence between attitudes and behavioral intentions (p-value= 0.000). People who are in favor of WWR will not change purchasing habits if they learn that vines are irrigated with treated wastewater. A reassuring effect of the information is also noted. Consumers are less hesitant with information. However, the threat of a 20% drop in local customers would not be acceptable in an agricultural and wine-growing area such as Pic Saint Loup.

Table 4 Effect of information on attitudes and purchasing intentions for wine

Attitudes	Info			No Info		
	Purchase	No purchase	Don't Know	Purchase	No purchase	Don't Know
Agree	91%	23%	41%	86%	22%	31%
Disagree	7%	75%	48%	13%	76%	38%
No opinion	2%	2%	11%	1%	2%	31%
Total	**75%**	**20%**	**5%**	**66%**	**26%**	**8%**

The results presented in this table for wine purchases are similar for vegetables or cheeses from breeding that consume fodder watered with wastewater.

Conclusions

On the territory of the Pic Saint Loup, our survey reveals similar results to national statistics. The practice seems to be unknown, as confirmed by our associative method. WWR has not yet raised high-profile controversies covered by the media that could shape contrasting opinions. The other results are in line with the literature on sociotechnical factors influencing attitudes of WWR. The most discriminating factors are perception, disgust and targeted use.

Finally, these surveys tend to confirm the role of information on the social perception of WWR. However, the effect of this brief information on opinions must be put into perspective. Research has indeed shown the bias of a recency effect with a decrease in the influence of information over time (Kemp et al., 2012).

The differences in results according to the type of information suggest the implementation of specific communication approaches to each territory rather than standardized strategy. However, our study also reveals a paradox related to communication. By communicating, agricultural producers would strengthen the social acceptability of their project at the expense of a potential loss of customers. Historical WWR projects such as Noirmoutier in France do not communicate on the origin of irrigation water. For 30 years, they irrigated potatoes there with treated wastewater without a health scandal. However, in the current social context, the managers of this irrigated perimeter could be accused of a lack of transparency. The current multiplication of WWR pilots may lead to local controversy. Will it be health-related or of a communicative nature?

References

Abric, J.-C. (2003). Méthodes d’étude des représentations sociales. Erès, Ramonville-Saint-Agne.

Ajzen, I. (1991). The theory of planned behavior. Organizational Behavior and Human Decision Processes, 50(2), 179‑ 211.

Barbier, R., & Nadaï, A. (2015). Acceptabilité sociale : partager l’embarras. VertigO - la revue électronique en sciences de l’environnement, 15(3).

Baumann, D. D., & Kasperson, R. E. (1974). Public acceptance of renovated waste water: Myth and reality. Water Resources Research, 10(4), 667‑674.

Bernard, F., & Joule, R. V. (2004). Lien, sens et action : vers une communication engageante. In Communication et organisation, Coexister dans les mondes organisationnels, Vol. 24, Bordeaux, France, pp. 347‑362

Berry, P., Strosser, P., & Berge, M. (2016). Investigating the public acceptance of wastewater reuse at the Vendée greenfield demonstration site, Demoware deliverable 6.4.

Cerceau, J. (2015). Acceptabilité sociale des projets de réutilisation des eaux usées, NOW MMA livrable 4.2, ARMINES/Ecole des Mines d'Alès, France.

CGAAER. (2017). Eau agriculture et changement climatique : statu quo ou anticipation, Rapport n° 16072, Paris, France

C.I.Eau. (2018). Les français et l'eau. Baromètre 22ème édition.

Dolnicar, S., Hurlimann, A., & Nghiem, L. D. (2010). The effect of information on public acceptance – The case of water from alternative sources. Journal of Environmental Management, 91(6), 1288‑1293.

Fielding, K. S., Dolnicar, S., & Schultz, T. (2018). Public acceptance of recycled water. International Journal of Water Resources Development, 1‑36.

Garin, P., Girard, S., Honegger, A., Degache, A., Gouton, C., & Pellen, M. (2018). Mesurer les apprentissages issus des dispositifs participatifs par les représentations sociales et territoriales: l'exemple de l'eau potable et de sa vulnérabilité au changement climatique, rapport final, Zone Atelier Bassin du Rhône.

Granjou, C., & Garin, P. (2006). Organiser la proximité entre usagers de l'eau : le cas de la Gestion Volumétrique dans le Bassin de la Charente. Développement durable et territoires, Dossier 7.

Hervé-Bazin, C. (2014). Boire en eaux troubles: La construction de la défiance et des risques de boire de l'eau. Communication et organisation, (45), 127‑138.

Kiesler, C. A. (1971). The psychology of commitment: Experiments linking behavior to belief, Academic Press.

Lazarova, V., & Brissaud, F. (2007). Intérêt, bénéfices et contraintes de la réutilisation des eaux usées en France, N°299, pp. 43-53.

Pichon, P.-E. (2006). Confiance et consommation alimentaire : De l'importance de la confiance dans les émetteurs des réducteurs de risque. In Actes des 5ème Congrès International des Tendances du Marketing, Venice, Italy.

Smith, H. M., Brouwer, S., Jeffrey, P., & Frijns, J. (2018). Public responses to water reuse – Understanding the evidence. Journal of Environmental Management, 207, 43‑50.

Potable Water Re-use: The influence of Trust and Water Scarcity

Anita Etale[1], Kelly Fielding[2], Andrea Iris Schäfer[3], Michael Siegrist[4]*

[1] Global Change Institute, University of the Witwatersrand, Johannesburg, South Africa,

[2]Institute for Social Science Research, University of Queensland, Queensland, Australia,

[3]Institute of Functional Interfaces, Karlsruhe Institute of Technology, Karlsruhe, Germany,

*[4]Institute for Environmental Decisions, ETH Zurich, Zurich, Switzerland. *aetale@gmail.com*

By the year 2050, >1 billion people will live in cities with perennial water shortages. Meeting the water demand from such large populations will, therefore, present considerable challenges for water supply authorities in the future. Recycled water holds potential for addressing this demand-supply gap. This study examined the influence of water scarcity, trust in water authorities, and biospheric values on peoples' willingness to use recycled water for potable purposes. We found that while trust in local water authorities predicted willingness to drink recycled water, water scarcity and biospheric values did not always have the same effect. Results are examined in relation to elements of institutional trust employed in the study.

Key words: Reclaimed water; Sustainable cities; Institutional trust; Climate change; South Africa; Australia

Introduction

A number of countries globally are already struggling to cope with increasing pressures on their water supplies; and population growth and climate change will likely exacerbate this pressure (Mekonnen and Hoekstra 2016). To address this challenge, water authorities are increasingly considering augmentation of their resources by reclamation of wastewater (Hurlimann and Dolnicar 2016). Technologies capable of treating wastewater to a quality superior to existing drinking water standards already exist (Umar et al., 2015). However, public support for recycled water use remains low due to several factors including perceived health risks, disgust, social norms, environmental concern, and institutional trust (Dolnicar and Schäfer, 2009; Fielding et al., 2018; Hurlimann and Dolnicar, 2016). Demographic

factors including age, income, level of education, and gender also influence acceptance: being younger, male, and having higher income and education levels are positive predictors of acceptance of recycled water (Dolnicar et al., 2011).

If recycled water is deemed by consumers to present some level of risk, then the decision drink or use for other purposes involves some degree of trust in, amongst others, its suppliers. Indeed, Ross et al. (2014) found that higher levels of trust in the water supply authority were associated with lower perceptions of risk and greater acceptance of recycled water. In the recycled water domain, previous work has investigated trust as a function of (i) the intentions with which water supply authorities were deemed to act, (ii) their ability to manage risks, and (iii) the trustworthiness of information they provided (Hurlimann et al., 2008; Ross et al., 2014). We investigated trust as determined through (i) judgements of personnel qualification, and (ii) management of water supply infrastructure. This latter factor is particularly significant because not only do many cities considering water reuse also grapple with ageing water supply infrastructure (Larsen et al., 2016), perceptions of authorities' abilities to manage infrastruture are critical to public trust as evidenced in the recent Flint water crisis in Michigan, USA (Morckel and Terzano 2018).

Pro-environmental values have also been found to influence willingness to drink recycled water. Fielding et al. (2015) found that individuals who believed that climate change was anthropogenic rather than the result natural of causes were more accepting of potable reuse. People espousing pro-environmental attitudes also have more positive attitudes towards indirect potable reuse (Po et al., 2005). This study explored whether biospheric values which underlie environmentally-friendly actions such as preservation of nature, predict acceptance of recycled water for potable.

Methods

Data were collected from urban residents in Australia and South Africa using internet panels from a commercial company (Lightspeed Research). A quota sample based on gender and age was recruited, resulting in 244 Australians (53.7 % male), and 238 South Africans (45.8 % male), ranging in age from 18 to > 60 years. Those aged 31 - 60 years comprised 49.1 % and 55.1% of the South African and Australian samples, respectively. Education levels were

also largely similar: >97.1 % of respondents in both countries had secondary education or higher.

Measures: Willingness to drink (WTD) recycled water was assessed on a 6-point scale 1 “very unwilling”, and 6 ‘very willing’, using the following question: “*Please state how willing you would be to use recycled water for drinking*”. Trust, also measured on a 6-point scale, was measured in terms of (i) confidence in quality of water supply, (ii) intentions with which the water supply authority was perceived to act, (iii) confidence in the expertise of personnel in charge of the water supply (iv) personal satisfaction with how the water supply authority managed supply, and (v) perceptions of whether the water supplied met international standards. Responses to the questions ranged from 1 “completely disagree” to 6 “completely agree”. The Cronbach alpha of this scale was .95.

Environmental value orientations were tested using measures in de Groot and Steg (2008). Because the particular interest of this study was the influence of biospheric values, only values in this dimension were selected i.e. preventing pollution, respecting the earth, unity with nature, and protecting the environment. Respondents rated the importance of each of the four values “as a guiding principle in their lives” on a 9-point scale: “1 = opposed to my values”, “0 = not important”, to “7 = extremely important”. They were asked to vary the scores and to rate only a few items as very important. Experience with water restrictions was used as a proxy for the influence of water scarcity and assessed using one binary response item: “*Have you ever experienced water restrictions?*” Demographic data i.e. education, age (years) and sex (male = 0, female = 1), were collected both to characterise the samples and for use as predictor variables.

Data analysis: Differences in responses by Australian and South African respondents were compared using independent samples *t*-tests. Linear regression analysis with forced entry was used to assess the relative importance of attitudinal and demographic factors for predicting WTD.

Results and Discussion

Significant differences between Australian and South African populations with respect to all the variables tested were found. South Africans were not only significantly less amenable

than Australians to the idea of drinking recycled water, $t(480) = -4.60$, $p < .001$, they also reported significantly lower levels of trust in LWAs, $t(453.13) = -2.68$, $p = .008$ (Table 1).

Table 1: Comparisons of South Africans' and Australians' ratings on WTD, trust in LWAs and biospheric values.

	South Africans (*n* =		**Australians (*n* = 244)**	
	Mean	**SD**	**Mean**	**SD**
Willingness to drink	2.99	1.89	3.75	1.75
Trust in LWAs	4.12	1.49	4.45	1.19
Biospheric values	7.93	1.40	7.04	1.80

Independent samples *t*-tests showed that South Africans were significantly less confident that (i) personnel in charge of their water supply were sufficiently qualified, $t(439.14) = -3.41$, $p = .001$, (ii) their water supply infrastructure was well managed by LWAs, $t(433.62) = -3.07$, $p = .002$, and (iii) the quality of their water met international standards, $t(432.30) = -4.49$, $p < .001$. There was also an association between country and experience with water shortages, χ^2 (1) = 9.72, $p = .002$. South Africans were 1.96 times more likely to have experienced water restrictions than their Australian counterparts. There was a significant negative correlation between experience of water shortages and trust in LWAs, but only in the Australian population, $r = -.17$, $p = .004$. Finally, biospheric values seem to have a significantly greater influence on South Africans than Australians, $t(457.42) = 6.07$, $p < .001$.

Predictors of willingness to drink: Results of linear regression analysis showed that the variables accounted for up to 22.3 % and 6.6 % of the variance in WTD amongst Australians and South Africans, respectively. Trust in local water authorities was the only predictor significant for both populations (Table 2). Sex, level of education and biospheric values were significant predictors but only in the Australian sample while age was not a significant predictor in either country.

Table 2: Multiple linear regression model of predictors of WTD recycled water.

	Australians					South Africans				
	b [CI]	SE *b*	*β*	*T*	*p*	*b* [CI]	SE *b*	*β*	*t*	*p*
Constant	0.39 [-1.00, 1.79]	0.71		0.56	.578	1.06 [-0.96, 3.08]	1.03		1.03	.303
Trust in local water authority	0.48 [0.30, 0.67]	0.09	0.33	5.19	**<.001**	0.28 [0.11, 0.45]	0.08	0.22	3.29	**.001**
Experience of water restrictions	0.21 [-0.24, 0.66]	0.23	0.06	0.92	.360	0.49 [-0.23, 1.02]	0.32	0.10	1.54	.124

Biospheric values	0.17 [0.04, 0.29]	0.06	0.17	2.65	**.009**	-0.01 [-0.25, 0.20]	0.09	-0.01	-0.15	.879
Sex	-0.55 [-0.96, -0.14]	0.21	-0.16	-2.62	**.009**	-0.08 [-0.57,0.42]	0.25	-0.02	-0.31	.756
Education	0.28 [0.09, 0.47]	0.10	0.17	2.87	**.005**	0.15 [-0.09,0.38]	0.12	0.08	1.22	.224
Age	-0.10 [-0.24, -0.03]	0.07	-0.09	-1.50	.136	-0.002 [-0.19, 0.19]	0.10	0.002	-0.02	.981

Together, these results highlight the significant place of trust in LWAs in consumers' decisions about drinking recycled water and reveal novel information about what consumers consider when making judgements of trustworthiness of water supply authorities. How qualified personnel are considered to be, how well water supply infrastructure is managed, and even the incidence of water shortages, all contribute to levels of trust accorded to LWAs. LWAs must therefore, pay attention to these factors because they determine their trustworthiness, which they may then draw upon when recycling initiatives are mooted to communities.

It also draws attention to a counter-intuitive finding: experience of scarcity alone may not be sufficient for acceptance of drinking recycled water. Thus, climate change and population growth may not be sufficient drivers for acceptance of recycled water. Nevertheless, some studies suggest that actual immediate experiences of running out of water can increase recycled water acceptance (Price et al., 2010).

Conclusions

Trust was the only variable found to be a significant predictor in both countries, of consumers' willingness to drink recycled water. It is therefore an important factor that water authorities need to consider in rolling out water recycling programs. The results of this study show that consumers' constructions of trust comprise of, among other factors, how skilled water authority personnel are deemed to be, their proficiency in managing infrastructure and in some cases, the incidence of water restrictions. As such, LWAs should pay attention to the professionalism of their personnel and the management of infrastructure, as these have a significant influence on how trustworthy they are deemed to be, and in turn, on acceptance of recycled water.

References

de Groot, J. I. M. and Steg, L. (2008). Value Orientations to Explain Beliefs Related to Environmental Significant Behavior. Environment and Behaviour, 40, 330–354.

Dolnicar, S., Hurlimann, A. and Grün, B. (2011). What affects public acceptance of recycled and desalinated water? Water Research, 45, 933–943.

Dolnicar, S. and Schäfer, A. I. (2009). Desalinated versus recycled water: Public perceptions and profiles of the accepters. Journal of Environmental Management, 90(2), 888-900.

Fielding, K. S., Dolnicar, S. and Schultz, T. (2018). Public acceptance of recycled water. Int. J. Water Resources Development, 1–37.

Fielding, K.S., Gardner, J., Leviston, Z. and Price, J. (2015). Comparing Public Perceptions of Alternative Water Sources for Potable Use: The Case of Rainwater, Stormwater, Desalinated Water, and Recycled Water. Water Resources Management, 29, 4501–4518.

Hurlimann, A. and Dolnicar, S. (2016). Public acceptance and perceptions of alternative water sources: A comparative study in nine locations. International Journal of Water Resources Develeopment, 32, 650–673.

Hurlimann, A., Hemphill, E., McKay, J. and Geursen, G. (2008). Establishing components of community satisfaction with recycled water use through a structural equation model. Journal of Environmental Management, 88, 1221–1232.

Larsen, T. A., Hoffmann, S., Lüthi, C., Truffer, B. and Maurer, M. (2016). Emerging solutions to the water challenges of an urbanizing world. Science, 352(6288), 928–933.

Morckel V. and Terzano K. (2018). Legacy city residents' lack of trust in their governments: An examination of Flint, Michigan residents' trust at the height of the water crisis. Journal Urban Affairs, 00:1–17.

Po, M., Nancarrow, B. E., Leviston, Z., Porter, N. B., Syme, G. J. and Kaercher, J. D. (2005). Predicting Community Behaviour in Relation to Wastewater Reuse: What drives decisions to accept or reject? CSIRO Land and Water: Perth.

Price, J., Fielding, K., Leviston, Z., Bishop, B., Nicol, S., Greenhill, M., and Tucker, D. (2010). Community Acceptability of the Indirect Potable Use of Purified Recycled Water in South-East Queensland: Final Report of Monitoring Surveys. Urban Water Security Research Alliance Technical Report No. 19.

Ross, V. L., Fielding, K. S. and Louis, W. R. (2014). Social trust, risk perceptions and public acceptance of recycled water: Testing a social-psychological model. Journal of Environmental Management, 137, 61–68.

Umar, M., Roddick, F. A., Fan, L., Autin, O. and Jefferson, B. (2015). Treatment of municipal wastewater reverse osmosis concentrate using UVC-LED/H_2O_2 with and without coagulation pre-treatment. Chemical Engineering Journal, 260, 649-656.

Operator models for the reuse of municipal wastewater in hydroponic systems: Potentials and options for Central and Mediterranean Europe

Björn Ebert, ISOE-Institute for Social-ecological Research, Frankfurt a. M., Germany; Thomas Dockhorn, TU Braunschweig, Braunschweig, Germany; Gudrun Peters, WEB, Wolfsburg, Germany; Engelbert Schramm, ISOE, Frankfurt a. M., Germany; Bernhard Teiser, AVB, Braunschweig, Germany; Martina Winker, ISOE, Frankfurt a. M., Germany,; ebert@isoe.de

Abstract

The joint research project HypoWave (2016-2019) is the first Central European study of a hydroponic greenhouse system that is operated with specifically treated municipal wastewater. The new production system enabling water and nutrient reuse needs to be adapted in operator models. Searching for appropriate organisational structures in four feasibility studies in Belgium, Germany and Portugal potentials and options for operator models in decentral, semicentral and central applications could be investigated. Differentiating between appropriate and ideal operator models, the main finding is that for each scale a matching model exists. Wastewater volumes, greenhouse farm sizes and appropriate operator models seem to be most advantageous in semicentral applications.

Keywords: technical, spatial and social scales; organisation; reuse; agriculture

Introduction

In theory, the reuse of municipal wastewater in hydroponic systems allows both the utilization of nutrients contained in wastewater and a significant increase in water resource efficiency. The cultivated plants grow in a nutrient solution without substrate. Technically the aim is to investigate whether it is possible to coordinate the wastewater management concerns and agricultural requirements that apply in (closed) hydroponic systems (cf. Bliedung et al., 2019). Three years of experiences and adaptations at the Hattorf wastewater treatment plant in Lower Saxony (Germany) have optimised the modes of operation to meet quality and safety demands. Beyond this technical feasibility, reuse always takes place in a context of more or less stable social-ecological problem settings. On the one hand operator models need to deal with stable system patterns (natural environment conditions resp. deep values like free-

dom, justice or solidarity), on the other hand they get confronted by societal dynamics. These are volatile due to markets, attitudes, opinions or technical novelties and influenced by the development in interdependent socioeconomic sectors (cf. Jenkins-Smith and Sabatier, 1994; Mollinga, 2008). Leaving the controlled conditions of the pilot installation demands for responses to challenges in different spatial and social settings. Part of this response is to find social innovations like appropriate new divisions of labour, redefinitions of roles, interactions and organisational structures (e.g. a joint understanding in quality assessment, cf. Zapf, 1994). The particular challenge at the intersection between municipal wastewater treatment and agricultural production is the heterogeneity of actors and beliefs which need to match an operator model (cf. Dolata, 2011). Therefore the paper addresses the following questions:

- Which are appropriate and ideal operator models at spatial and social scales?
- Which are the responses necessary at which scale?

First defining appropriate and ideal operator models as well as its systematic development, the results are presented along problem solutions from decentral to central as well as with respect to spatial and social scales (cf. Beveridge et. al., 2017).

Material and Methods

Operator models structure every day interactions of actors being involved into reusing municipal wastewater in hydroponic crop production. As negotiating operator models means finding hybrid technical-organisational arrangements in a context of established hierarchies, market structures and networks, the starting point for the cooperation management approach was analysing actor-related, institutional and legal framework conditions (cf. Werle, 2005; Mollinga, 2008; Ott et al., 2017). Together with the evidence of forty expert interviews the aforementioned desktop analysis set the stage for optimized ideal operator models highlighting product standards and technical-organisational infrastructures such as the characteristics of actors responsible for advanced wastewater treatment, water storage, distribution and hydroponic operation. Whereas an ideal operator model minimises coordination demands (cf. Ott et al., 2017), appropriate operator models highlight the balancing of beliefs, claims, power relations and needs incorporated in innovations. Operator models have been investigated in feasibility studies maximising the variance of initial conditions like wastewater infrastructure, agricultural and socioeconomic structures in Belgium, Germany and Portugal (cf. Mohr et al., 2019).

Results and Discussions

The overall result of the operator model development is twofold. First of all, organisationally reuse of municipal wastewater in hydroponic systems is possible at every social and spatial scale. However, in the feasibility studies where there has been both potential for decentral and central solutions, the semicentral approaches seem to be a good entry opportunity for the technical concept.

Decentral approaches

Starting with decentral approaches, there is a considerable variance of urban and rural applications. Due to the small wastewater volumes the hydroponic systems can be conceptualized for self-sufficiency and wastewater reuse at site demanded by actors who would like to gain sovereignty in food production. Gourmet restaurants, (group) catering or hotels in arid areas could control the quality during whole production process and even the products' consumption. Being a unitary actor fully informed about water usages, knowledge diffusion between organisations is not necessary (cf. Kluge; Schramm, 2002). For some specific tasks like monitoring it might nevertheless be useful to engage in subcontracting.

From a legal perspective, as soon as food is distributed, irrigation water has to fulfil legal standards and technical norms like DIN 19650 (1999). Further requirements for example by certifiers or food retailers are relevant beyond usages for self-sufficiency at more central scales. In an urban context – like the roof top farm at Block 6 in Berlin – reuse becomes part of blue-green infrastructure (cf. Bürgow 2014). In rural decentral applications further incentives are the avoidance of very costly long-distance sewer lines and complementing the agricultural production of remote farms.

Semicentral approaches

In Central and Mediterranean Europe wastewater associations in rural areas have implemented mostly public infrastructure for at least primary treatment. Due to a socially and technically demanded collection of wastewater, for semicentral solutions it is appropriate to integrate wastewater associations, allowed and willing to partly delegate a sovereign task to a private entity, into operator models. Ideal semicentral site conditions are clarification ponds or chamber pits connected to a sewer system which are surrounded by fields (cf. Mohr et al., 2019). Greenhouses corresponding to the population equivalents match the spatial size of averaged farms (cf. ZBG, 2017; Mohr et al., 2018). A further advantageous agricultural precondition is light soils. Their low capacity to hold water and nutrients together with the current irrigation and

nutrition practices enables chemical substances to pollute soils and waters. In contrast, hydroponic systems are sealed against the environment.

For the operator model it is crucial to create relationships that are perceived as just ways to maintain individual decision making in collectively relevant issues like the treatment process, plant nutrition and nature conservation. Balancing the different requirements is in need of *contractual relationships* between heterogeneous entities like wastewater associations and hydroponic operators. Combined with a technical approach returning the greenhouse discharge back into the area of responsibility of the wastewater association, the water for irrigation and nutrition only gets temporarily ceded to the operator (cf. Mohr et al., 2018). Without this appropriate operator model contract negotiations might fail. Although contracts have proven to be an appropriate way of organising a small number of farmers involved, opportunity costs and ambiguity in responsibilities rise with every further individually negotiated contract.

For a semicentral case an ideal model suggested by the cooperation management approach is an independent nutrient, water and quality manager. This *new actor* reduces coordination demand. Knowing the demands of the hydroponic operators – or even acquiring them – a practice hardly known to public entities – and being acknowledged by the wastewater association, the manger integrates specialised knowledge for the novel production processes. With an established intermediary actor the wastewater association has to negotiate a single contract and reduces every day interaction. Because of potential liability cases it is in the manager's self-interest to document the incoming and leaving streams very well. These procedures could be certified by quality assurance systems for food (cf. Schramm et al., 2019), reducing opportunity costs once again. However, establishing a novel actor is dependent on start-ups, spill overs from other sectors or spill-offs (e.g. irrigation masters or farmers, see Dolata, 2011). Although this operator model might be ideal, it is not yet considered. Instead, for larger groups to be coordinated already existing irrigation associations get assigned the role of a networking or boundary spanning actor.

Central approaches

Here, central applications are defined as settlements with wastewater treatment plants of size classes four and five. Beyond central wastewater infrastructure larger grid connected distribution systems are needed. The place of wastewater discharge gets highly disconnected to the places of reuse. Socially this disconnection implies that the irrigation associations get an important partner in the operator models. Own-

ing distribution infrastructure, irrigation associations are perceived to be familiar with the water cycle in general and consulting, service provision and water legislation in particular. As spatial disconnection also means loosing information about water quantities and qualities, intervention by structural policy gets much more relevant. The more metropolitan sealed space grows the more challenging requirements for building permissions and the citizens' perception on the aesthetics of greenhouse landscapes are going to be. Political will at least in Germany foresees to improve the performance of large wastewater treatment plants with a fourth purification stage. In this window of opportunity, the needs of farmers could be responded emphasising high quality demands for irrigation. For central applications it is recommended that hydroponic crop production goes much more hand in hand with tasks in public interest like conservation. The alliance of operator models with structural planning is in particular relevant in larger conversion areas (e.g. brown coal mining areas, former sewage farms, industrial or military grounds, airports). Complementing usages for the common good additionally legitimise operator models, also relevant for funding. The challenge is balancing the demands of self-determined solutions and state intervention. Probably, operators in central approaches are a larger group, which should both organise its common interests towards state actors and with respect to the market power of the food industry and retailers.

Conclusions

More or less appropriate operator models as well as ideal operator models for the reuse of municipal wastewater in hydroponic systems are available from decentral to central applications. The more central the scale, the more actors need to get involved, the less knowledge about the previous water usage is available and the higher the dependency on natural grid-based monopolies. Semicentral applications are characterised by a good match of spatial, social and technical scales. The ideal operator model of a nutrient, water and quality manager as a coordinating actor nearly reducing the interactions necessary for operation to the ones of a decentralised ideal unitary actor is not yet congruent with the contractual arrangements considered appropriate by most experts.

Acknowledgements

The authors would like to thank the Federal Ministry of Education and Reseach for funding the research project "HypoWave – New Pathways Towards Wastewater Re-Use in Agriculture" (grant number: 02WAV1402).

References

Beveridge R., Moss T., Naumann M. (2017). Sociospatal Understanding of Water Politics: Tracing the Multidimensionality of Water Reuse, in: Water Alternatives, 10(1), 22-40

Bliedung A., Dockhorn T., Ebert B., Jörn G., Mohr M., Schramm E., Winker, M. (2019). HypoWave - Ressourceneffiziente Nutzung von gereinigtem Abwasser in hydroponischen Systemen, in: Zentralblatt für Geologie und Paläontologie Teil I, 95-104

Bürgow G. (2014). Urban Aquaculture. Water-senitive transformation of cityscapes via blue-green infrastructure, in: Schriftenreihe der Reiner Lemonie-Stiftung, Shaker Verlag, Aachen

DIN 19650 (1999). Bewässerung. Hygienische Belange von Bewässerungswasser, Beuth Verlag, Berlin, Ref. Nr. DIN 19650 : 1999-02

Dolata U. (2011). Wandel durch Technik. Eine Theorie sozio-technischer Transformation, Campus Verlag, Frankfurt am Main

Jenkins-Smith H. C., Sabatier, P. A. (1994). Evaluating the Advocacy Coalition Framework, in: Journal of Public Policy, 14 (2), 175-203

Kluge T., Schramm E. (2002). Regional Approaches to Sustainable Economy: Potentials and Limits. Experiences from German Case-Studies, in: ISOE-Materialien Soziale Ökologie, 19

Mollinga P. P. (2008). Water, Politics and Development: Framing a Political Sociology of Water Resources Management, in: Water Alternatives, 1 (1), 7-23

Mohr M., Ebert B., Schramm E., Germer J., Bürgow, G. (2018). Nutzung des Ablaufs eines Klärteichs zur Gemüseproduktion im Landkreis Gifhorn, Fraunhofer IGB, Stuttgart

Mohr M., Günkel-Lange T., Fischer M., Germer J., Winker M. (2019). Water reuse in hydroponic systems: results from four European feasibility studies, IWA-Conference Paper

Ott R., Trapp J. H., Schramm E. (2017). Koordinationsbedarfe und -optimierungen, in: Winker M., Trapp J. H. (Hrsg.): Wasserinfrastruktur: Den Wandel gestalten. Technische Varianten, räumliche Potenziale, institutionelle Spielräume, Edition Difu, Band 16, pp. 207-218

Schramm E., Beythien U., Dockhorn T., Ebert B., Fischer M., Mohr M., Wieland A., Winker M., Zimmermann M. (2019). Wasserwiederverwendung zur landwirtschaftlichen Nutzung in hydroponischen Systemen: Anforderungen an die Qualitätssicherung. Zentralblatt für Geologie und Paläontologie Teil I, 73-82

Werle R. (2005). Institutionelle Analyse technischer Innovation, in: Kölner Zeitschrift für Soziologie und Sozialpsychologie (KZfSS), 57 (2), 308-332

Zapf W. (1994). Über soziale Innovationen. In: Wolfgang Zapf (Hg.): Modernisierung, Wohlfahrtsentwicklung und Transformation. Soziologische Aufsätze 1987 bis 1994, Ed. Sigma, Berlin, pp. 23-40

ZBG (2017). Kennzahlen für den Betriebsvergleich im Gartenbau. Gruppenübersicht 2017 - Vorauswertung. Zentrum für Betriebswirtschaft im Gartenbau, Hannover

Establishment of a national learning platform for direct potable reuse in South Africa

Lakesh Maharaj[1,2], *Megan Schalkwyk*[1], *Mluleki Mnguni*[1]
[1]*Umgeni Water, Pietermaritzburg, South Africa*
[2]*University of KwaZulu-Natal, Durban, South Africa*

South Africa has been severely impacted by the drought over the last four years resulting in the need for water utilities to consider alternative raw water sources to meet the potable water demand. Umgeni Water is in the process of installing a 2Ml/d direct potable reuse demonstration plant at the Darvill Wastewater Works in Pietermaritzburg, KwaZulu-Natal (KZN).

The main expectation from this study is for the future implementation of direct reuse as a sustainable potable water source in South Africa with full public support for the technology and operational effectiveness, and the final water quality. Other impacts include the development of extensive process expertise in the selection of appropriate treatment technologies and optimized operating conditions for the removal of microorganisms and emerging contaminants as well as future research areas to be considered in the field of DPR.

The demonstration plant presents an opportunity for the establishment of a national learning platform in South Africa. Visitors will be able to interact with the process and learn about the specific technologies through plant tours, presentations and visual demonstrations in a classroom environment by various internal specialists. The architectural design was aimed at public buy-in and especially to address their negative perceptions and concerns.

Keywords: water reuse; direct potable reuse; public perceptions; demonstration plant; reuse technology.

Introduction

Water reuse for potable purposes involves the reclamation of wastewater for drinking purposes after it has undergone advanced treatment to produce water that is safe for human consumption. Public perception of wastewater recycling in South Africa for direct potable reuse is highly variable due to the perceived health risk associated with Direct Potable Reuse (DPR).

Adewumi *et al*. (2009) conducted a Water Research Commission (WRC) study (Project No: K5/1701) and the key recommendations pertaining to public perceptions and awareness of reuse are summarised below:

(i) If municipalities are considering supplying reused water to the communities, they first have to demonstrate competency and proven consistent supply of other services to increase public trust.

(ii) An integrated water reuse education/awareness programme would be beneficial for potential consumers to understand wastewater reuse. This programme can be enhanced using case studies of wastewater reuse in other communities.

The Department of Water Affairs published the National Water Resources Strategy 2 (NWRSII): National Strategy for Water re-use in 2013 which has encompassed the above recommendations in a more holistic approach to water management. A short term WRC project (KV320/13) was conducted by van Niekerk and Schneider (2013) to generate a sector discussion document for the implementation of the water re-use strategy. The authors noted that public perceptions and community acceptance of direct re-use of treated wastewater remains a challenge to direct re-use.

Sgroi *et al*. (2018) stated that a holistic approach, that takes into account all the reuse factors (political, decisional, social, economic, technological and environmental factors) is needed for a sustainable water reuse implementation. Marks (2006) conducted research on the social effects of implementing innovative solutions to sustainable water management in the United States and Australia. The research

showed that there needs to be greater dialogue throughout all communities and relevant stakeholders. He noted that full transparency is required at these dialogues.

Binz *et al*., (2016) focused on the implementation of reuse schemes in California where the understanding of reuse acceptance as a complex socio-technical development process was successfully addressed through a 40-year-long system building process. Examples of some of the forms of institutional work that is required is shown in Table 1. Smith *et al*., 2017 indicated that such efforts will allow the field to move past the view that deeply entrenched emotional reactions are fixed, and improve understandings of how they can potentially be shifted through long-term societal legitimation and narrative building processes.

Table 1: Selected examples of forms of institutional work, related to public engagement around water reuse (adapted from Binz et al., 2016 and cited by Smith et al., 2017)

Form of institutional Work	Examples related to water reuse
Changing normative associations	Associating water reuse with positive applications instead of its source
Constructing normative networks	Creating independent review panels for reuse schemes; certification processes for treatment technologies or water quality
Mimicry	Selling bottles recycled water alongside spring water
Educating	Providing information about treatment processes; publishing results from water testing; conducting tours of treatment plants
Valorising and demonising	Giving awards to reuse schemes, or the people/organisations associated with them; using celebrities to promote recycled water
Mythologizing	Outlining the history of a well known “great” reuse scheme
Imagery	Images of children drinking or playing in clean water; using evocative positive terminology such as “water recycling”

Smith *et al*. (2017) conducted a review of public responses to direct reuse in California. The review concludes that critics can employ the use emotive language to discourage community acceptance by emphasising health risks and possible economic downturn due to negative imagery. An example of this was Toowoomba where a group called Citizens Against Drinking Sewage incited the community with negative imagery (Toowoomba meaning Garden City being replaced by Poowoomba)’ in order to appeal directly to residents' affective reactions by emphasising potential health risks as well as concerns over the town's image.

Smith *et al*. (2017) review also showed that some significant advancements in thinking in this field stem from the increasingly sophisticated understanding of the 'yuck factor' and the role of such pre-cognitive affective reactions in shaping responses. Overall, the study revealed that much of the work in this area has benefited from strong engagement with other related literature (risk perception, behavioural psychology, socio-technical theory, etc.) and future research should continue to promote cross-fertilisation, especially on the aspect of understanding affective reactions.

These preliminary literature studies will assist towards the development of a draft methodology for addressing public perceptions and acceptance of the direct re-use at the Darvill DPR demonstration plant.

Darvill DPR demonstration plant

Umgeni Water commissioned and completed a number of projects on water reuse and these have provided information on the process technology selections for a direct reuse plant at the Darvill site. A 2Ml/d direct reuse demonstration plant was constructed and consists of a conventional and advanced water treatment plant (ATP). The conventional process includes coagulation, flocculation, lamella clarification and rapid gravity filtration. The ATP consists of ultrafiltration, advanced oxidation with hydrogen peroxide and ozone, granular or biologically activated carbon (GAC/BAC) filtration followed by onsite electrolytic chlorination (OSEC) for disinfection of the final water. Figure 1 shows the overall block flow diagram for the advanced portion of the demonstration plant.

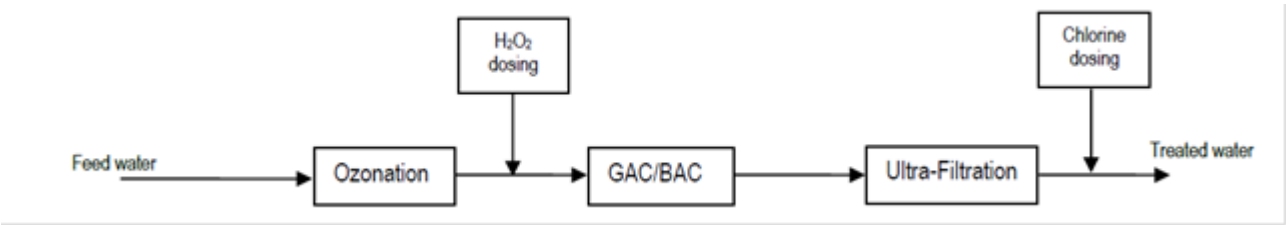


Figure 1: Block Flow Diagram of the Darvill WW Direct Potable Reuse Demonstration Plant

Umgeni Water proposed a design concept for the new classroom in the ATP building (Figure 2) where various stakeholders would be invited during plant tours. The

concept was envisioned to have clean sharp lines to emote precision and sterility. Whilst, the wood and organic features evoke images of natural clean water.

Figure 2: Darvill DPR Plant – Interactive Classroom

PUBLIC ENGAGEMENT PROTOCOL

- To develop practical public acceptance strategies for a DPR plant that is aligned to national and international best practice.
- To incorporate some of the institutional work and examples considered by Binz *et al.* 2016 and other studies discussed.
- To invite external stakeholders to the Darvill DPR demonstration plant for annual National Forum to discuss reuse technology and operational issues,
- Community and external stakeholder engagement will entail several levels of education from young children, primary and secondary school groups, tertiary institutions and academics, the general public, community and political leaders, local and national government, various specialists, including visitors from outside KZN.
- Visitors will be able to view and be educated on the specific selection of treatment technology, undertake plant tours, attend presentations and visual demonstrations in a classroom environment by various UW specialists working on the project.
- Use of questionaires and discussion forums to formulate acceptance strategies.
- To gradually gain the buy-in of the public and especially to address their negative perceptions and concerns.
- A water reuse master class will be considered as one of the annual initiatives.
- To increase the water reuse network for the sector by establishing the KwaZulu-Natal Water Reuse Chapter.

Conclusions

The Darvill DPR demonstration plant presents an opportunity for establishing a national learning platform in South Africa. Umgeni Water aims to lead this initiative over the next five years during the initial commissioning and operation of the DPR demonstration plant. It is envisaged that the annual national forum sessions will be utilized for engaging with all stakeholders and slowly sensitising everyone on the issues and strategies that are in-place by Umgeni Water and the research team.

Acknowledgements

The researchers would like to acknowledge the Water Research Commission (WRC) of South Africa and Umgeni Water for co-funding the project.

References

1. Adewumi,J.R., Ilemobade, A.A., and van Zyl, J.E. (2009). Treated wastewater reuse in South Africa: Overview, potential and challenges. School of Civil Engineering. University of Cape Town, South Africa. Resources, Conservation and recycling, pp. 221-231.
2. Binz, C., Harris-Lovett, S., Kiparsky, M., Sedlak, D.L. and Truffer, B. (2016). The thorny road to technology legitimation — Institutional work for potable water reuse in California, Technological Forecasting & Social Change, 103, pp. 249-263.
3. Marks, J.S. (2006).Taking the public seriously: the case of potable and non potable reuse, Desalination 187, pp.137-147.
4. Metcalf, G. Pillay, L. Murutu, C. Chiburu, S., Gumede, N and Gaydon P., (2014). Wastewater reclamation for potable reuse Volume 2: Integration of MBR technology with advanced treatment processes, Water Research Commission Report No.T611/14, p88-89.
5. Metcalf, G. Pillay, L. Murutu, C. Chiburu, S., Gumede, N and Gaydon P. (2014). Wastewater reclamation for potable reuse Volume 1: Evaluation of membrane bioreactor technology for pre-treatment, Water Research Commission Report No.1894/1/14, p.67-68.

6. Sgroi, M., Vagliasindi, F.G.A. and Roccaro, P. (2018). Feasibility, sustainability and circular economy concepts in water reuse, Current Opinion in Environmental Science & Health, 2, pp.20-25.
7. Smith, H.M., Brouwer, S., Jeffrey, P. and Frijns J. (2018). Public responses to water reuse - Understanding the evidence, Journal of Environmental Management, 207 pp.43-50.
8. Van Niekerk, A.M and Schneider, B. (2013). Implementation plan for direct and indirect water re-use for domestic purposes – sector discussion document, WRC Report No. KV 320/13, pp.17-33.

Promoting waste water reuse through a Reclaimed Water Master Plan in a Local Water Administration (Consorci Besòs Tordera)

Begoña Martínez López, Reclaimed Water Program Manager, Consorci Besòs Tordera, Granollers, Barcelona; Pere Aguiló Martos, Operations Director, Consorci Besòs Tordera, Granollers, Barcelona

Abstract:

As a result of the water stress that lashes Mediterranean arch, CBT has developed its own Reclaimed Water Master Plan (RWMP) The aim of the RWMP is the detection, and quantification of the potential of reclaimed water demands in the Besòs and Tordera basins in order to plan not only the amount and the technological requirements of reclaimed water facilities but where they fit in the territory according to sustainable and economical constrictions.

Keywords: Reclaimed water, Reclaimed Water Master Plan, Reclaimed Water Site, Cost recovery,

Introduction

Consorci Besòs Tordera (CBT) is a public administration based in Catalonia. During its 30 years of history it has been managing up to 22 Waste Water Treatment Plants (WWTP), with a volume of 34hm³ of raw water treated in 2017. CBT is formed by a cluster of 64 municipalities that are highly populated, concentrating intensive industrial and agricultural water demands. Water scarcity prompts to investigate alternative water resources to mitigate the balance between resources and demands in highly populated areas. Despite the fact that the regulatory framework for water reuse is still different in various parts of the World, management practices in countries of long-lasting water scarcity are evolving due to the imperative needs to obtain additional sources of water, that is the Spanish case where since December 2007 there is a state law (RD1620/2007) that allow the reuse of water for several uses depending on the water quality achieved. On the other hand Europe, has not yet implemented a definitive framework directive of water reuse for the state members, only a recent proposal on minimum requirements for water reuse in agriculture (COM (2018) 337 final). Hence, programs for water reuse or for non-potable water exist and are being implemented in arid parts of the World, where alternative uses are given to reclaimed water. In this context, CBT has developed its

own Reclaimed Water Master Plan (RWMP). The aim of the RWMP is the detection, and quantification of the potential of reclaimed water demands in the Besòs and Tordera basins in order to decide how many reclaimed water sites will be needed, its technological requirements, and also where they will be spotted in the territory according to sustainable and economical constrictions. This RWMP has included different tasks from the identification of reclaimed water demand and characterization of source waters from water treatment plants to the design of the most appropriate Reclaimed Water Sites (RWS) and piping network to transport the reclaimed water to its final user.

Material and Methods

This article presents the methodology developed by CBT to integrate reclaimed water in order to attain a more sustainable water basin management.

- Reclaimed water demands and sources: The demands of the whole basin have been classified following the 5 main end users that the RD1620/2007 identifies for reclaimed water: urban, agricultural, industrial, recreational and environmental uses.

  The urban demands have been estimated by means of personal interviews with each city water manager (mainly council towns). These demands include municipal gardening and street cleaning, urban orchards… Industrial demands have also been approached using specific surveys including the quality requirements of their needs. Recreational water demands have been facilitated by main users (mainly golf courses), council towns and the Catalan Water Agency (CWA). Agricultural demands have been calculated using the specific water demand of each crop type. Finally, environmental demands have been considered mainly, taking into account those areas with higher pressure over groundwater resources, through a specific study of aquifers.

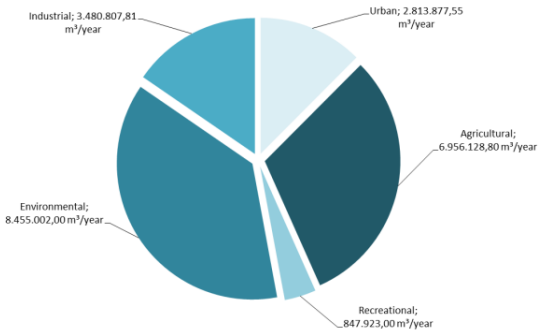


Figure 1: Reclaimed water demand according to use.

- Aquifers' study: In this area 19 aquifers have been identified. These can be classified in 4 main types:
  - Alluvial aquifers.
  - Detritic aquifers below alluvial aquifers.
  - Local aquifers in low permeability media.
  - Karstic aquifers.
- Treatment technologies for RWS: In order to be able to appropriately respond (in quality and volume) to detected demands, 14 RWS have been planned including two types of regeneration systems.

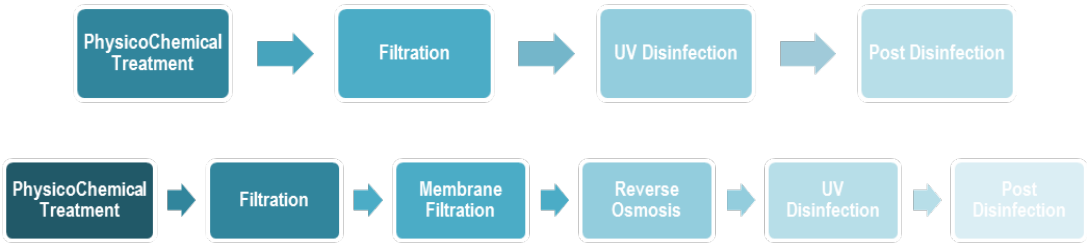


Figure 2: Selected regeneration systems

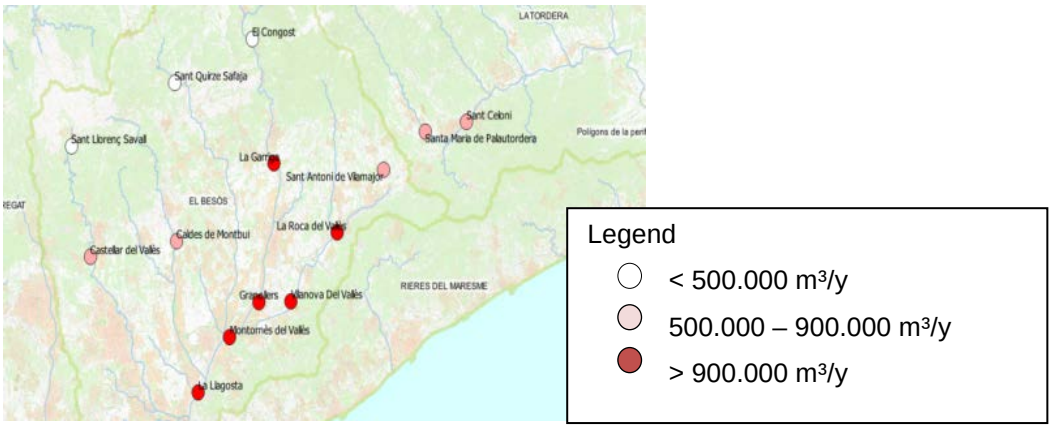


Figure 3: Territorial deployment of RWP

RWS Caldes de Montbui	2,70%
RWS Castellar del Vallès	2,59%
RWS Congost	0,15%
RWS Granollers	6,03%
RWS La Garriga	5,58%
RWS La Llagosta	45,45%
RWS La Roca del Vallès	4,05%
RWS Montornès del Vallès	16,83%
RWS Sant Antoni de Vilamajor	6,02%
RWS Sant Celoni	0,17%
RWS Sant Llorenç Savall	0,03%
RWS Sant Quirze Safaja	0,80%
RWS Santa Maria de Palautordera	1,44%
RWS Vilanova del Vallès	8,16%

Table 2: Distribution of flowrate demands in the different RWP.

Moreover, a network of 165 km length has been raised in order to distribute 70% of reclaimed water.

- Economic study: The economic review covers the minimum income structure that would allow full cost recovery (mandatory through European Water Framework Directive (WFD)) in a 50 year timescale.

  The basis of the economic study settles in the following premises:

  - Total CAPEX divided in three stages (years 1, 6 and 11)
  - Assets replacement cost due to ending of its operating life: Technology replacement in 15y, civil engineering and transport network replacement in 50y
  - Annual 1% growth in operation and maintenance cost
  - Cost recovery finding NPV > 0, being the updating rate 4%

  The fee-rate structure integrates a fixed term and a variable one (€/m³) depending on the flowrate demand. The fixed term is addressed to recover the total investment and to ensure the replacement of the assets at the end of their operating life. Furthermore, the variable cost pursues the recuperation of daily operation costs. Moreover, in order to promote the efficient use of water, the variable term will differ depending on stages of consumption.

Cost Recovery Study	Variable Term	It depends on, - User type - Consumption flowrate
	Fixed Term	It remains, - Constant for each user type - Independent from the consumption flowrate

		Consumption stages
Urban use	1	1 m³ < Consumption < 15.000 m³
	2	15.000 m³ < Consumption < 50.000 m³
	3	Consumption > 50.000 m³
Industrial use		No stage stablished
Agricultural use		
Environmental use		

Figure 4: Cost recovery study's details.

Four different scenarios have been analyzed considering the investment, cost of operation and maintenance for the whole scope of the RWMP.

The matrix for developing different frameworks is presented below,

		Investment subsidy	
		Not Included	Included
Cost of transport network	Included	Framework 1	Framework 2
	Not Included	Framework 4	Framework 3

Figure 5: Studied scenarios matrix

Results and Discussion

Any Master Plan has to follow a well-known structure, but there are non-avoidable singularities that irretrievably set a different path in each case. The CBT RWMP tries to

find best place to bring together technological issues and other particular issues like, fragmentation of available water in the WWTP, dispersion of potential users etc.

RWMP ensures efficiency considering the cost of treating and distributing reclaimed water and the necessary investment for this purpose. In this way, 70% of the detected demands will be fulfilled through the transport network and up to 90% of the demands will be fulfilled by a hydrant located in the RWS. This seems to be the best way to equilibrate investments and incomes, those demands located in remote zones or those with minimum volume requirements will not be supplied by a network, but by the RWS' hydrant. Environmental uses are mainly addressed to managed aquifer recharge, in this way, to locate the aquifer recharging areas in the selected aquifers, three constrictions have been followed:

- Distance from water treatment not far than 2,5 km
- Land use has to be compatible with recharging system (preferably far from urban or populated areas)
- Safety criteria between recharging area and existing downstream wells for drinking water uses (this is a distance > than 1 km or retention time > 6 months).

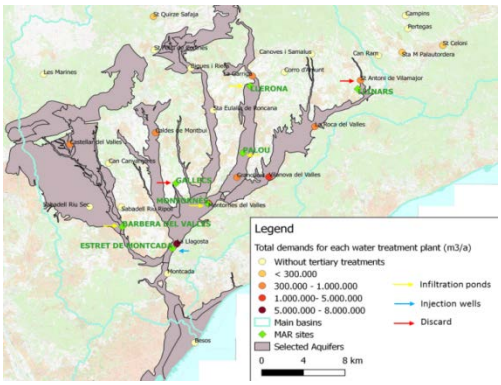


Figure 6: Selected managed aquifer recharge areas

Fee-rate structure is estimated to be homogeneous (for each type of user) through the whole territory, which means a dampening effect between users and municipalities. As explained above, 4 different scenarios have been studied, resulting in the next fee-rate structures,

Table 2: Fee-rate structure for different frameworks.

	Framework 1				Framework 2			
	Fixed term				Fixed term			
	0,637 €/m³				0,582 €/m³			
	Variable Term				Variable Term			
	Industrial	Urbà	Ambiental	Agrìcola	Industrial	Urbà	Ambiental	Agrìcola
Stage 1	0,375 €/m³	0,345 €/m³	0,200 €/m³	0,200 €/m³	0,375 €/m³	0,345 €/m³	0,200 €/m³	0,200 €/m³
Stage 2	0,415 €/m³	0,385 €/m³			0,415 €/m³	0,385 €/m³		
Stage 3	0,455 €/m³	0,415 €/m³			0,455 €/m³	0,415 €/m³		

	Framework 3				Framework 4			
	Fixed term				Fixed term			
	0,479 €/m³				0,535 €/m³			
	Variable Term				Variable Term			
	Industrial	Urbà	Ambiental	Agrìcola	Industrial	Urbà	Ambiental	Agrìcola
Stage 1	0,359 €/m³	0,335 €/m³	0,180 €/m³	0,180 €/m³	0,359 €/m³	0,335 €/m³	0,180 €/m³	0,180 €/m³
Stage 2	0,405 €/m³	0,375 €/m³			0,405 €/m³	0,375 €/m³		
Stage 3	0,445 €/m³	0,405 €/m³			0,445 €/m³	0,405 €/m³		

The study considers 4 different scenarios, taking into account the possibility of public subsidy for the investment,. The network seems to be the best way to get reclaimed water to the end users, but if it is not a feasible possibility due to technical or economical reasons reclaimed water can be collected through the planned hydrant located in each RWS, therefore, scenarios #3 and #4 show the fee-rate with no transport facility at all.

Conclusions

RWMP has achieved previously presented challenges boosting public investment in reclaimed water plants as a way to enable the creation of dialog between all the players (municipal, agricultural and industrial partners). RWMP integrates water reclamations systems into the CBT's WWTP ecosystem.

It confirms the need of introducing reclaimed water in the CBT scope for different purposes, such as agricultural, urban, environmental or industrial uses. In this way the cost recovery study (in four different study cases) confirms the feasibility of engineering a sustainable system through applying different fee-rates.

References

Consorci Besòs Tordera (2019). Pla Director d'Aigües Regenerades (PDAR).

RD1620/2007. https://www.boe.es/eli/es/rd/2007/12/07/1620/con

CEE 2000/60.:
https://www.miteco.gob.es/es/agua/temas/planificacion-hidrologica/marco-del-agua/LegislacionDMA.aspx

Water Reuse Hubs as enablers of water reuse implementation

C.Echevarria[1]; M.Arnaldos[1]; X.Bernat[1]; M.Termes[1,2]

[1] CETaqua, Centro Tecnológico del Agua. Crta. de Esplugues, 75, 08940 Cornellà de Llobregat, Spain

2, Economics and Business Faculty, University of barcelona

ABSTRACT:

Water Reuse represents a key strategic topic in the circular economy framework and a pillar for territorial resilience over climate change. Despite its known benefits (environmental, economic and social) and existing successful worldwide experiences, water reuse is far from its potential and local barriers must be identified. *Water Reuse Hubs*, defined by CETAQUA, will allow giving answer to the need of a new perspective and paradigm for water reuse management, easing infrastructures planning, enhancing the use of reclaimed water and promoting its associated economic and environmental benefits.

Keywords: circular economy; water reuse hubs; barriers; drivers; network

Water reuse drivers and barriers to overcome:

The need to adapt to extreme climatic events, as well as to develop strategies in the circular economy framework, **evidence water reuse as the most sustainable alternative to the use of conventional water resources or seawater desalination in terms of cost and environmental impact**. Additionally, water reuse can be used to enhance the environment through the augmentation of natural/artificial streams, fountains and ponds by helping to meet quantitative and qualitative objectives of surface water or groundwater bodies. These environmental benefits are also translated to economic advantages when a relatively low-energy based produced water is locally guaranteed in quality and quantity for the economic sector uninterruptedly. Water Reuse also presents social benefits by helping to achieve Sustainable Development Goals (SDGs) through the use of appropriate technological solutions for environmental protection and through the enhancement of environmental amenities (landscape irrigation, recreational and green areas irrigation, fire protection systems and natural bodies' status maintenance) and through the fostering of territorial circular economy approaches.

Nevertheless, despite mentioned benefits and the fact that extensive research and development efforts have been invested in the optimization of water reclamation processes, **water reuse implementation is far from its potential and from being a reality in many countries** with water scarcity, particularly in Europe, and it is necessary to study and understand the keys of success as well as failure and to propose integrated solutions that can address them.

Water reuse challenges, or barriers to overcome, can be divided in 4 pillars: Technical, economic, social and governance (Figure 1). Technical issues do not represent anymore a challenge, since technology has a readiness level enough to guarantee any water quality, at least at urban/municipal water reuse stage.

Reclaimed water source (wastewater treated effluents) has raised public awareness on related human health & environmental risks, usually generating misunderstandings and a negative public perception. In this line, **awareness rising campaigns and dissemination activities focused on water reuse benefits with citizens & key end-users are necessary to build trust and credibility on water reuse** (Deloitte, 2015). Moreover, to adapt regulation to establish quality standards for water reuse it is only the beginning, being necessary to: (i) match produced reclaimed water quality and stakeholder's requirements, and (ii) develop risk management strategies to control the whole process and generate the correspondent mitigation strategies to guarantee water safety.

Figure 1 Water Reuse identified barriers

On the other hand, local economic feasibility represents also an important constraint in water reuse projects implementation. **Capital and operational expenditures of switching from a freshwater source to reclaimed water need to be understood and explained** to relevant local and territorial actors and financial opportunities should be explored and maximized. Additionally, in water scarcity regions, reclaimed water is often priced just below the consumer price of drinking water with the aim to make it more attractive to potential users but affecting the ability of cost recovery. **Long term economic feasibility of water resources should be evaluated at macro-scale, taking into account all nonmonetary benefits for sustainable development and integrated water resource management.**

Finally, as stated EPA (2017), key stakeholder's involvement and engagement into **decision-making** in all levels is critical to achieve favorable policy decisions and citizen's acceptance. How to involve them, manage available information, maintain their motivation and address the correct keywords are important factors to take into account (Hartley 2006).

Water Reuse worldwide experiences

Some worldwide experiences can be found in California, Texas or Singapore, and can be taken as references in order to study the success path followed. The **main driver in all these cases is "necessity"**, pushed by water scarcity (Walters, Oelker,

& Lazarova, 1995); nevertheless, **all of them involved from the beginning the main stakeholder's of the territory and performed intense communication and educational campaigns**. The Singapore Public Utility Board (PUB), in 2007, boosted a terminology change regarding reclaimed water and has been essential to improve public acceptance: *wastewater* was recalled *used water,* and *tertiary treated water* was branded as *NEWater* (Allen et al., 2017). Other sites such as in Orange County (California, USA) through the emblematic Groundwater Replenishment System (GWRS), has allowed to consolidate one of the most famous indirect potable reuse (IPR) schemes in the USA. Another example is the Edward C. Little Water Recycling Plant from West Basin Municipal Water District, which allows fit-for-use reclaimed water production for urban, industrial and environmental uses in El Segundo (California, USA). Finally, some experiences have also allowed to demonstrate the technical, economic and social feasibility of direct potable reuse (DPR) schemes such as in Big Spring DPR project (Texas, USA) or the long-term strategy performed in Windhoek, Namibia since 1968.

Water Reuse Hubs implementation to overcome local barriers

As it has been mentioned, information access and its proper communication from the beginning are essential to improve public perception and gain the acceptance of water reuse projects by the whole value chain.

CETAQUA has defined physical-virtual centers of expertise in water reuse focused on gathering real territorial data and translating it automatically into evidences (Figure 2). These centers of expertise have been named *Water Reuse Hubs,* and aim to adapt current water reuse perspective to the present and future needs, in order to unlock local barriers and maximize its potential benefits. Two pillars conform the Water Hubs: (i) the quantification of key indicators to plan for the best water reuse implementation actions to be carried out in a territory; and (ii) the engagement of key stakeholders to co-create and make decisions based on the calculated impacts.

In Spain, Alicante and Sabadell have been selected as potential sites to implement this solution. By interconnecting these different *Reuse Hubs*, it is possible to build up a network where different experiences, point of views and indicators can be exchanged and where the keys of success of each site as well as their business models are evidenced. The specific implementation of these Hubs related to their local challenges will be described as well as the ultimate goals of incremented water reuse in each of the cases. Ultimately, the idea is to act locally to implement water

reuse and scale up a network to achieve global impacts such as consolidate water reuse in Europe.

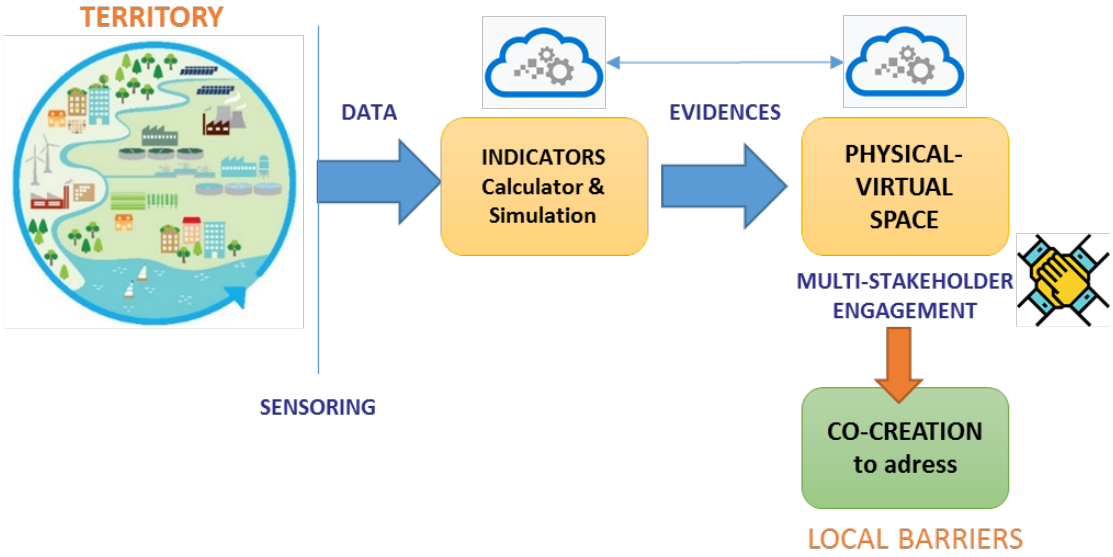


Figure 2 Water Reuse Hub Concept

REFERENCES

Allen, G. et al. (2017) Desalination & Water Reuse; Global Water Intelligence.

BIO by Deloitte. (2015) *Optimizing Water Reuse in the EU, Public Consultation analysis report.*

Hartley, T. (2006) Public Perception

EPA (2017) Potable Reuse Compendium

Compliance of combined nature-based and engineered systems with European water reuse regulations

U. Miehe, D. Wicke, J. Vosse, Kompetenzzentrum Wasser Berlin, Berlin, Germany; D. Sauter, Berliner Wasserbetriebe, Berlin, Germany; A. Brunsch, Erftverband, Bergheim, Germany; I. Nydrioti, NTUA, Athens, Greece

Abstract:

For Antiparos WWTP (Greece), a combination of constructed wetlands (CW) and chlorination, a detailed benchmarking of the achieved effluent quality was performed to assess transferability of the concept within Europe. Despite the mostly high effluent quality, the compliance with national water quality limits for reuse is mostly limited by suspended solids and electric conductivity (E.C.). The combination of the two-stage CWs with chlorination as disinfection achieved a water quality suitable for “restricted irrigation” according to the Greek and French regulation as well as according to the limits proposed by the European Commission (COM337, 2018). Overall, the transfer of treatment concepts across Europe is strongly hindered by the variations in reuse classes, limits and compliance levels.

Keywords: water reuse, constructed wetlands, combined systems, legislation, Europe

Introduction

Increasing demands for high water quality standards in surface waters, for drinking water production and for safe water reuse have driven the search for new solutions and adding tertiary treatment stages. In this context, the European project *AquaNES* focused on the demonstration of treatment schemes combining natural and engineered systems (cNES) for water treatment. Main components are bank filtration, managed aquifer recharge and wastewater treatment systems. This paper focuses on CW with post-disinfection and the evaluation of the investigated system in regard to European water reuse regulations.

Material and Methods

Demonstration sites: Within AquaNES, improved wastewater treatment is realized in demonstration sites combining CW with different technical pre-treatment (primary clarification, conventional activated sludge) or post-treatment (ozonation or

chlorination). For this paper, the demonstration site of Antiparos (Greece) was selected to highlight the methodology for benchmarking.

Antiparos demonstration site: In the Antiparos WWTP, influent undergoes screening, grit removal, flocculation and primary sedimentation. The main treatment step consists of two stages of CWs. The outflow of the second stage of CWs is collected in one sealed stabilization pond. After the pond, the effluent is disinfected by chlorination. Monthly influent and effluent samples have been analyzed for the period February 2016 - January 2019. For the benchmark against the different legal limits for effluent quality, only data from 2018 was selected. Data from 2017 revealed optimization demand on various levels which were adapted in the winter period 2017/18 and strongly improved effluent quality.

Review of EU legislations on water reuse: Results of the demonstration sites are evaluated in regard to European legislations for water reuse. In five countries, water reuse is regulated at a national level: Greece, Spain, Italy, Cyprus and France. Allowed types of water reuse, number of relevant microbiological and physico-chemical water quality parameters and their limits in regard to reuse classes vary considerably. In an attempt to unify minimum requirements for water reuse at a European level, the European Commission recently published a proposal with four different reuse classes and four parameters (COM/2018/337).

Definition of reuse case for comparative study: Furthermore, the regulated reuse purposes included in the different national regulations vary in number and detail of description. Therefore, a direct comparison of quality classes of the different regulations is difficult, as similar reuse purposes might be included in different water quality classes. Consequently, in order to compare the suitability of the reclaimed water for reuse purposes within the national regulations, three specific reuse cases are defined, which can be placed in one of the classes in all regulations (see table 1):

- **Case 1 “Restricted irrigation”**: Irrigation of beans using drip irrigation exclusively (vegetable that is not eaten raw / not in contact of reclaimed water)
- **Case 2 “Unrestricted irrigation**”: Irrigation of tomatoes with no limitation in the irrigation method used (vegetable consumed raw and being in potential contact with reclaimed water)
- **Case 3 “Urban irrigation”**: Irrigation of a public park with restrictions either to the opening hours for the public during irrigation, or to the irrigation method used

Results and Discussion

The comparison of effluent water quality parameters against the legal limits for the Antiparos demonstration site is summarized in tables 2-4. The data set behind the table is the same for all national legislations. Differences in the absolute numbers result from varying compliance levels. Most countries rely on fixed percentiles (Spain 90 %, Italy 80 %, Greece 80 % or 95 %, EC proposal 90 %) and a maximum deviation allowance for single values. In France and Cyprus, all values for *E.Coli* have to be below the given limit meaning that the maximum value is given in the table. For chemical parameters, fixed or variable percentiles are used depending on the country, parameter and the water reuse type, e.g. for restricted irrigation in Greece the 80 % percentile is used for TSS, the 50 % percentile for turbidity and the annual average for TN.

Regarding the individual reuse purposes, the water quality requirements for “restricted irrigation” are in compliance with the French and the Greek regulation as well as with the proposal by the EC. Electrical conductivity is the only parameter exceeding the limit in the Spanish regulation, while it is E.C. and TSS in the Italian one. For Cyprus, the concerned purpose falls into a relatively higher, more restricted quality class than in the other regulations. This is why the limits for most parameters are being exceeded.

For case two “unrestricted irrigation”, TSS is the parameter (as well as E.C.) which exceeds the limit in every single regulation. Furthermore, BOD_5 and COD also exclude reuse for this purpose in all regulations except for Italy (and for Spain – both parameters not included in the Spanish regulation).

Case three “urban irrigation” of a public park is not included in the EC-proposal. For Cyprus, this purpose falls in a comparatively low, less restricted quality class, which is why the limits are mostly met except for the parameter E.C.. TSS is the parameter exceeding the relevant limit in all other regulations. BOD_5 and COD also exceed the limits in the Greek and French regulation, respectively.

Conclusions

The variability of limits for water reuse across European countries poses a barrier for the transfer of treatment concepts for water reuse, resulting in an under-development of the water reuse sector in Europe. Each regulation considers different reclaimed water uses associated with different quality classes and respective definitions. Apart

from defined water reuse classes, regulated parameters and relevant limit values, the national reuse regulations also differ in regard to the compliance requirements, which further complicates evaluations. All in all, the combination of constructed wetland and chlorination, as implemented in Antiparos, does only allow restricted irrigation under the legislations of France, Greece and the EC proposal, mainly due to exceeded TSS and E.C. limits for the unrestricted irrigation and urban irrigation. High values for E.C. in WWTP effluent, originating from poorly desalinated tap water and sea spray, would prohibit most reuse applications in countries whose reuse legislations include this parameter (Cyprus, Italy, Spain).

References

COM337 (2018). Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse. European Commission, Brussels.

DM (2003). Ministry Decree (DM) No. 185. Technical Measures for reuse of wastewater (in Italian). Government of Italy.

JMD (2011). Joint Ministerial Decision No. 145116. Determination of measures, limits and procedures for the reuse of treated wastewater (in Greek). Amendment: JMD (2013) no. 191002. Government of Greece.

JORF (2014). Journal Officiel de la Republique Francaise (JORF) no. 0153. Order of 25 June 2014 amending the order of 2 August 2010 on the use of water from urban wastewater treatment for the irrigation of crops or green spaces (in French). Amendment: JORF (2016) no. 0119 “Arrêté du 26 avril 2016”. Government of France.

JORF (2015) no. 0190 “Arrêté du 21 juillet 2015”, French adaptation of European Urban WasteWater Directive (UWWD, 1991).

K.D.P. (2015). Κ.Δ.Π. No. 379. General terms for waste disposal from wastewater treatment plants in agglomerations with less than 2,000 p.e. (in Greek), and associated regulation of Law 106(I)2002, Government of Cyprus.

Paranychianakis, N. V., Salgot, M., Snyder, S. A. & Angelakis, A. N. (2015). Water Reuse in EU States: Necessity for Uniform Criteria to Mitigate Human and Environmental Risks, Critical Reviews in Environmental Science and Technology. Vol. 45:13, p. 1409-1468.

RD (2007). Royal Decree No. 1620. Legal Framework for the reuse of treated wastewater (in Spanish). Government of Spain.

Table 1 Relevant water quality classes as given in national water reuse regulations and in the EC proposal for the three considered water reuse cases specified above (Source: legal documents of national water reuse legislations, see references)

Country	"Restricted irrigation"	"Unrestricted irrigation"	"Urban irrigation"
Cyprus	2	1	3
France	B	A	A
Greece	3	2	1[(1)]
Italy	1	1	1
Spain	2.2	2.1	1.2
COM337 (2018)	C	A	n.a.[(2)]

[(1)]In the Greek regulation sprinkler irrigation is prohibited for "urban irrigation" purposes. / [(2)]The EU proposal includes only agricultural irrigation purposes for water reuse.

Table 2 Case 1 "Restricted irrigation": Antiparos effluent concentrations and number of samples exceeding the limits (Bold values: limit exceeded).

Compliance with national regulation of:	class	*E. coli*		BOD_5		COD		TSS		EC		TN		NH_4		TP		$Cl._{res.}$	
		cfu/100mL		mg/L		mg/L		mg/L		µS/cm		mg/L		mg/L		mg/L		mg/L	
Cyprus	**2**	0		**20**		**71**		**27**		**6,414**								0	
# exceedings of limit / max. dev.		**0**	**0**	**9**	***n.l.***	**2**	***n.l.***	**6**	***n.l.***	**1**	**1**							**0**	**0**
France	**B**	0				69		27											
# exceedings of limit / max. dev.		**0**	**0**			**0**	**0**	**8**	**0**										
Greece	**3**	0		19				27				16		*n.l.*				*n.a.*	
# exceedings of limit / max. dev.		**0**	***n.l.***	**0**	***n.l.***			**0**	***n.l.***			**0**	***n.l.***						
Italy	**1**	0		17		55		**15**		**6,414**		16		0.59		0.20		0	
# exceedings of limit / max. dev.		**0**	**0**	**2**	**2**	**0**	**0**	**4**	**4**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Spain	**2.2**	0						27		**6,414**		*n.a.*				*n.a.*			
# exceedings of limit / max. dev.		**0**	**0**					**0**	**0**	**1**	***n.l.***								
COM337 (2018)	**C**	0		19				27											
# exceedings of limit / max. dev.		**0**	**0**	**0**	**0**			**0**	**0**										
Total number of samples (effluent)		10		10		10		10		1		10		2		10		4	

Table 3 Case 2 "Unrestricted irrigation": Antiparos effluent concentrations and number of samples exceeding the limits(Bold values: limit exceeded).

Compliance with national regulation of:	class	*E. coli**		BOD_5		COD		TSS		EC		TN**		NH_4**		TP		$Cl._{res.}$	
		cfu/100mL		mg/L		mg/L		mg/L		µS/cm		mg/L		mg/L		mg/L		mg/L	
Cyprus	**1**	0		**20**		**71**		**27**		**6,414**								0	
# exceedings of limit / max. dev.		**0**	**0**	**9**	***n.l.***	**2**	***n.l.***	**6**	***n.l.***	**1**	**1**							**0**	**0**
France	**A**	0				**76**		**31**											
# exceedings of limit / max. dev.		**0**	**0**			**6**	**6**	**6**	**6**										
Greece	**2**	0	0	**19**				**27**				16		*n.l.*				**0**	
# exceedings of 80-perc. / 95-perc.		**0**	**0**	**9**	**--**			**6**	**--**			**0**	**--**					**0**	**--**
Italy	**1**	0		17		55		**15**		**6,414**		16		0.59		0.20		0	
# exceedings of limit / max. dev.		**0**	**0**	**2**	**2**	**0**	**0**	**4**	**4**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Spain	**2.1**	0						**27**		**6,414**		*n.a.*				*n.a.*			
# exceedings of limit / max. dev.		**0**	**0**					**4**	**1**	**1**	***n.l.***								
COM337 (2018)	**A**	0		**21**				**27**											
# exceedings of limit / max. dev.		**0**	**0**	**9**	**2**			**6**	**4**										
Total number of samples (effluent)		10		10		10		10		1		10		2		10		4	

*GR: (E. coli) Two limits must be met by 80 & 95-percentile; there is no maximum deviation limit / **GR: (TN & NH4) Limits for reuse in non-nitrat vulnerable zones

Table 4 Case 3 "Urban irrigation": Effluent concentrations and number of samples exceeding the limits (Bold values: limit exceeded).

Compliance with national regulation of:	class	*E. coli**		BOD_5		COD		TSS		EC		TN		NH_4		TP		$Cl._{res.}$	
		cfu/100mL		mg/L		mg/L		mg/L		µS/cm		mg/L		mg/L		mg/L		mg/L	
Cyprus	**3**	0		20		71		27		**6,414**								0	
# exceedings of limit / max. dev.		**0**	**0**	**0**	***n.l.***	**0**	***n.l.***	**0**	***n.l.***	**1**	**1**							**0**	**0**
France	**A**	0				**76**		**31**											
# exceedings of limit / max. dev.		**0**	**0**			**6**	**6**	**6**	**6**										
Greece	**1**	0	0	**19**				**27**				**16**		0.59				**0**	
# exceedings of 80-perc. / 95-perc.		**0**	**0**	**9**	**--**			**7**	**--**			**6**	**--**	**0**	**--**			**0**	**--**
Italy	**1**	0		17		55		**15**		**6,414**		16		0.59		0.20		0	
# exceedings of limit / max. dev.		**0**	**0**	**2**	**2**	**0**	**0**	**4**	**4**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Spain	**1.2**	0						**27**		*n.a.*		*n.a.*				*n.a.*			
# exceedings of limit / max. dev.		**0**	**0**					**4**	**1**										
COM337 (2018)	**n.a.**																		
Total number of samples (effluent)		10		10		10		10		1		10		2		*10*		4	

GR: Limit for TC instead of E. coli for class 1 (Two limits must be met by 80 & 95-perc.); there is no maximum deviation limit / **GR: Sprinkler irrigation is prohibited /***SP: EC only applicable for "Agricultural uses"

Capacity Development for Wastewater Management and Water Reuse in Informal Partnerships in Northern Namibia

Fanny Frick-Trzebitzky, Martin Zimmermann, Thomas Kluge, ISOE – Institute for Social-Ecological Research, Frankfurt am Main, Germany; frick@isoe.de

Abstract: Municipal partnerships for wastewater treatment have thus far emerged out of need in self-organised manner. What is the potential for such partnerships, and how can they be designed and implemented to improve capacity development in the Namibian context? Experiences from EPoNa project show a need for creating synergies. Outsourcing of public responsibilities in provision of services has led to outsourcing of both technology and knowledge/ capacity, reinforcing low levels of institutional capacity within the municipalities, and creating dependency on consultants. The partnership established created a space for both formal and informal mutual learning. A great potential for developing and strengthening capacities and reducing municipal costs for wastewater treatment was identified. How this can be used will depend on the long-term commitment of town councils to work in partnership for which political backing is key.

Introduction

The combination of urbanisation and climate change impacts exacerbates challenges in wastewater management in arid regions. Environmental health risks from poorly treated wastewater are particularly high where the water cannot be discharged into larger water bodies during the dry season. Overflowing of wastewater ponds during the rainy season leads to flooding of inhabited areas with untreated water and associated health risks. Municipalities in Northern Namibia face multiple challenges in managing these risks under conditions of continued rise in wastewater quantities to be managed, limited technical capacities, insecure and unreliable financial assistance from the state and new legal obligations to be met.

Water supply is also an issue in arid regions such as Namibia. Here direct reuse is the only option to reduce the pressure on wastewater ponds while also reducing freshwater supply needs. Only a technically sound treatment can enable such reuse to be safe. Pioneering have been developed for instance in Spain (Domènech et al. 2014).

Government support, legal and regulatory framework, institutional arrangements, financial arrangements and socio-cultural attitudes towards reuse are all considered part of an enabling environment for wastewater reuse (Reymond et al. 2018; Di Mario et al. 2018). Participation as well as political alliances are key to implementing innovative approaches and sustainable management practices (Reymond et al. 2018; Kjellén 2018; Furlong et al. 2016). This is particularly important because generating resources from wastewater is generally not profitable in economic terms (Di Mario et al. 2018). Innovative reuse systems tend to be developed in isolated, highly subsidized pilot projects that are difficult to upscale (Reymond et al. 2018).

Practical examples of municipal cooperation in water reuse suggest its potential in supporting capacity development. Here ‘wastewater treatment plant partnerships’ are understood as semi-formal networks of knowledge exchange and for sharing special technical equipment. The research question addressed here is therefore: What is the potential for municipal partnerships in reuse, and how can they be designed and implemented to improve capacity development for water reuse in the Namibian context?

Method

A transdisciplinary mode of research was applied using an approach inspired by so-called real-world laboratories. Real-world interventions (real-world experiments) are the core of real-world laboratories and are framed by co-design, co-production and co-evaluation. The three steps are in a flexible order and usually repeated several times (Wanner et al. 2018). The approach was operationalized in the EPoNa project by developing and piloting the technical approach in Outapi in close cooperation with the town council. The establishment of a partnership for wastewater treatment among neighbouring municipalities and regional authorities in Northern Namibia served to address economies of scale and create an enabling environment for upscaling of pond enhancement for reuse in the region.

In order to address the research question, we conducted a generic analysis of the emergence and performance of wastewater treatment plant partnerships in Germany and in Northern Namibia. Inner and outer perspectives are combined by looking at partnerships in Germany through documents and expert interviews, and at the partnership formed in Namibia based on project documents and own account of the process.

Results and discussion

Municipal partnerships for wastewater management in Germany were initiated in the 1960s, in the context of increasing regulation and associated legal obligations for wastewater treatment for which municipalities were poorly equipped. Accordingly, the main purpose of the first partnerships was to facilitate knowledge exchange and focused trainings for technicians and senior technicians who were being qualified while on the job. Over time more and more partnerships formed and training programs became more institutionalized with specialized and professionalized curricula drafted and coordinated under the umbrella organization DWA. Other formats of knowledge exchange have remained rather informal and decentralized, with cost sharing among all partners, rotating meeting hosts and voluntary ‘teachers’ providing inputs. As of 2017, 313 wastewater treatment plant partnerships exist in Germany, operating 7400 treatment plants.

In the context of the EPoNa project regular workshops have been held with project partners and municipal and regional councils in Northern Namibia since April 2017 in order to form a wastewater treatment plant partnership (WWTPP) within these municipalities. The overall objective of the WWTPP is to address challenges in wastewater management with mutual help and beneficial possibilities. In the initial phase, a specialist from EGLV and chairman from two German WWTPPs, visited several municipalities in order get an overview on their situations and challenges. His reports served as a basis for identification of potential benefits of the WWTPP. The following challenges have been identified in his reports and subsequent discussions in the partnership:

Firstly, general financing problems and insufficient maintenance lead to mismanagement and eventually overflowing of ponds. On average, less than half of the population is connected to municipal wastewater systems. Household costs for wastewater infrastructure and services are a barrier to wider coverage. However, municipalities struggle with lowering the fees as there is no governmental budget to support maintenance of the treatment plants which would enhance their longevity and capacity.

Secondly, a lack of capacity development and specialized training furthermore lead to mismanagement of the wastewater ponds and puts a further constraint on budgeting. In some municipalities, for instance, trainings have to be paid from the

same financial pool as maintenance of the treatment system. Mismanagement of wastewater ponds in form of omissions to desilt ponds contributes to blocking of pumps and overflowing, especially in the rainy season.

Thirdly, many citizens are not aware about what not to dispose through the wastewater systems, nor about reuse potential of treated wastewater. Plastic waste and hygiene articles can be found in pipes and ponds. Other inflows that affect the water quality are detergents from car wash and fat from restaurants. Reuse of the treated wastewater is difficult to realize in the municipalities, mainly because cultural views, societal disapproval and insufficient water quality are considered as hindering factors.

These challenges were addressed in thematic discussions based on expert inputs on water reuse, joint procurement, pump maintenance and water quality. The WWTPP was increasingly formalized over time, as summarized in figure 1. The first committee of the WWTPP was appointed at the 4th workshop in October 2018.

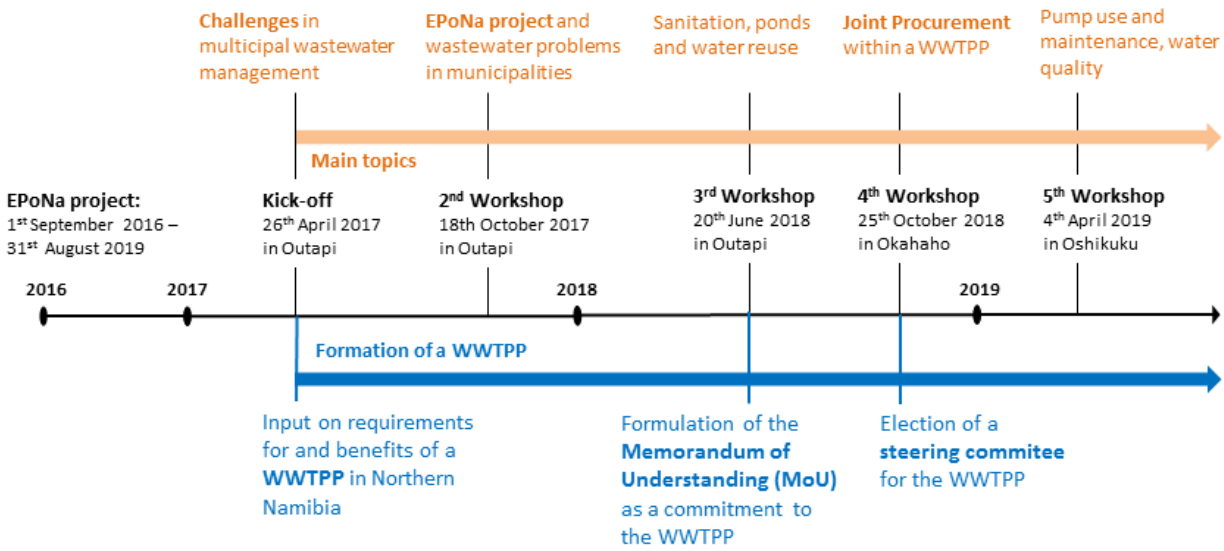


Figure 1: Formalisation of the wwtpp in North Central Namibia

A comparison of the two cases (see table 1) reveals key aspects of governance context for capacity development on water reuse in informal networks.

Table 1: Comparison of scopes and formats of knowledge exchange in wwtpps in Germany and North Central Namibia

	Germany	**North Central Namibia**
Incentives/drivers for partnering	Changing legal requirements for wastewater treatment combined with lack of capacity at municipal level	Enhanced environmental risk from insufficiently managed wastewater in context of limited capacity at municipal level and dynamic population growth
Formats and topics of knowledge exchange	Informal learning in rotational meetings on operational topics; establishment of formal education/ apprenticeship system	Semi-formal meetings (workshops) on operational and management topics
Institutional context and design	Self-organised networks of municipalities; voluntary teachers; collaboration with DWA (umbrella organization on water management in Germany) on formalized capacity development program	Network of village, regional and municipal councils initially coordinated by research partners; external expert inputs
Economies of scale	Capacity development at national and local/regional scales (apprenticeship curricula; direct knowledge exchange); sharing of equipment such as specialized tools and machinery	Joint procurement envisioned; potential for reducing municipal costs by appointing consultants and contractors jointly identified but not yet implemented

The German experience supports theses on informal, organizational and social learning in adaptive governance according to which informal spaces for information and knowledge exchange need to complement formal top-down information flows (Pahl-Wostl 2019). In addition to learning, the material exchange of tools has contributed to capacity development in the WWTPP cases in Germany.

In the EPoNa case, structural limitations to capacity development at municipal level become visible from the process of network establishment that the WWTPP can help address. Most importantly, the institutional context of devolution of responsibility for municipal wastewater management in Northern Namibia, where most municipalities and their governments have only existed for less than two decades, has led to outsourcing of all major planning steps from initial design to technical maintenance. In this context of dependency on consultants, options and opportunities for sharing costs by exchanging tools and machines are barely visible to municipal decision-makers. Further stock-taking and situational analyses are needed to start collaborating on specific technical items and associated tendering. Moreover, council members increasingly raised the issue of political backing needed for a meaningful

commitment to the WWTPP. This will involve broad awareness raising in the wider public, as well as among local politicians.

Conclusion

Experiences from EPoNa project show a need for creating synergies. Outsourcing of public responsibilities in provision of services (here: wastewater treatment/ sanitation) has led to outsourcing of both technology and knowledge/ capacity, reinforcing low levels of institutional capacity within the municipalities, and creating dependency on external consultants. The partnership established created a space for both formal and informal mutual learning. A great potential for developing and strengthening capacities and reducing municipal costs for wastewater treatment was identified. How this can be used will depend on the long term commitment of town councils to work in partnership for which political backing is key.

Publication bibliography

Di Mario, Luca; Rao, Krishna; Drechsel, Pay (2018): The enabling environment and finance for resource recovery and reuse. 19. In Miriam Otoo, Pay Drechsel (Eds.): Resource recovery from waste. Business models for energy, nutrient and water reuse in low- and middle-income countries. London, New York: Earthscan from Routledge Taylor & Francis Group, pp. 777–800.

Domènech, Laia; March, Hug; Vallès, Maria; Saurí, David (2014): Learning processes during regime shifts:Empirical evidence from the diffusion ofgreywater recycling in Spain. In : Environmental Innovation and Societal Transitions, vol. 107.

Furlong, Casey; Silva, Saman de; Guthrie, Lachlan; Considine, Robert (2016): Developing a water infrastructure planning framework for the complex modern planning environment. In *Utilities Policy* 38, pp. 1–10. DOI: 10.1016/j.jup.2015.11.002.

Kjellén, Marianne (2018): Wastewater Governance and the Local, Regional and Global Environments. In *Water Alternatives* 11 (2), pp. 219–237.

Pahl-Wostl, Claudia (2019): The role of governance modes and meta-governance in the transformation towards sustainable water governance. In *Environmental Science & Policy* 91, pp. 6–16. DOI: 10.1016/j.envsci.2018.10.008.

Reymond, Philippe; Abdel Wahaab, Rifaat; Moussa, Moustafa Samir; Lüthi, Christoph (2018): Scaling up small scale wastewater treatment systems in low- and middle-income countries. An analysis of challenges and ways forward through the case of Egypt. In *Utilities Policy* 52, pp. 13–21. DOI: 10.1016/j.jup.2018.03.008.

Wanner, Matthias; Hilger, Annaliesa; Westerkowski, Janina; Rose, Michael; Stelzer, Franziska; Schäpke, Nico (2018): Towards a Cyclical Concept of Real-World Laboratories. A Transdisciplinary Research Practice for Sustainability Transitions. In *disP - The Planning Review* 54 (2), pp. 94–114. Available online at disP - The Planning Review.

Development of novel treatment concepts based on sequential biofiltration for indirect potable reuse

U. Hübner, K. Hellauer, J. Müller, and J.E. Drewes

Chair of Urban Water Systems Engineering, Technical University of Munich, Am Coulombwall 3, 85748 Garching, Germany; u.huebner@tum.de

Abstract:

The concept of sequential biofiltration (SBF) combines two infiltration steps with an intermediate aeration to establish favorable oxic and carbon-limited conditions for enhanced biotransformation of trace organic chemicals (TOrCs). This study provides results from combination of SBF with pre-treatment by coagulation, flocculation and sedimentation (CFS), intermediate ozonation, and activated carbon post-treatment for water reuse. Removal of DOC, particularly humic substances by CFS reduced consumption of dissolved oxygen in biofilters in addition to efficient removal of total phosphorus. Multi-barrier systems with activated carbon and/or intermediate ozonation showed highly efficient removal of most TOrCs. By applying smart combinations, synergies of different processes can be maximized.

Keywords: Granular activated carbon; indirect potable reuse; ozonation; sequential biofiltration; trace organic chemicals

Introduction

The removal of pathogens (i.e., viruses; antibiotic resistant bacteria) and trace organic chemicals (TOrCs) is critical for indirect potable reuse schemes, as these contaminants cannot be completely removed through current wastewater treatment practices (Glassmeyer et al., 2005). Significant removal of such contaminations has been demonstrated in managed aquifer recharge (MAR) systems (Amy and Drewes, 2007). However, the physical footprint and retention times of such systems limit applications in land-locked locations. Thus, the sequential managed aquifer recharge technology (SMART) was developed, where two MAR systems are combined with an intermediate aeration step (Regnery et al., 2016; Hellauer et al., 2018). Oxic and BDOC limited conditions in the second infiltration step facilitate the growth of microorganisms that are capable of degrading many TOrCs within a few days of subsurface retention time.

In order to transfer the positive results from SMART applications into a highly controlled above-ground treatment system, the concept of sequential biofiltration (SBF) was introduced. SBF systems consist of a backwashable first filter stage to reduce BDOC followed by intermediate aeration and a second filter step operated under oxic and carbon-limited conditions for enhanced TOrC removal. Results clearly demonstrated the benefits of SBF compared to conventional single-stage biofiltration with similar empty bed contact times (EBCT) for TOrC removal (Müller et al., 2017). However, some highly persistent compounds like carbamazepine are not removed by SBF. With respect to indirect potable reuse, additional barriers applying different mechanisms like oxidation and/or adsorption are needed to provide efficient elimination of TOrCs with varying physicochemical properties. In this study, combinations of SBF with coagulation, flocculation and sedimentation as pre-treatment, intermediate ozonation as well as activated carbon filtration as post-treatment were evaluated to develop a cost-efficient multi-barrier treatment concept for indirect potable reuse.

Material and Methods

The experimental setup consisted of two parallel SBF trains with two filter columns operated in series under oxic conditions (Müller et al., 2017). One system consisted of an anthracite column (A1/A2, length (l): 1.05 m; inner diameter (ID): 0.15 m, EBCT: 45 min) and a subsequent sand column (S1/S2/S3; l: 0.95 m; ID: 0.1 m, EBCT: 200 min). System A1+S1 was operated as a reference SBF system with intermediate aeration (SBF(Air)) and fed with tertiary effluent from the WWTP effluent Garching, Germany. Experiments were conducted in two phases:

1. A share of A1 effluent was ozonated and fed into column S2 (SBF(O_3)). In addition, 3 paired rapid small scale column tests (RSSCTs) were operated, fed with WWTP effluent, SBF(Air) effluent and SBF(O_3)effluent.
2. A second SBF train (A2, S3) was operated with pre-treatment by coagulation, flocculation and sedimentation (CFS) and is referred to as SBF(CFS).

For intermediate ozonation 500 – 1,000 L of column A1 effluent was collected over several days and ozonated twice a week in a pilot-scale ozonation system (G-PSA, 150 g/h, Sewec Ozon, Germany). The ozone gas was introduced at a gas flow of 0.65 m^3/h into the liquid phase using a venturi injection system. After ozonation, the ozonated water was stripped with oxygen for one hour to remove residual ozone from

the water phase and stored in a gastight flexible PVC storage tank (0.5 m^3) from where it was fed to column S2 via a peristaltic pump.

To determine the effect of pre-treatment on the breakthrough of TOrCs in granular activated carbon (GAC) adsorbers, three RSSCTs were designed following the constant diffusivity approach (Crittenden et al., 1991) to mimic a full-scale GAC adsorber (average GAC grain size = 2 mm; l = 1 m; reactor volume = 785 L) with an EBCT of 24 min. Glass columns (l = 30 cm; ID = 1cm) were prepared with a GAC bed lengths of 6 cm, supported by thin layers of glass wool and filled up with 1 mm glass beads. GAC (CycleCarb 401, Chemviron) was grinded with a ball mill to obtain an average particle diameter of 250 µm. The compounds atenolol, carbamazepine, citalopram, diclofenac, iopromide, metoprolol, phenytoin, primidone, sulfamethoxazole, tramadol, and trimethoprim were spiked (1,000 – 2,000 ng/L) prior to experiments.

For experiments with pre-treatment of WWTP effluent by CFS, coagulation was conducted with 30 mg/L ferric chloride (35 %) in a 1 L completely stirred tank reactor, followed by flocculation in a 5 L reactor at low mixing speed, sedimentation in a 33 L tank and feeding of column A2. Flocculation sludge was removed from the sedimentation tank every three hours.

Weekly samples were filtered using 0.45 µm cellulose acetate membrane filters and analyzed for DOC, UV absorbance and trace organic chemicals according to methods described in Müller et al. (2017). Dissolved oxygen in filter influents and effluents was measured using fiber optics in flow-through cells (FTC-PSt3, PreSens, Germany).

Results and Discussion

Redox conditions and bulk organic carbon removal. Dissolved oxygen (DO) consumption as well as reduction of DOC and UV absorbance are illustrated in Figure 1 for all experiments. Results from the reference system SBF(Air) indicate a significant difference between the two experiments which illustrate seasonal changes of water quality from WWTP effluent. Pre-treatment with CFS removed DOC by approximately 1 mg/L, which could mainly be attributed to humic substances by the enhanced reduction of UV absorbance. The DOC removal resulted in decreased oxygen demand in subsequent filtration steps. As expected, ozonation did not directly

remove DOC but strongly changed UV absorbance of the water matrix. Reactions of ozone, however, slightly increased biodegradability of DOC and thereby enhanced overall DOC removal in the second-stage filter.

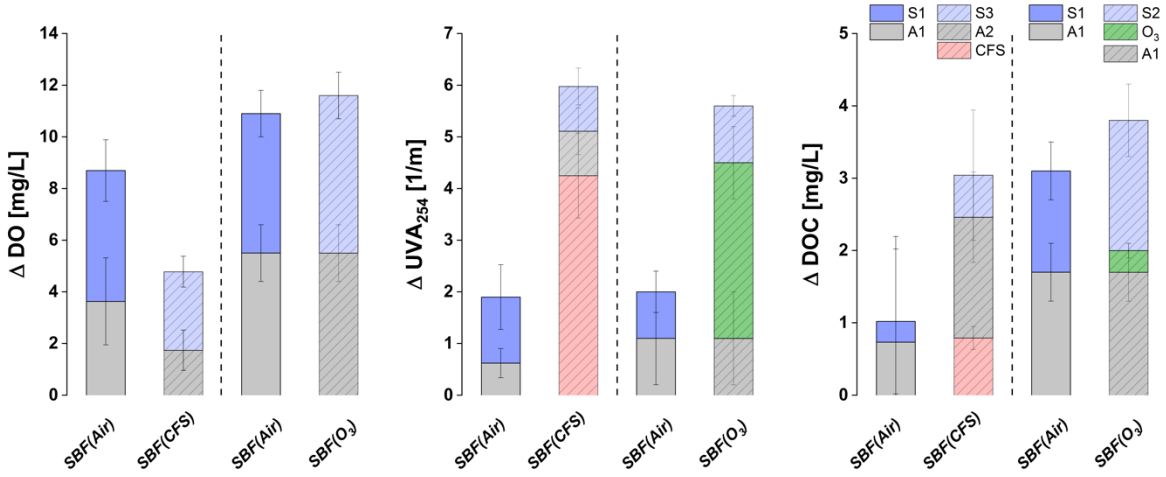


Figure 1. Consumption of DO and removal of DOC and UV absorbance in both experiments

Enhanced removal of trace organic chemicals (TOrCs) in multiple barriers. In previous studies, sequential biofiltration proved to be a more effective treatment technology for the removal of many compounds in comparison to single-stage biofiltration (Müller et al., 2017). Its combination with intermediate ozonation further expanded the range of eliminated compounds to TOrCs persistent to biodegradation (Figure 2, left).

Only few ozone-resistant and persistent compounds (e.g. primidone) are removed with efficiencies <70%. In this combination, biological pre-treatment in the first stage biofilter can also enhance ozonation efficiency by removing BDOC and nitrite from secondary/tertiary effluents.

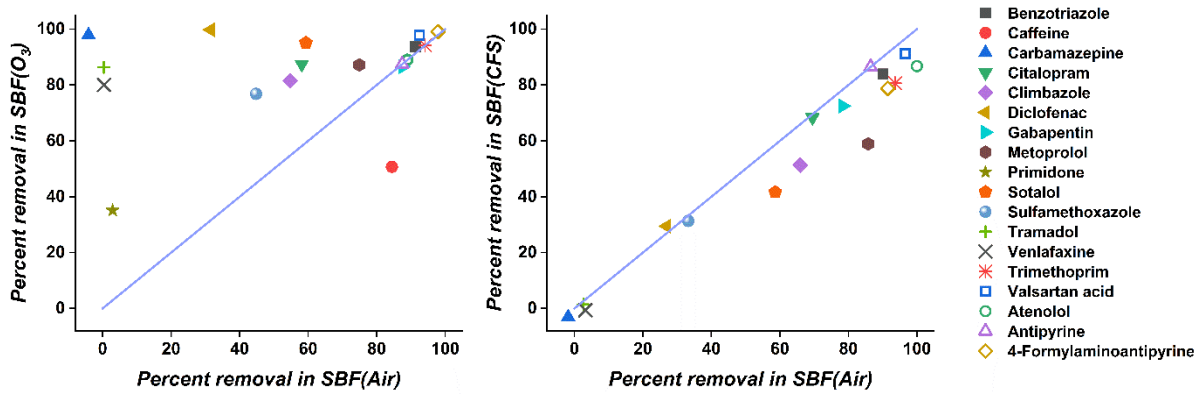


Figure 2. Comparison of compound removal in SBF with a) intermediate aeration (SBF(Air)) and intermediate ozonation (SBF(O_3)) and b) without (SBF(Air)) and with pre-treatment by coagulation, flocculation and sedimentation (SBF(CFS)).

Results from GAC-RSSCTs confirmed the efficacy of GAC adsorbers for the attenuation of many different TOrCs, especially in the beginning of the operation. However, the time until filter breakthrough occurs was compound dependent and especially highly polar compounds such as gabapentin showed only limited or no adsorption onto activated carbon (Figure 3). The obtained data indicate significantly earlier breakthrough of compounds in the RSSCT fed with WWTP effluent and most prolonged GAC filter lifetimes when fed with effluent from system SBF(O_3). This observation is believed to be attributed to the removal of dissolved organic matter during biofiltration and an increasing polarity of dissolved organic matter after treatment with ozone resulting in decreased competitive adsorption in the GAC.

Optimization of SBF conditions. Although a significant reduction of DO consumption was observed in SBF(CFS), pre-treatment did not significantly affect overall elimination of TOrCs during sequential biofiltration (Figure 2, right). This can be explained by similar redox conditions, which can be characterized as oxic (DO > 1 mg/L) in both systems. For operation with feed waters containing higher BDOC levels, pre-treatment with coagulation, flocculation and sedimentation could be a valuable option to maintain oxic conditions throughout the second filter stage.

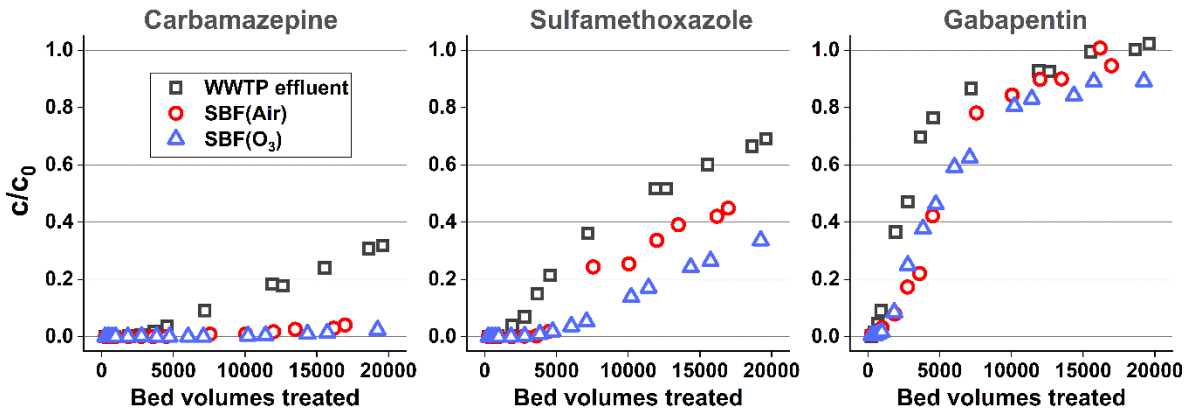


Figure 3. Breakthrough of selected trace organic chemicals in GAC-RSSCTs fed with WWTP effluent and effluents from systems SBF(Air) and SBF(O_3).

Conclusions

SBF proved to be an effective barrier for many TOrCs. However, its application is limited to source waters with a limited DO demand of less than approximately 15

mg/L and to biodegradable substances. Pre-treatment with coagulation, flocculation and sedimentation proved to reduce DO consumption in biofilters which might be an option to allow for oxic conditions even when feed waters with higher DO demand are applied. In addition, it provides an effective removal of phosphorus. The combination with intermediate ozonation, post-treatment in GAC adsorbers or all three barriers showed high potential for additional removal of persistent TOrCs with comparably long GAC adsorber lifetimes due to removal of competitors in preceding steps. For a comprehensive assessment of SBF and the tested combinations, ongoing experiments focus on the removal viruses, bacteria, and antibiotic microbial resistance.

References

Amy, G., Drewes, J., 2007. Soil aquifer treatment (SAT) as a natural and sustainable wastewater reclamation/reuse technology: fate of wastewater effluent organic matter (EfOM) and trace organic compounds. Environ. Monit. Assess. 129 (1–3), 19–26.

Crittenden, J.C., Reddy, P.S., Arora, H., Trynoski, J., Hand, D.W., Perram, D.L., Summers, R.S., 1991. Predicting GAC Performance With Rapid Small-Scale Column Tests. J. Am. Water Works Assoc. 83, 77–87.

Glassmeyer, S. T.; Furlong, E. T.; Kolpin, D. W.; Cahill, J. D.; Zaugg, S. D.; Werner, S. L.; Meyer, M. T.; Kryak, D. D, 2005. Transport of chemical and microbial compounds from known wastewater discharges: Potential for use as indicators of human fecal contamination. Environ. Sci. Technol. 2005, 39, 5157–5169.

Hellauer, K., Karakurt, S., Sperlich, A., Burke, V., Massmann, G., Hübner, U., Drewes, J.E., 2018. Establishing sequential managed aquifer recharge technology (SMART) for enhanced removal of trace organic chemicals: Experiences from field studies in Berlin, Germany. J. Hydrol. 563, 1161–1168.

Müller, J., Drewes, J.E., Hübner, U. (2017). Sequential biofiltration – a novel approach for enhanced biological removal of trace organic chemicals from wastewater treatment plant effluent, Water Res. 127, 127-138.

Regnery, J., Barringer, J., Wing, A.D., Hoppe-Jones, C., Teerlink, J., Drewes, J.E., 2015. Start-up performance of a full-scale riverbank filtration site regarding removal of DOC, nutrients, and trace organic chemicals. Chemosphere 127, 136–142.

Emerging Frontiers in Potable Reuse Ozone-Biofiltration Treatment Systems

Vijay Sundaram, PE, University of Nevada, Reno, USA; Lin Li, University of Nevada, Reno, USA; Tatiana Guarin, University of Nevada, Reno, USA; Lydia Peri, PE, Washoe County CSD, Reno, USA; Krishna Pagilla, PhD, PE, BCEE, University of Nevada, Reno, USA; vsundaram@nevada.unr.edu

Abstract:

Ozone-biofiltration based advanced water treatment (AWT) trains are being studied and implemented for potable reuse in inland communities in the United States. Ozone-biological activated carbon (BAC) processes provide excellent removal of many chemicals of emerging concern (CECs). Formation of ozonation byproducts such as bromate with MCL of 10 ppb is a topic of concern. The primary objective of this study conducted by Universtiy of Nevada, Reno and regional partners is to investigate the long-term performance (over 20 months) of ozone-BAC systems regarding removals of CECs and ozonation byproducts. Two parallel BAC filters were operated side-by-side at various design condtions such as empty bed contact times (EBCTs) of 10 minutes and 20 minutes. Results indicate that ozone dose and BAC EBCT are critical design parameters that needs to be optimized based on project-specific factors such as influent bromide concentration.

Keywords: Potable Reuse; Advanced Water Treatment; Ozonation; Biofiltration; Bromate; NDMA; CECs

Introduction

University of Nevada, Reno (UNR) Nevada Water Innovation Institute is conducting a potable reuse feasibility study for the regional municipal agencies under the OneWater Nevada initiative. The goal of the study is to demonstrate that a “membrane-free” ozone-BAC based advanced water treatment (AWT) train can meet Nevada Category A+ reclaimed water standards for injection well indirect potable reuse (IPR). Since 2008, the regional municipal agencies in Reno have led multiple investigative studies on ozone-BAC as a potential alternate to reverse osmosis (RO) treatment for IPR projects. RO generates a continuous reject stream of brine waste

requiring zero liquid discharge for most inland communities which is costly and consumes considerable energy.

Ozone-BAC based AWT train being investigated in Reno is shown in Figure 1. The AWT train consists of Coagulation/Flocculation/Clarification/Granular Media Filtration (CFCGMF), ozone, biological activated carbon (BAC), granular activated carbon (GAC), and UV treatment processes. Ozone-BAC serve as critical barrier providing significant removal of contaminants of emerging concern (CECs).

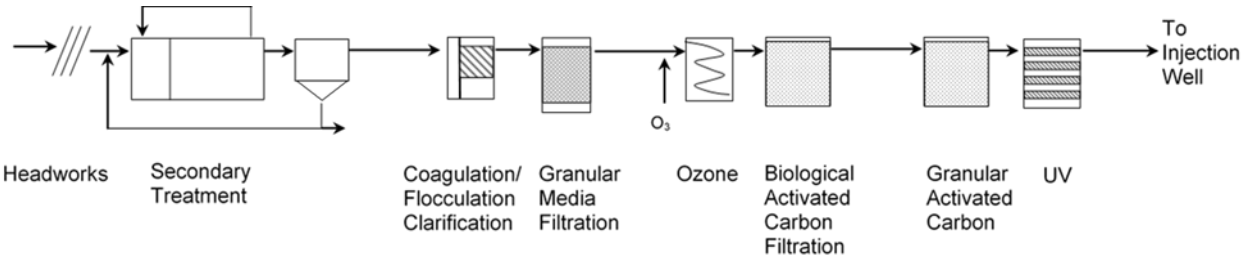


Figure 1. Components considered for financial cost and benefit parameters of IPR

UNR conducted comprehensive pilot testing from February 2018 to June 2019 investigating the emerging frontiers in potable reuse ozone-BAC treatment. The objectives of the investigation were: 1) Determine the effect of ozone dose (or Ozone:(TOC+Nitrite)) on removal of chemicals of emerging concern (CECs), bulk organics (such as TOC), and ozone byproduct formation (such as bromate and NDMA); 2) Determine the effect of BAC EBCT on CECs, bulk organics, and ozone byproducts removal; and 3) Identify critical control points for ozone-BAC.

Biofilter EBCT is one of the critical design parameters which has direct impact on capital and operations and maintenance costs. One of the goals of the project was to conduct a side-by-side testing of two biofilters operated at different EBCTs to demonstrate each's long term performance regarding removals of CECs, and ozonation byproducts.

Materials and Methods

A self-contained Xylem Oxelia^{TM} ozone/BAC unit was provided by Xylem (New York, USA) and evaluated at Washoe County's South Truckee Meadows Water Reclamation Facility (STMWRF). STMWRF has nitrification-denitrification secondary treatment with a mean cell residence time of 10 days and treatment capacity of 4.1 Mgal/d. Secondary effluent is conveyed to Parkson DynaSand continuous backwash

sand filters. A portion of the STMWRF filtered effluent (13 - 20 gpm) was diverted to the ozone-BAC unit. The ozone-BAC unit was operated continuously since September 2017. The first year of the pilot testing was conducted under the Water Research Foundation Project “Reuse-15-10”. The study team from UNR and Washoe County continued the operation and testing of the ozone/BAC system since February 2018.

An ozone generator supplied gaseous ozone to the injection system, which transferred the ozone gas to filtered effluent. Two stainless steel tanks provided adequate contact time after ozone injection. Applied ozone that was not transferred into the liquid was treated in the off-gas stream in an ozone destruction unit. Ozonated water was stored in a break tank and pumped to two parallel BAC filters (BAC 1 and BAC 2). Ozone transfer efficiency was monitored using an in-line ozone gas monitor. Ambient ozone gas monitors were utilized to detect leaks inside and outside the ozonation system. Ozone system was operated at ozone dose to TOC+Nitrite ratio range of 0.9 to 2.

GAC media (Filtrasorb F400, Calgon Carbon Corp., Pittsburgh, PA, USA) was utilized as BAC media. BAC filters are either backwashed regularly for biomass control based on the headloss across the media or at preset backwash interval, whichever occurs first. BAC 1 and BAC 2 filters with identical media and received the same. BAC 1 was operated at an EBCT of 10 minutes, whereas BAC 2’s EBCT was 20 minutes. This study captured the performance of BAC filters operated at different EBCTs over an extended operational period after treating up to 65,000 bed volumes. Three sampling campaigns were conducted while ozone-BAC system had been in operation for over 450 days. CECs were quantified by Eurofins Eaton Analytical Laboratory (Monrovia, California, USA) utilizing their EEA 9609 Method. Bromate and bromide were quantified utilizing EPA Method 317 and Method 300.0, respectively. Influent TOC and nitrite were monitored continuously using an online monitor (YSI NiCaVis) and verified in the lab. General water quality parameters including TOC, nitrite, pH, dissolved oxygen, ammonia, nitrate, and turbidity were also monitored by collecting periodic samples and analyzing them in the laboratory using Standard Methods (APHA, 2017).

Results and Discussion

Bromate is an ozonation byproduct with a MCL of 10 ppb. Based on previous studies in the region and the literature, the formation of bromate is found to be a function of influent bromide concentration, applied ozone dose, presence of scavengers such as organics and carbonates, presence of ammonia, presence of chloramine, and pH. Formation of bromate prior to treatment by BAC as function of Ozone:(TOC+Nitrite) is shown in Figure 2. Average influent bromide concentration observed in this study was 103 ppb. Bromate concetration was below the detection limit (1 ppb) at lower ozone dose and was below the MCL of 10 ppb at higher ozone dose (~4 ppb). A past ozone-BAC investigation that was conducted at another water reclamation facility in Reno reported bromate concentration of up to 20 ppb at ±0.7 Ozone:TOC. The influent bromate concentration was three times higher than the current study (Sundaram, et al., 2014). Results show that bromate formation during ozonation is primarily governed by influent bormide concentration and is proportional to ozone dose when other factors such as influent bromide, ammonia, and pH remained within a relatively narrow range during the study period.

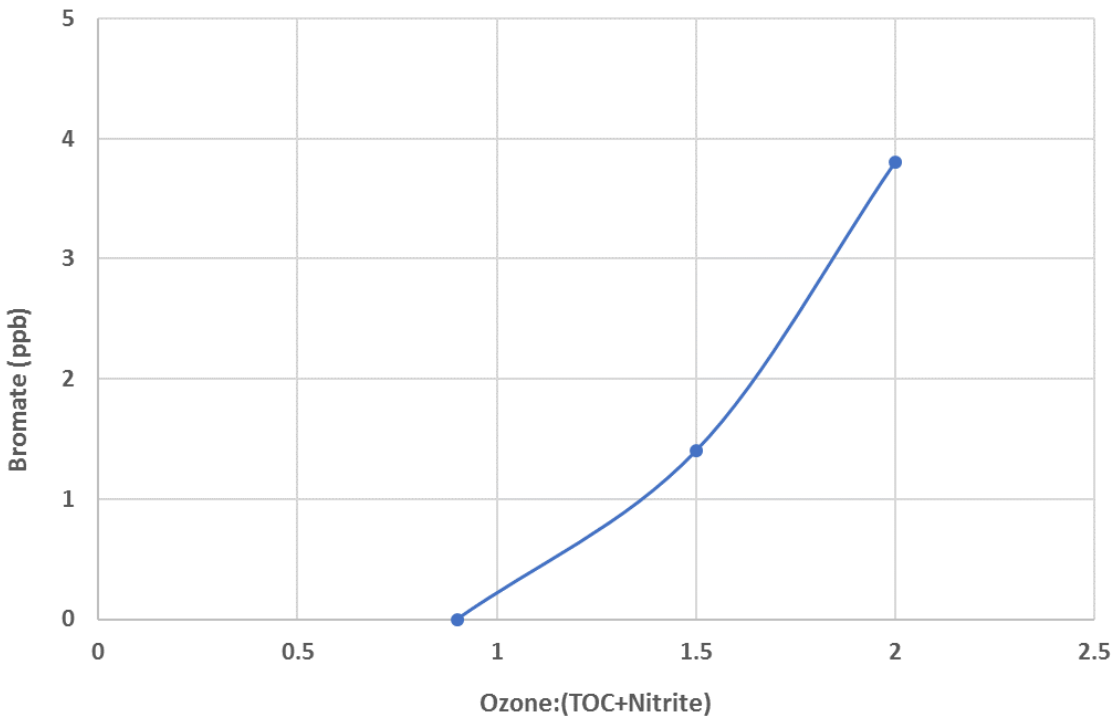


Figure 2. Bromate Formation as a Function of Ozone:(TOC+Nitrite)

Iohexol is a contrasting agent utilized during X-rays. Change in iohexol concentration by ozone-BAC pilot system operated at various ozone:(TOC+nitrite) ratios and two EBCTs (BAC 1 and BAC 2 with 10 and 20 minutes, respectively) is shown in Figure 3.

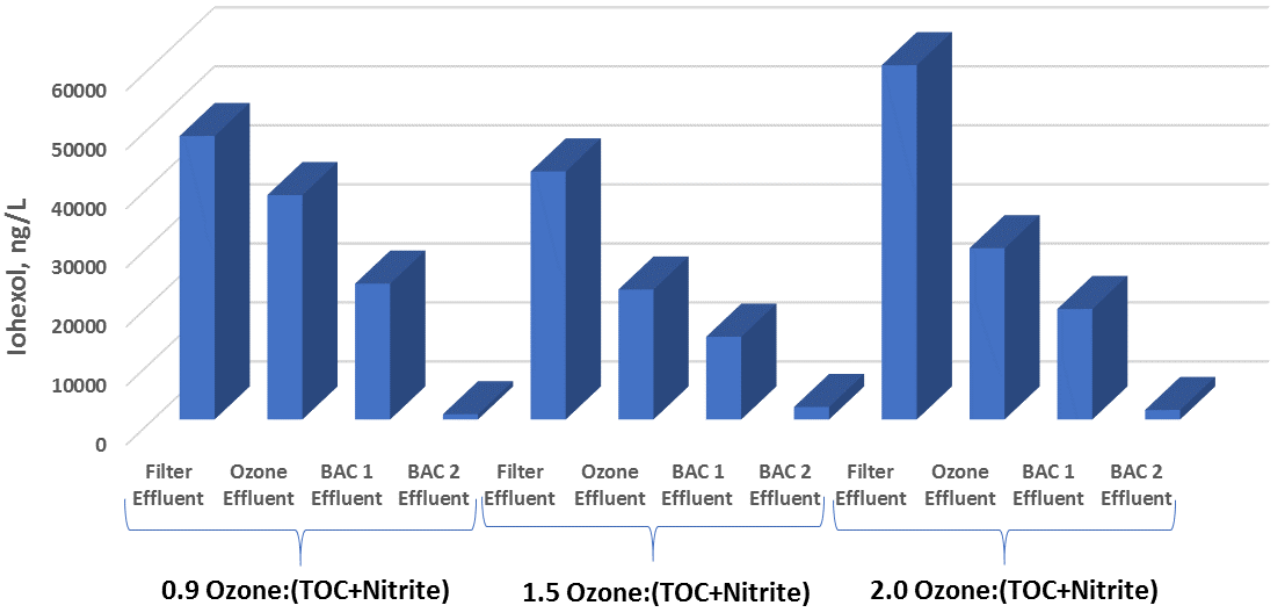


Figure 3. Iohexol Concentration Arcoss Ozone-BAC

Increasing the ozone:(TOC+Nitrite) from 0.9 to 1.5 increased the extent of iohexol oxidation. Percent removals increased from 21% to 48%. However, futher increase in ozone:(TOC+Nitrite) to 2, resulted in marginal increase in iohexol removal (52% removal). BAC 1 with 10 minutes EBCT provided around 36-39% removal of iohexol. BAC 2 with 20 minutes EBCT provided almost 100% removal. Results indicate that removal of iohexol could be attributed to ozone oxidation, biodegradation (as observed in BAC 1 with higher loading rate), and adsorption (as observed in BAC 2 with lower loading rate and residual adsoprtion capacity). Other contrasting agents such as iopromide that are commonly detected in wastewater eflfuents were not detected in this study (Iopromide method reporting limit was 5 ng/l). A previous ozone-biofiltration study reported 30% removal of iopromide during ozonation and almost no removal of iopromide during biofiltration (Blackbeard et al., 2015). Compared to iopromide, iohexol appears to be more amenable to ozone oxidation, biodegradaton, and adsorption.

Conclusions

Results from this work provided long term comparative performance data on ozone-BAC treament processes operating at varying EBCTs. Bromate formation during ozonation was found to be a fuction of ozone:(TOC+Nitrite) and influent bromide concentration. CECs are mitigated in ozone-BAC via oxidation, biodegradation, and adsoprtion. Performance data from BAC 1 (EBCT = 10 minutes) and BAC 2 (EBCT = 20 minutes) provided evidence that all three mechanisms are in play. However, removal of specifc CECs is found to be dependent on chemical-specific characteristics.

References

APHA (2017) Standard Methods for the Examination of Water and Wastewater, American Public Health Association, 23rd Edition, Washington, DC

Blackbeard, J., Lloyd, J., Magyar, M., Mieog, J., Linden, K.G., and Lester, Y. (2015) Demonstrating organic contaminant removal in an ozone-based water reuse process at full scale, Environmental Science: Water Research & Technology 2(1) DOI: 10.1039/C5EW00186B

Sundaram, V. Emerick, R.W., and Shumaker S.E. (2014) Advanced treatment process for pharmaceuticals, endocrine disruptors, and flame retardants removal. Water Environment Research 86 (2), 111-22.

Evaluating Direct Potable Reuse using Ozone Biological Filtration without Reverse Osmosis

Denise Funk, Gwinnett County Water Resources, Lawrenceville, GA, USA;
Jennifer Hooper, CDM Smith, Bellevue, WA, USA;
Katherine Bell, Brown and Caldwell, Nashville, TN, USA;
Justin Mattingly, Water Research Foundation, Alexandria, VA, USA

Abstract:

Gwinnett County, Georgia, USA currently practices potable reuse through surface water augmentation. Advanced treated wastewater from the F. Wayne Hill Water Resources Center (FWH WRC) is returned into Lake Sidney Lanier (Lake Lanier), the County's sole drinking water supply. Both the FWH WRC and the drinking water treatment plant, the Shoal Creek Filter Plant (SCFP), use ozone/biofiltration in their treatment trains. As part of a tailored collaboration project with the Water Research Foundation (Reuse Project 15-11), the feasibility of direct potable reuse (DPR) was evaluated by pilot testing blends of FWH WRC effluent with water from Lake Lanier. Two independent, side-by-side, pilot treatment trains which simulated the SCFP were tested over 10 months. Four blending ratios (15%, 25%, 50%, and 100%) of advanced treated water from the FWH WRC were combined with the raw water from Lake Lanier and fed to the DPR pilot. Results from the DPR pilot were benchmarked against a parallel indirect potable reuse (IPR) pilot plant that operated to simulate the current IPR scenario with influent from Lake Lanier water only. Results were also compared to the full scale SCFP.

Pilot testing of ozone/biofiltration (ozone-BAF) without the use of reverse osmosis (RO) demonstrated that all evaluated potable water quality criteria were met at a 15% blend of advanced treated water. Higher blends had some United States Environmental Protection Agency maximum contaminant level (MCL) exceedances for cyanide, nitrate, and bromate. Higher blends may be possible, but mitigation of bromate and nitrate would be required at the advanced water reclamation facility. Cyanide was formed during chlorine disinfection at the DPR pilot. Further study is warranted to determine the cause of cyanide formation and determine whether results were actual or associated with sampling and analysis techniques.

Advanced treated water from the FWH WRC effluent was of higher quality than Lake Lanier for all biological parameters measured including heterotrophic plate counts (HPC), total coliform, fecal coliform, somatic and male-specific(F+) coliphage (MS2), *Enterococcus*, *Legionella*, *Cryptosporidium*, and *Giardia*. There were no detections of these organisms in the pilot effluent, indicating that DPR could lower acute microbial risks compared to the current lake water source.

This ozone/biological filtration treatment train was also more economical compared to the conventionally applied full advanced treatment (FAT) which utilizes RO. The 30-year amortized costs were less than half of FAT. As a result, inland facilities that do not have access to a marine discharge for RO concentrate disposal may find a more economical alternative by considering ozone/biofiltration without RO.

Keywords: ozone-BAF; direct potable reuse; alternative treatment process

Introduction

Increasing demands on available water supplies have led many utilities to consider potable reuse. Reverse osmosis (RO) has been included in many potable reuse facilities for removing total dissolved solids (TDS) and contaminants remaining after secondary treatment; however, RO has a high capital and operational cost. When TDS are below the secondary MCL, non-RO based treatment trains may provide a lower-cost alternative. This project examined the feasibility of direct potable reuse (DPR) using a non-RO treatment train with two-stage ozone-biological filtration in Gwinnett County, Georgia, USA. DPR water quality and operations were compared to the utility's current practice of indirect potable reuse (IPR) through surface water augmentation.

Gwinnett County provides drinking water, water reclamation and stormwater services to nearly 1 million residents in the metropolitan Atlanta area. Advanced treated wastewater from the F. Wayne Hill Water Resources Center (FWH WRC) is returned into Lake Sidney Lanier (Lake Lanier), the County's sole drinking water supply. Both the FWH WRC and the drinking water treatment plant, the Shoal Creek Filter Plant (SCFP), use ozone/biofiltration in their treatment trains. As part of a tailored collaboration project with the Water Research Foundation (Reuse Project 15-11), the

feasibility of DPR was evaluated by pilot testing blends of FWH WRC effluent with water from Lake Lanier.

Material and Methods

Independent, side-by-side, pilot treatment trains which simulated the full-scale drinking water treatment process were tested over 10 months. Four blending ratios (15%, 25%, 50%, and 100%) of advanced treated water from the FWH WRC were combined with the raw water from Lake Lanier and fed to the DPR pilot. Each blend was evaluated for a minimum of one month and two blends (25% and 50%) were repeated during different time periods to capture temperature differences and seasonal effects. Results were benchmarked against a parallel pilot plant that operated to simulate the current IPR scenario with lake water only, as well as the full scale SCFP. Figure 1 shows the configuration of the pilots with respect to full-scale treatment.

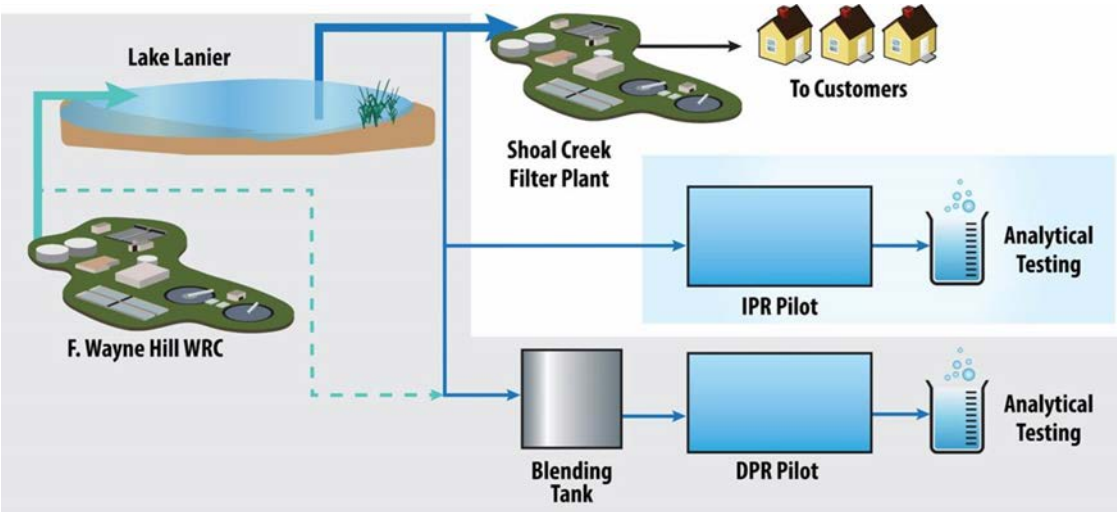


Figure 1 Overview of pilot plant configuration for this study *(adapted from Funk et al., 2018)*

The pilot plants were installed and commissioned in April 2016, with testing and additional modifications completed by July 2016. The pilot testing program was conducted from August 2016 through May 2017 and included four phases: 1) baseline characterization and biofilter acclimation, 2) DPR blend ratio testing, 3) robustness testing during lake water quality challenges, and 4) benchmark sampling with the full-scale plants and the IPR pilot plant. Figure 2 shows the process flow diagrams for the pilot plants and full-scale drinking water treatment facility. Figure 3

shows the process flow diagram for advanced wastewater treatment facility, FWH WRC.

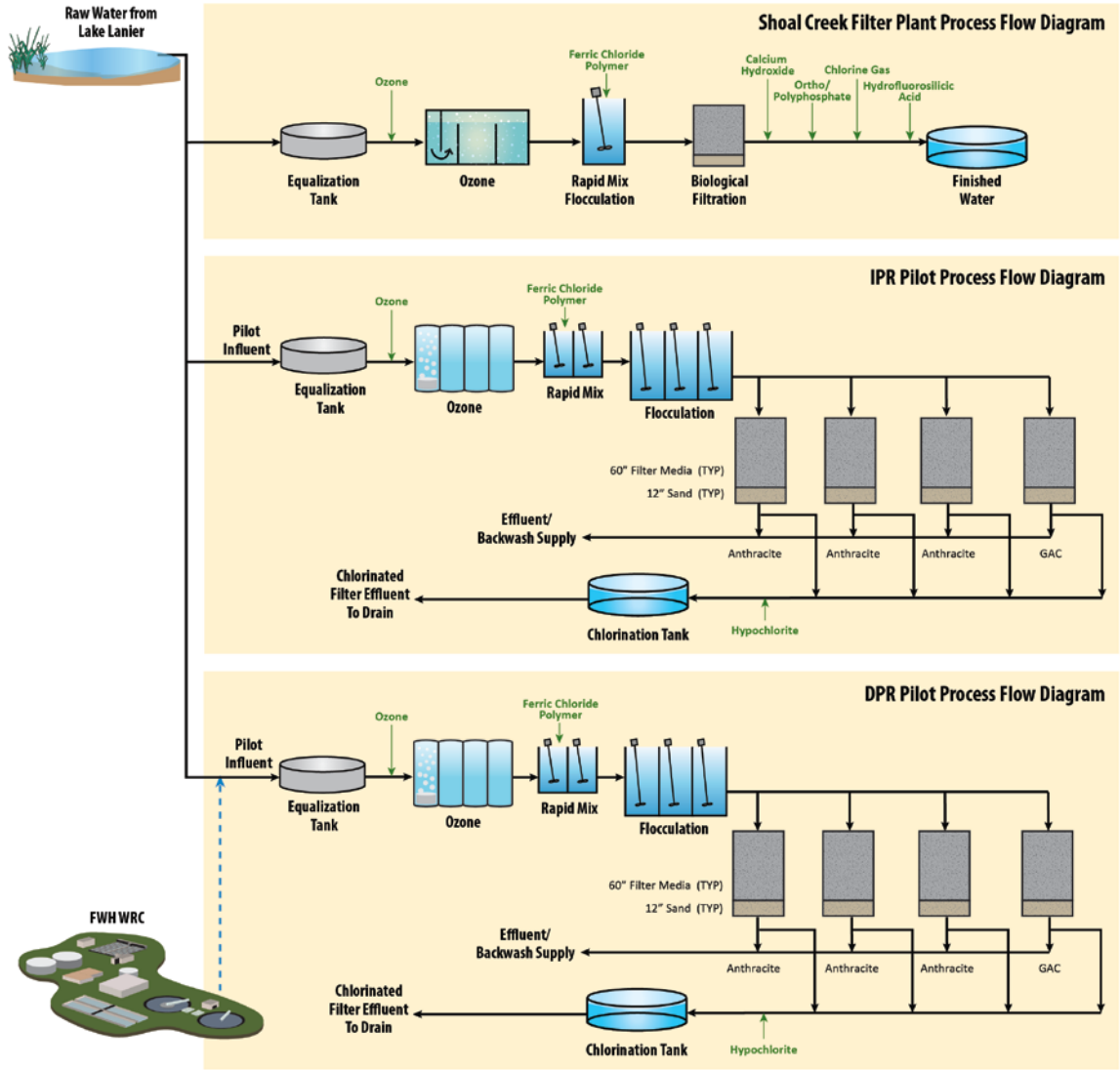


Figure 2 Process flow diagrams for SCFP and IPR and DPR pilot trains

(reprinted from Funk et al, 2018)

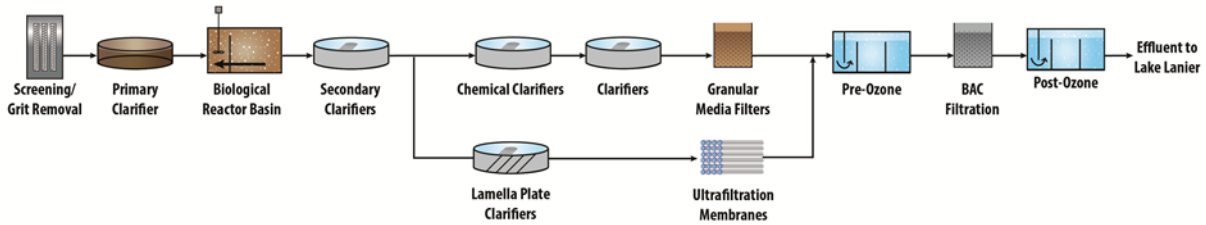


Figure 3 FWH WRC process flow diagram *(reprinted from Funk et al, 2018)*

A detailed sampling and analysis plan was implemented for the DPR blending evaluation. Routine monitoring of the pilot plants during each test phase focused on operational parameters and general water quality (e.g., temperature, turbidity), organic carbon [e.g., total organic carbon (TOC), dissolved organic carbon (DOC), chemical oxidant demand (COD), ultraviolet absorbance at 254 nanometers (UV254)] and nitrogen species (e.g., nitrate, nitrite, ammonia). Signals from online instrumentation were recorded at 5-minute intervals and grab samples were analyzed on a weekly or three-times-per-week basis. Expanded sampling at the end of each blend evaluation included most United States Environmental Protection Agency (US EPA) primary and secondary maximum contaminant levels (MCLs), and several contaminants on the unregulated contaminant monitoring rule (UCMR) list.

Results and Discussion

The study demonstrated that ozone-biofiltration provided water of equal or higher quality than current drinking water supplies without the use of RO when blended at 15%. At higher blends, US EPA primary drinking water MCLs were exceeded for nitrate, bromate, Di (2-ethylhexyl) phthalate (DEHP), and cyanide. Table 1 summarizes results for primary and secondary US EPA standards as well as state health advisory limits with the result compared to the MCL value or state limit.

Table 1 DPR Pilot Finished Water Quality Results (Funk and Hooper, 2018)

15% FWH WRC Blend	25% FWH WRC Blend	50% FWH WRC Blend	100% FWH WRC Blend
• **Met ALL Primary and Secondary MCLs evaluated**	• **Cyanide**: 0.29 mg/L > 0.2 mg/L MCL • **NDMA**: 25 ng/L > 10 ng/L CA&MA action levels	• **Nitrate**: 8.20 ± 3.87 mg-N/L, 5/17 samples > 10 mg-N/L MCL • **Bromate:** 13 µg/L > 10 µg/L MCL • **Di(2-ethylhexyl) phthalate:** 8 µg/L > 6 µg/L MCL • **Color:** 166 CU > 15 CU SMCL *(robustness only)* • **Manganese:** 0.06 mg/L > 0.05 mg/L SMCL • **NDMA:** 11 ng/L > 10 ng/L CA&MA action level	• **Nitrate:** 14.3±9.5 mg-N/L > 10 mg-N/L MCL • **Bromate:** 11 µg/L > 10 µg/L MCL • **Cyanide:** 0.27 mg/L > 0.2 mg/L MCL

For all blends, biological parameters measured in the pilot finished water were below detection, including total coliform, fecal coliform, *Escherichia coli* (*E. coli)*, coliphage (somatic and male-specific/F+-specific coliphage, MS2), *Clostridium perfringens*, *Enterococcus*, *Legionella*, *Cryptosporidium*, and *Giardia*. This finding indicates that

DPR could be of lower acute risk than the current lake water source with respect to microbial contaminants.

Disinfection byproducts (DBPs) measured 3 hours after chlorinating pilot effluent were also low for all blends with haloacetic acids averaging below 22 μg/L and trihalomethanes averaging below 13 μg/L.

Another key finding from this study was the significant cost savings to implement DPR using the advanced treatment train at FWH WRC compared to an RO-based treatment scheme. The capital and operational costs for a new 60 million gallon per day (MGD) (2.63 cubic meters per second [m^3/s]) advanced water treatment facility supplying 15% of the raw water supply to a new 98 MGD (4.29 m^3/s) potable water treatment facility were calculated for two scenarios:

1) Advanced water treatment facility utilizing the treatment process currently employed at FWH WRC
2) Advanced water treatment facility utilizing FAT (MF/RO/UV-AOP) with mechanical evaporation of RO concentrate.

In both scenarios, the new potable water treatment facility utilized the SCFP treatment train. The RO-based system (Scenario 2) had a 30-year capital and O&M cost of $3,200/MG water treated. The two-stage ozone-BAF system implemented at FWH WRC and the SCFP was less than half the cost, at $1,500/MG water treated. The major driver for the cost differential was the capital cost of mechanical evaporation for brine disposal and RO operating costs for power was more than double the cost for the ozone-BAF process. This result has significant implications on the economic feasibility of DPR, particularly for inland facilities. The findings from this research project indicate that non-RO based treatment schemes involving ozone-BAF can produce high-quality potable water at significant cost savings compared to FAT (Funk et al, 2018).

References

Funk D., Hooper J., Noibi M., Goldman J., Oliva R., Schulz C. Bell K., Huang C., and Machek E. (2018) Ozone Biofiltration Direct Potable Reuse Testing at Gwinnett County. Water Research Foundation Project 15-11 Report, USA.

Funk D. and Hooper J. (2018) Direct Potable Reuse Using Ozone-Biological Filtration without RO. WateReuse Symposium presentation, Austin, TX, USA

Post-treatment options for ozonation in tertiary municipal wastewater treatment

D. Sauter, A. Sperlich, R. Bloch, R. Gnirss, Berliner Wasserbetriebe, Cicerostr. 24, 10709 Berlin, Germany; J. Schuetz, Kompetenzzentrum Wasser Berlin, Cicerostr. 24, 10709 Berlin, Germany; daniel.sauter@bwb.de

Abstract:

Three deep-bed filters and two vertical-flow constructed wetlands (CW) were operated in parallel as post-treatment for ozonation in tertiary wastewater treatment in order to investigate their capacity for additional organic micropollutant (OMP) removal. While a conventional non-adsorptive sand/anthracite filter did not show any OMP removal, biological activated carbon filters exhibited stable reduction for a number of compounds, indicating the involvement of biodegradation processes, besides adsorption. CW reduced OMP to a limited extent but performed best for bulk organics which demonstrates that they are a suitable nature-based post-treatment alternative.

Keywords: tertiary treatment, ozonation, post-treatment, organic micropollutants

Introduction

Due to limited water resources, many water utilities have to rely on indirect potable water reuse for drinking water supply. This is of special concern when surface waters are impacted by wastewater treatment plant (WWTP) effluents which are known to be major point sources for organic micropollutants (OMP) (Luo et al., 2014). Ozonation followed by sand filtration as biological post-treatment has been shown to be a suitable process combination to remove OMP and their oxidative transformation products (TP) (Hollender et al., 2009). However, the appropriate design and operation of biological filtration as post-treatment are still under discussion. Contact time is an important operational parameter with impact on kinetically driven biotransformation processes. Also, the choice of filter material can influence treatment results. Several studies concluded that granular activated carbon (GAC) was the more favorable filter material compared to non-adsorptive media because it exhibited improved removal of OMP and TP from ozonation effluent (Bourgin et al., 2018; Knopp et al., 2016; Reungoat et al., 2011). Although biological transformation

processes were taken into consideration for explaining the better removal on GAC the final role of adsorption and biodegradation remains largely unclear.

As part of the EU Horizon 2020 project AquaNES the present study investigates the long-term operation of a number of different post-treatment options for ozonated WWTP effluent that allow for comparison of the effectiveness of different filter media and operational aspects such as contact time.

Material and Methods

As shown in Figure 1 secondary effluent from a full scale WWTP is treated with ozone, followed by different deep-bed filter systems and two vertical-flow constructed wetlands (CW).

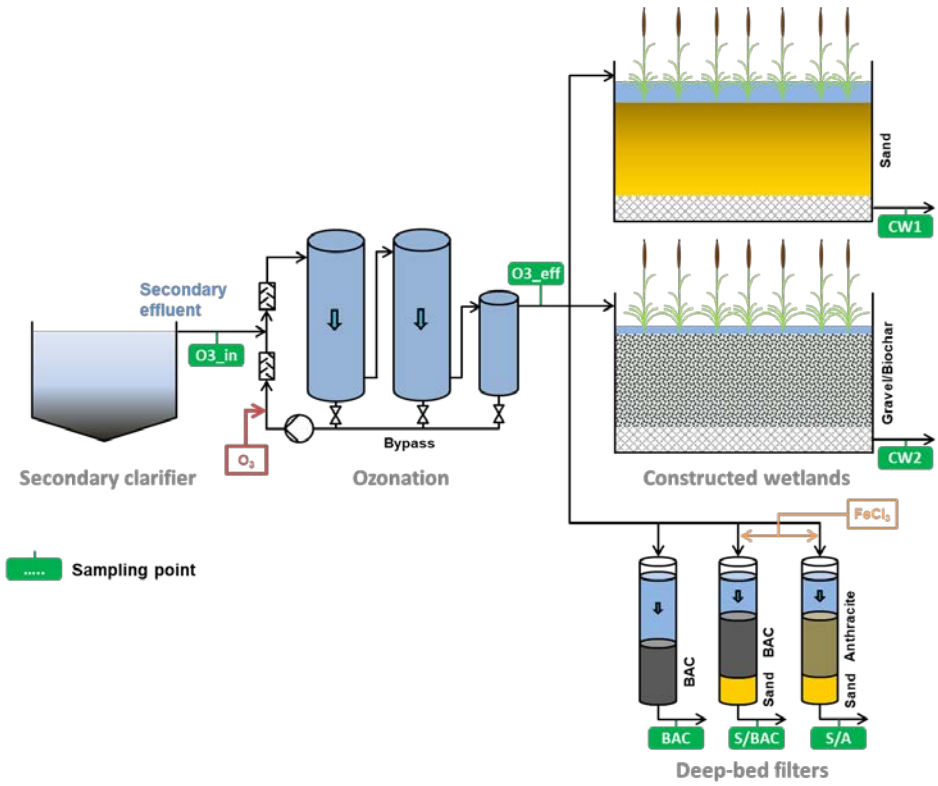


Figure 1 Simplified flow scheme of the pilot plant.

The ozonation unit was operated with a target value for the specific applied ozone dose of 0.7 mg O_3/mg DOC. Ozone was dosed in-line with a Venturi injection system. Hydraulic retention time in the ozone reactor was at least 15 min at all times in order to guarantee complete reaction of ozone with water constituents.

All deep-bed filter columns were identically constructed with a diameter of 0.3 m but differ in their filter media. The three filters designated as BAC, S/BAC and S/A are operated in parallel and contain GAC (d = 1.4-2.4 mm), sand (d = 0.7-1.25 mm) / GAC (d = 1.4-2.4 mm) and sand (d = 0.7-1.25 mm) / anthracite (d = 1.4-2.5 mm),

respectively. The dual-media filters S/A and S/BAC were additionally equipped with coagulant dosing ($FeCl_3$) for phosphorus removal. In two operational phases treatment performance of the filters was compared for empty bed contact times (EBCT) of ~7.5 min (~0-30000 BV) and ~15 min (>30000 BV).

Both CW have a surface area of 11 m² each and were planted with *Phragmites australis* and *Carex acutiformis* in equal parts. In CW1, technical sand is used as filter material (bed depth = 0.55 m, d = 0.2-2 mm). In CW2, coarser filter material (bed depth = 0.8 m) consisting of a homogeneous mix of lava gravel (d = 4-8 mm) and biochar (d = 8-20 mm) is tested. They were operated under saturated conditions with filtration rates of approximately 200 mm/d (EBCT: 2.75 d in CW1, 4 d in CW2), 400 mm/d (EBCT: 1.4 d in CW1, 2 d in CW2) and 1000 mm/d (EBCT: 0.55 d in CW1, 0.8 d in CW2) in different phases.

Samples were taken as 24h-composite samples and a time offset between influent and effluent according to the hydraulic retention time of the treatment process was considered. DOC quantification was carried out with a TOC analyser (TOC-L, Shimadzu, Kyoto, Japan) in accordance with DIN EN 1484 (H03). COD was analysed with cuvette tests according to DIN ISO 15705. Analysis of OMP was performed with HPLC-MS/MS methods according to DIN 38407-F47 and DIN 38407-F36.

Results and Discussion

Organic bulk parameters DOC and COD were used to assess the behavior of organic matter in the different processes. Figure 2 displays their concentrations before and after the treatment steps, only taking into account data after steady-state conditions for DOC were reached in the filters (~10000 BV).

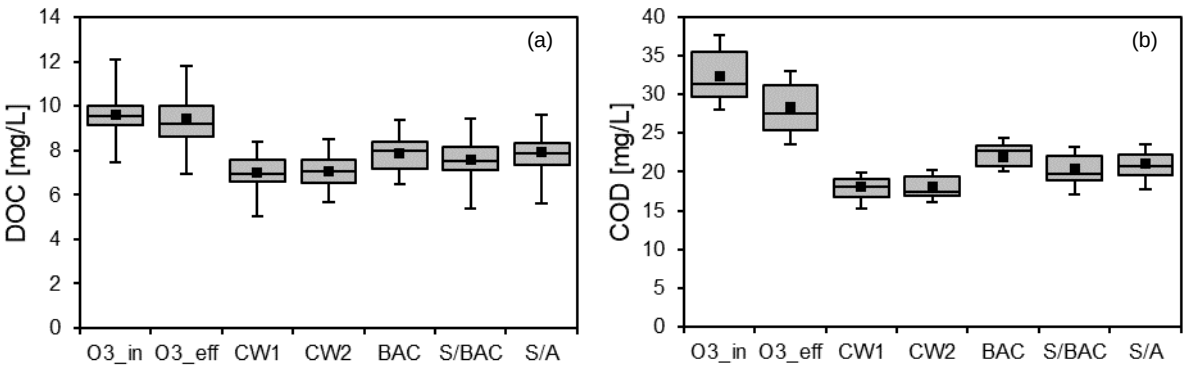


Figure 2 Box-plots of (a) DOC (n = 23-39) and (b) COD (n = 23-29) concentrations at different sampling points; box: 25th and 75th percentile, line: median, square: mean, whiskers: minimum and maximum.

Ozone treatment did not reduce DOC substantially while COD was removed by ~15 % on average. This is in line with the knowledge that ozonation does not lead to mineralization but to partial oxidation of organic matter. In the deep-bed filters average DOC removals of ~14 % in BAC, ~19 % in S/BAC and ~15 % in S/A were observed. Since operational parameters were identical in both the dual-media filters and no more adsorption of DOC onto GAC was expected, the enhanced DOC removal in S/BAC indicates a higher biological activity on activated carbon compared to anthracite. The best results for bulk organics abatement were achieved with CW post-treatment which demonstrates the beneficial effect of increased contact time on biodegradation. Both CW performed very similarly with mean removal efficiencies of ~22 % and ~33 % for DOC and COD, respectively.

A set of 20 OMP was regularly monitored for assessment of the different treatment processes. Ozonation (specific applied ozone dose: 0.65 ± 0.09 mg O_3/mg DOC) efficiently reduced the cumulative concentration of monitored OMP by approximately two thirds. However, average removal performance for individual compounds strongly varied from >98 % (e.g. diclofenac, formylaminoantipyrine) down to no removal at all (e.g. metformin, tris(2-chloropropyl)phosphate (TCPP)). One main objective of the study was, to investigate whether post-treatment is capable of compensating shortcomings of the ozone treatment for certain substances. 11 out of 20 compounds were still present after ozonation at sufficient concentrations to analyze their behavior during post-treatment. Figure 3 shows their mean removal in the different filtration systems.

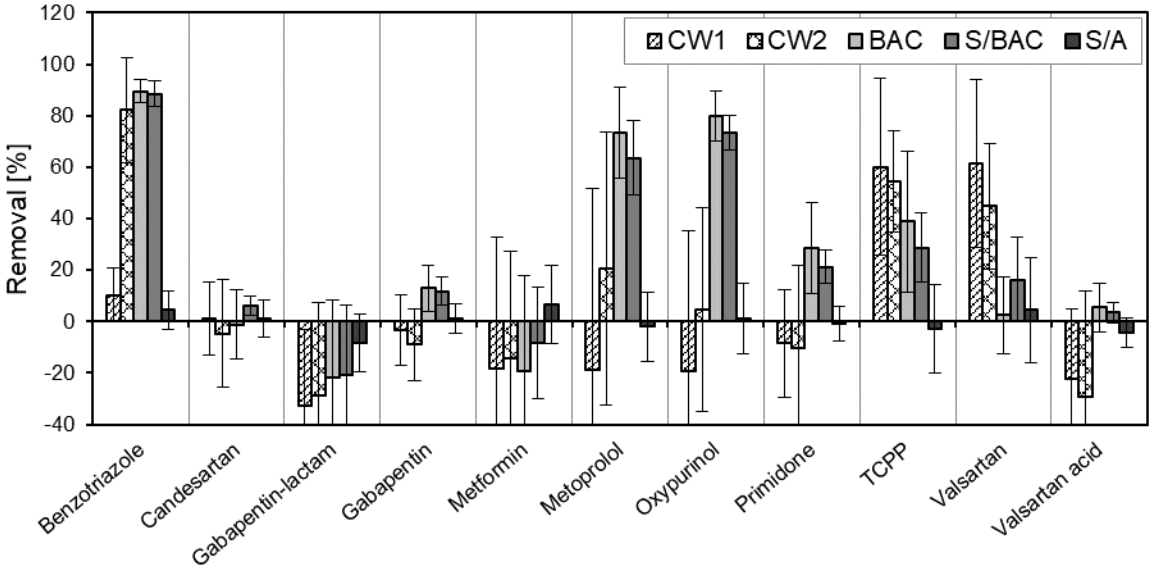


Figure 3 Mean OMP removal with standard deviation for different post-treatments (n=3-27). All data before BAC throughput had reached 20000 BV were excluded.

Despite long retention times in CW only valsartan and TCPP showed steady reduction in CW1 and CW2. Since both compounds are poorly adsorbable and CW1 does not contain adsorptive filter material biotransformation seems to be the dominant removal process. Well-adsorbing benzotriazole was additionally removed in CW2 by adsorption onto biochar. However, quickly advancing breakthrough of benzotriazole in CW2 (~25 % at ~700 carbon bed volumes (BV)) revealed that sorption capacity of biochar was very limited compared to GAC.

With contact times of only several minutes conditions for biotransformation processes are less favorable in deep-bed filters. Accordingly, none of the OMP that were still present after ozonation could be further removed in the S/A filter. Interestingly, both BAC containing filters showed substantial additional mean removal for the following OMP: benzotriazole (~90 %), oxypurinol (~75 %), metoprolol (~70 %), TCPP (~30 %), primidone (~20 %) and gabapentin (~10 %). Breakthrough curves for these compounds had a similar shape. As shown exemplarily for benzotriazole and primidone in Figure 4, after an initial increase the relative effluent concentration stabilized at a certain level, corresponding to the above-mentioned removal. This behavior clearly indicates that besides adsorption, biological transformation processes are involved in OMP removal during BAC filtration. Similar observations were reported by Bourgin et al. (2018) where a loaded GAC filter as post-treatment after ozonation steadily removed a number of OMP until the end of the testing period (~50000 BV) while a sand filter operated in parallel did not contribute to further OMP reduction.

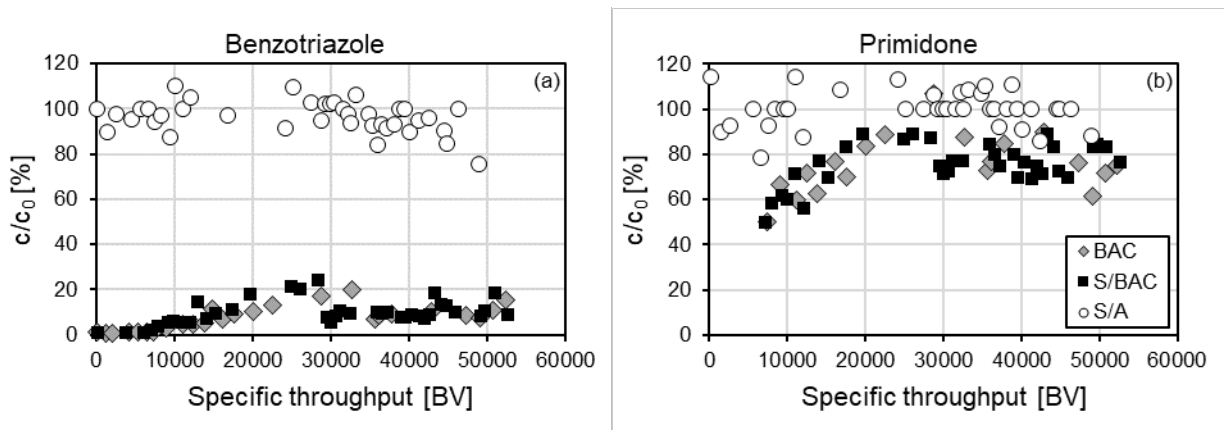


Figure 3 Relative effluent concentrations of (a) benzotriazole and (b) primidone over specific throughput for the deep-bed filters BAC, S/BAC and S/A.

Conclusions

The results highlight that BAC filters are a promising option for post-treatment after ozonation since they achieved substantial additional removal of organic contaminants. Beyond OMP removal by adsorption results clearly point at the involvement of biotransformation processes in the BAC filters which is crucial for long-term water quality gains without frequent exchange of the costly filter material.

CW achieved the highest removal efficiencies for bulk organics and thereby proved their high biological activity. Additional OMP removal was limited but still higher than in the S/A filter. Hence, CW demonstrated to be a nature-based alternative for post-treatment after ozonation that is ready for use where local conditions allow for it (surface area demand by factor of several hundred larger than deep-bed filters).

References

Bourgin, M., Beck, B., Boehler, M., Borowska, E., Fleiner, J., Salhi, E., Teichler, R., Gunten, U. von, Siegrist, H., McArdell, C.S., 2018. Evaluation of a full-scale wastewater treatment plant upgraded with ozonation and biological post-treatments: Abatement of micropollutants, formation of transformation products and oxidation by-products. Water research 129, 486–498.

Hollender, J., Zimmermann, S.G., Koepke, S., Krauss, M., McArdell, C.S., Ort, C., Singer, H., Gunten, U. von, Siegrist, H., 2009. Elimination of organic micropollutants in a municipal wastewater treatment plant upgraded with a full-scale post-ozonation followed by sand filtration. Environ. Sci. Technol. 43 (20), 7862–7869.

Knopp, G., Prasse, C., Ternes, T.A., Cornel, P., 2016. Elimination of micropollutants and transformation products from a wastewater treatment plant effluent through pilot scale ozonation followed by various activated carbon and biological filters. Water research 100, 580–592.

Luo, Y., Guo, W., Ngo, H.H., Nghiem, L.D., Hai, F.I., Zhang, J., Liang, S., Wang, X.C., 2014. A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. The Science of the total environment 473-474, 619–641.

Reungoat, J., Escher, B.I., Macova, M., Keller, J., 2011. Biofiltration of wastewater treatment plant effluent: Effective removal of pharmaceuticals and personal care products and reduction of toxicity. Water research 45 (9), 2751–2762.

O3/BAC versus Chloramines: Innovative Pretreatment to Membranes and Enhanced Energy Efficiency of Potable Reuse Treatment Train

R. Shane Trussell, Trussell Technologies, Inc., San Diego, USA; Aleksey N. Pisarenko, Trussell Technologies, Inc., San Diego, USA; Elise Chen, Trussell Technologies, Inc., San Diego, USA; Aviv Kolakovsky, Trussell Technologies, Inc., San Diego, USA; Lauren Breitner, Trussell Technologies, Inc., San Diego, USA; Joseph Quicho, City of San Diego Public Utilities Department, San Diego, USA

The advent of potable reuse poses new challenges to water treatment as the boundaries between wastewater and drinking water processes fade and these systems become integrated. California has taken a leading role in advancing potable reuse and, as part of this endeavor, the City of San Diego is embarking on a multi-phase project to provide 30 million gallons per day of purified water through potable reuse. The initial phase of this project involved the construction of a demonstration facility, the Pure Water Demonstration Facility (PWDF), to serve as a proof of concept and inform design and operation of the full-scale plant.

Funded by the US Bureau of Reclamation and City of San Diego's Public Utilities Department, this study was conducted at the PWDF and evaluated a new, innovative biological and organic membrane fouling control in potable reuse using O_3/BAC as an alternative to chloramine treatment, which is the standard practice in the industry. Chloramines have a proven track record of biological fouling control in membrane filtration systems. However, increased oxidative damage of RO membranes, shortening of their useful life, and increased salt passage seem to accompany chloramine application. In addition, chloramines reduce the UV transmittance of the UV/advanced oxidation process (AOP) influent, increasing the energy use of the AOP system.

The goal of this study was to characterize the potential energy and chemical savings associated with the implementation of O_3/BAC pretreatment in advanced treatment trains in potable reuse schemes. To this end, this study evaluated the effects of O_3 and BAC pretreatment on the biological and organic fouling of UF and RO membranes, the frequency of Clean-In-Place (CIP) procedures, the replacement frequency of RO membranes, and the water quality of the UV/AOP influent.

Four test conditions were evaluated:

1. Use no form of biofouling control
2. Use O_3/BAC pretreatment for membrane biofouling control
3. Use chloramines for membrane biofouling control
4. Use chloramines and O_3/BAC membranes for biofouling control

Preliminary results indicate that the rate of fouling in the ultrafiltration (UF) system is elevated under operation without any form of biofouling control or with chloramines only while operation with either O_3/BAC or with O_3/BAC and chloramines is feasible. As expected, the test conditions that included O_3/BAC pretreatment (2 and 4) offered substantially lower power use and CIP chemical costs than the ones that did not use O_3/BAC pretreatment (1 and 3). However, using O_3/BAC as the only form of biofouling control results in a steady decrease in temperature-corrected specific flux and requires more frequent chemical cleaning. However, based on this analysis, it is also evident that the cost of continuous chloramines addition is much higher than the cost for enhanced flux maintenance chemicals and is >70% of the cost of power use. Minimizing the use of chloramines and optimizing chemical cleaning frequency may provide the best balance of lower power and lower chemical costs. Similar evaluations were performed on the RO system, where power use and chemical cleaning costs were compared. The UV/AOP system operated at up to 50% lower power use when chloramines were not being dosed upstream of the membranes systems. The study included several challenge tests to bench-mark AOP performance for removal of 1,4-dioxane, an indicator compound to assess performance at different power and oxidant conditions.

This study demonstrates that the use of O_3/BAC pretreatment offers significant improvements in the operating efficiency of the UF and RO membranes, and the energy-intensive UV/AOP system while continuing to demonstrate high standards of water quality. This results in a more efficient and robust potable reuse treatment train. Pending the conclusion of the study, it is expected that the total operation and maintenance cost savings will offset the additional energy used by the O_3/BAC pretreatment.

Impact of operating conditions of an advanced wastewater treatment plant combining ozonation and granular activated carbon on antibiotic resistant bacteria and antibiotic resistance genes

Katarzyna Slipko[1], Lina Wallmann[1], Elena Radu[1,2], Heidemarie Schaar[1], Ernis Saracevic[1], Markus Wögerbauer[2], Peter Hufnagl[2], Jörg Krampe[1], Norbert Kreuzinger[1]

[1]Vienna University of Technology, Institute for Water Quality and Waste Management, Karlsplatz 13/226-1, 1040 Vienna, Austria

[2]AGES - Austrian Agency for Health and Food Safety, Spargelfeldstraße 191, 1220 Vienna, Austria

Abstract:

The aim of the study was to assess the impact of operating conditions in a multi-barrier advanced wastewater treatment plant combining ozonation and GAC filter on the removal of micropollutants and fate of antibiotic resistant bacteria and genes over one year of continuous monitoring. Ozone treatment (doses ≥ than 0.31 g O_3/g DOC) resulted in an average removal of 2.5 log units of total and resistant *Escherichia coli* from the effluent of the full-scale wastewater treatment plant. With increased ozone dose, the blaTEM gene become more abundant, suggesting survival of ampicillin resistant bacteria. Ozone doses ≥ than 0.25 g O3/g DOC allowed to completely remove diclofenac. Abundance of targeted bacteria after GAC filter remained at the same order of magnitude as in ozonated effluent.

Keywords: antibiotic resistance; ozonation; granular activated carbon; wastewater treatment

Introduction

Wastewater treatment plants (WWTP) based on conventional technologies are a relevant vector for the release of organic and microbiological contaminants into the environment (Alexander et al. 2016, Rizzo et al. 2013). The release of antibiotic resistant bacteria (ARB) and antibiotic resistance genes (ARGs) into the environment by even treated effluents is of international concern due to the risk of antibiotic resistance spread and development in human pathogens and environmental bacteria.

Operation of conventional WWTP is generally based on the elimination of carbon, nitrate and phosphate (Luddeke et al. 2015) and applied technologies are not

specifically designed for removal of emerging contaminants, like organic micropollutants or even bacteria including ARB (Jager et al. 2018). Thus, there is a need to evaluate technologies that could reduce the discharge of these contaminants with WWTP effluents. The combination of ozonation with granular activated carbon (GAC) adsorption is a promising multi-barrier system for advanced treatment targeting micropollutant abatement. Because first full-scale plants are already implemented, there is a need for investigations evaluating efficiency of this combination for ARB and ARGs removal.

The main objective of this study was to assess the impact of operating conditions in a multi-barrier advanced wastewater treatment plant combining ozonation and GAC filter on ARB and ARGs removal over one year of monitoring. Despite automated process control, typical fluctuations in the quality of wastewater may have an effect on the performance of advanced treatment, which was aimed to be assessed during the monthly monitoring campaigns. Beside a regular monthly monitoring based on a standard operation and automated process control, further investigations were carried out to assess the effect of the specific ozone dose on ARB and ARGs in the short time intervals avoiding the impact of the water matrix fluctuations and keeping the matrix constant. Furthermore, results from ARB and ARGs removal are correlated to the abatement of organic micropollutants analyzed in parallel.

Material and Methods

Over one year, samples of effluent are collected on a monthly basis from a full-scale WWTP with installed pilot-scale plant combining ozonation and GAC filtration for 7,250 population equivalents. A simplified scheme of the plant is shown in Fig. 1. The ozonation consists of three 4 m^3 reactors operated in series at a specific ozone dose between 0.2 and 0.8 g O_3/g DOC during the monitored routine operation. The subsequent GAC filter was operated at an empty bed contact time of about 14 min.

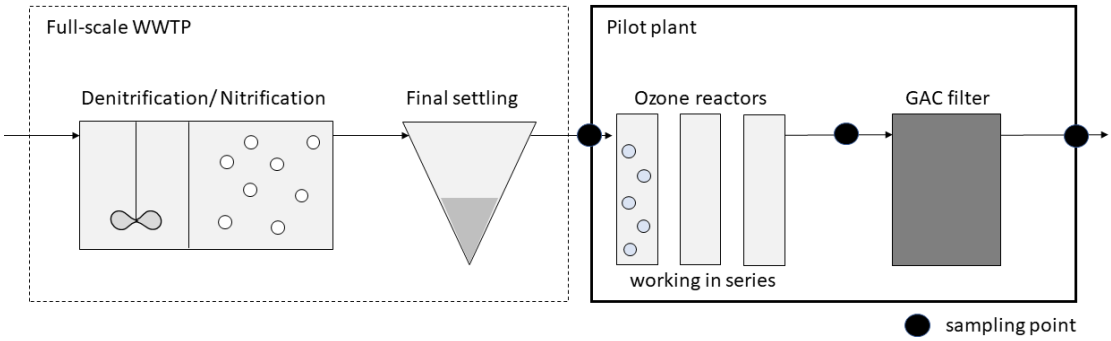


Figure 1. A schematic representation of the multi-barrier advanced wastewater treatment pilot plant combining ozonation and GAC filter.

Samples were collected from effluent of the full-scale WWTP (influent to pilot plant), after ozonation, and after GAC filter (final effluent) and processed within 24 h. The test aiming to assess the effect of the specific ozone dose on ARB and ARGs was performed within 1 d, to minimize the impact of fluctuations in the water matrix.

Samples were analyzed for abundance of bacteria by filtration and placing the filter (0.45 µm pore size, PALL) on a specific medium. Total heterotrophic bacteria were enumerated on R2A agar (VWR), total *Escherichia coli* on CCA (Chromogenic Coliform Agar, VWR) medium and antibiotic resistant *Escherichia coli* on CCA medium spiked with antibiotics: ampicillin (32 mg/L) or sulfamethoxazole (76 mg/L) with trimethoprim (4 mg/L). CCA plates were incubated 24 h at 37 °C, R2A for 5 d at 37 °C. DNA was extracted from biomass captured on filters (0.45 µm pore size, PALL) with DNeasy PowerWater Kit (Qiagen) according to manufacturer's protocol (with use of Fast Prep, MP Biomedicals, for cell lysis). Gene abundance was quantified with qPCR. TaqMAN systems for 16S, sul1 and blaTEM (Ingenetix GmbH, Austria) were applied according to manufacturer's protocol with LC-480 Light Cycler (Roche).

In addition to biological analyses, an array of micropollutants was tested, including benzotriazole, acesulfame K and diclofenac. Chemicals were monitored by automated online solid phase extraction (Phenomenex Strata X On-Line extraction cartridge) coupled with LC/MS/MS (HPLC separation with 0.1% acetic acid solution and 0.1% acetic acid in acetonitrile solution; the MS/MS system - hybrid triple quadrupole linear trap/ion trap tandem mass spectrometer Q Trap 3200 (Applied Biosystems)).

Results and Discussion

At 0.18 g O_3/g DOC, during ozone dose experiment performed within one day, log removal value (LRV) for all selected groups of bacteria was below one (Fig. 2). Increasing the ozone dose to 0.31 g O_3/g DOC resulted in a substantial shift towards 3 LRV. At higher ozone doses, removal of ampicillin resistant E. coli reached 3 LRV. The rest of tested groups of bacteria showed similar behavior corresponding to 99.9% removal. This trend can be observed also for samples taken during other months, when reactors were operated with 0.25, 0.63 and 0.83 g O_3/g DOC.

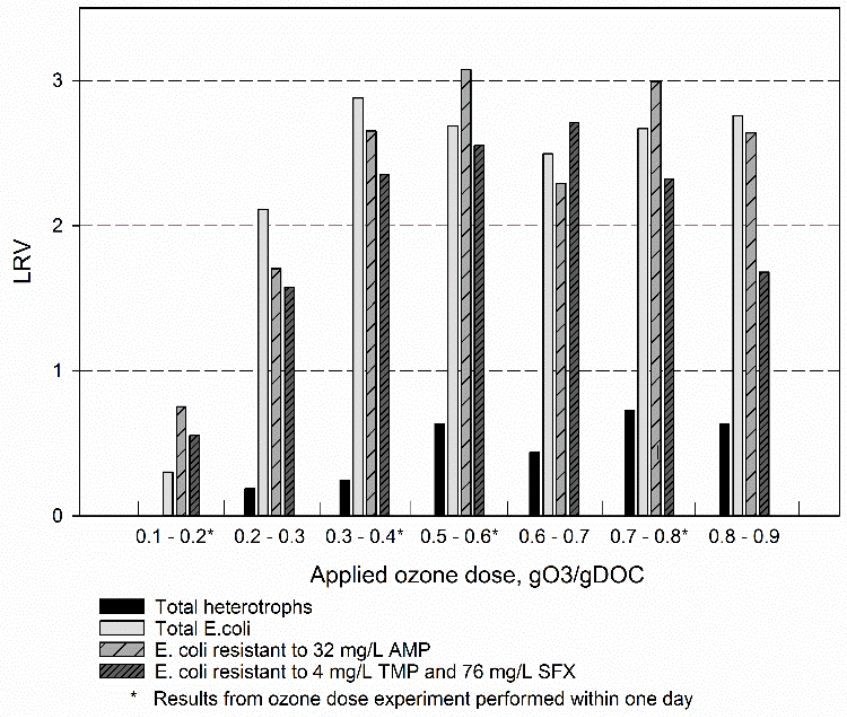


Figure 2. Log removal values for targeted groups of bacteria.

The abundance of 16S gene copies gives an estimation of a general number of bacteria in the sample. Decrease in sul1 gene abundance appeared to be correlated with applied ozone dose (Tab. 1), with a substantial reduction of sul1/16S ratio, therefore the share of this gene in the bacterial community. Application of increased ozone doses (0.55 and 0.75 g O_3/g DOC) resulted in increase of blaTEM absolute abundance as well as blaTEM/16S ratio, suggesting survival of bacteria possessing the blaTEM gene.

Table 1. Gene copy numbers for targeted ARGs and 16S before and after ozonation for ozone dose experiment performed within one day. Sample before ozonation was marked with asterisk (*).

O3 dose, g O_3/ g DOC	16S copies/ 100 ml	Sul1 copies/ 100 ml	Sul1/16S copies	BlaTEM copies/ 100 ml	BlaTEM/ 16S copies
0*	5.07E+08	3.28E+07	0.06	4.38E+04	0.00
0.18	5.10E+08	7.57E+07	0.15	7.05E+03	0.00
0.31	2.13E+08	2.28E+06	0.01	6.22E+03	0.00
0.55	1.56E+08	2.14E+06	0.01	1.39E+05	0.06
0.75	1.53E+08	6.19E+05	0.00	5.99E+05	0.97

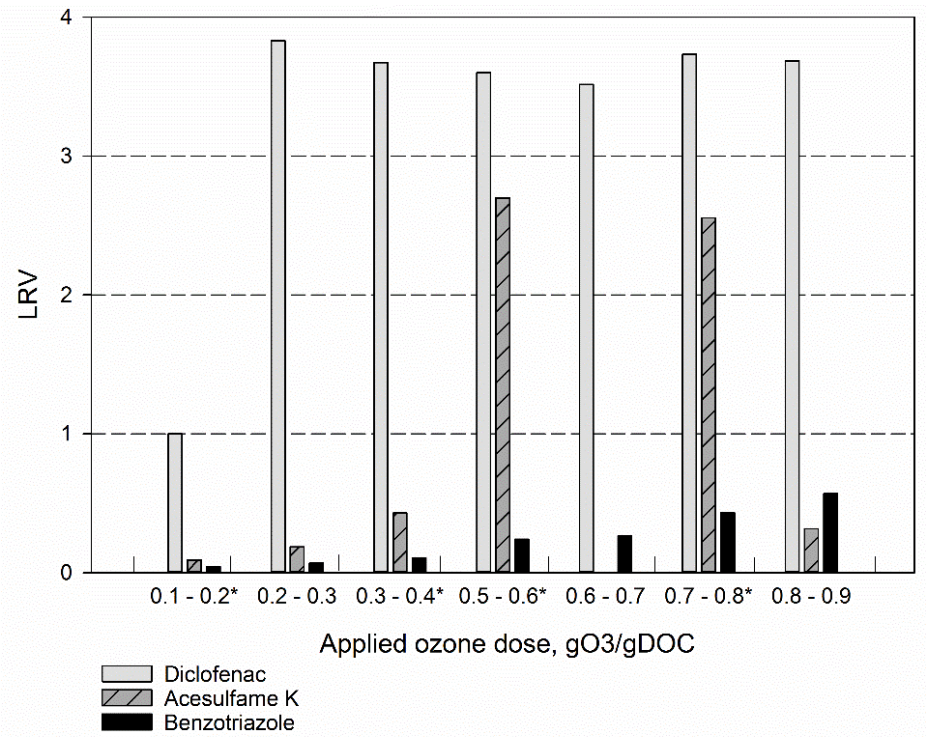


Figure 3. Log removal values for chosen chemicals.

Diclofenac was completely removed by ozone applied in doses equal or higher than 0.25 g O_3/g DOC and no differences between sampling months (thus – water matrices) were observed (Fig. 3). The difference in LRV between sampling months was observed for acesulfame K, suggesting the effect of water matrix (there was a significant difference between one day ozone dose experiment and sampling in another days).

Application of the GAC filter resulted in close to 1 log removal of benzotriazole (average LRV from 4 sampling points was 0.97 ± 0.89), which was hardly removed by ozone treatment (Fig. 3). Removal of acesulfame K varied strongly between sampling points (from 1.12 LRV to -1.09). The GAC filter did not result in a substantial reduction of targeted bacteria groups and abundances in effluent were observed at the same order of magnitude (average LRV for total heterotrophs was -0.02 ± 0.67, total *E. coli*: -0.02 ± 0.12, ampicillin resistant *E. coli*: 0.12 ± 0.06, trimethoprim and sulfamethoxazole resistant *E. coli*: 0.40 ± 0.56).

Conclusions

The main conclusions from the study are:

- Application of ozone doses equal or higher than 0.31 g O_3/g DOC resulted in a substantial shift towards 3 LRV of total and antibiotic resistant *E. coli* (with average removal of around 2.5 log units).

- Absolute and relative abundance of sul1 gene decreased with increasing ozone dose reaching 1.68 LRV for 0.75 g O_3/g DOC. For ozone doses equal or higher than 0.55 g O_3/g DOC, blaTEM absolute abundance as well as blaTEM/16S ratio increased. This observation may suggest survival of bacteria possessing the blaTEM gene.
- Diclofenac was completely removed by ozone applied in doses equal or higher than 0.25 g O_3/g DOC. The effect of water matrix was significant in removal of acesulfame K.
- GAC filter application resulted in close to 1 log removal of benzotriazole, which was hardly removed by ozone treatment. On the other hand, it did not result in a substantial reduction of targeted bacteria groups, which abundance remained stable at the same order of magnitude as in ozonated effluent.

References

Alexander, J., Knopp, G., Dotsch, A., Wieland, A. and Schwartz, T. (2016) Ozone treatment of conditioned wastewater selects antibiotic resistance genes, opportunistic bacteria, and induce strong population shifts. Science of the Total Environment 559, 103-112.

Jager, T., Alexander, J., Kirchen, S., Dotsch, A., Wieland, A., Hiller, C. and Schwartz, T. (2018) Live-dead discrimination analysis, qPCR assessment for opportunistic pathogens, and population analysis at ozone wastewater treatment plants. Environmental Pollution 232, 571-579.

Luddeke, F., Hess, S., Gallert, C., Winter, J., Gude, H. and Loffler, H. (2015) Removal of total and antibiotic resistant bacteria in advanced wastewater treatment by ozonation in combination with different filtering techniques. Water Research 69, 243-251.

Rizzo, L., Manaia, C., Merlin, C., Schwartz, T., Dagot, C., Ploy, M.C., Michael, I. and Fatta-Kassinos, D. (2013) Urban wastewater treatment plants as hotspots for antibiotic resistant bacteria and genes spread into the environment: A review. Science of the Total Environment 447, 345-360.

Electro-Fenton treatment of real pharmaceutical wastewater: a feasibility study

H. Olvera-Vargas[1], N. Gore-Datar[2], S. Mutnuri[2], O. Lefebvre[1]

[1]Centre for Water Research, National University of Singapore, 1 Engineering Drive 2, Singapore, 117576, Singapore.

[2]Department of Biological Sciences, BITS Pilani, K K Birla Goa Campus, NH 17 B, Zuarinagar, Goa, 403 726, India.

The reuse of treated wastewater is now well recognized as a potential source of water supply. Industrial wastewater is generally contaminated with hazardous and biorecalcitrant substances that are hardly removed by conventional biological treatment methods. Pharmaceutical wastewater is of special interest because it contains organics with potential biological effects. In fact, the presence of pharmaceuticals in the environment and their toxic impacts have been well documented [1].

Electrochemical advanced oxidation processes (EAOPs) have emerged as promising methods to treat refractory effluents with significant advantages, including the lack of external addition of oxidizing agents, no production of secondary sludge and environmental compatibility. The electro-Fenton (EF) process has been one of the most studied EAOPs. EF is based on the *in-situ* cathodic generation of H_2O_2 promoting the Fenton's reaction according to Eq. (1-3) [2]. One of the most remarkable features of EF is that it utilizes economic carbon-based electrodes for H_2O_2 production, which positions it as the most feasible electrochemical technique in terms of costs.

$$O_2 + 2H^+ + 2e^- \rightarrow H_2O_2 \quad (1)$$

$$Fe^{3+} + e^- \rightarrow Fe^{2+} \quad (2)$$

$$Fe^{2+} + H_2O_2 + H^+ \rightarrow Fe^{3+} + H_2O + {}^{\bullet}OH \quad (3)$$

In this context, the present work aims at evaluating the efficiency of the EF process on the treatment of a real pharmaceutical effluent making use of inexpensive carbon-brush as cathode and two kinds of anode materials: Ti/IrO_2-RuO_2 and boron doped diamond (BDD). It was found that the best COD and TOC removal yields (90% and 95%, respectively) were obtained with BDD/carbon-brush after 6 h of treatment (with optimal j = 7.35 mA cm^{-2} and 0.2 mM of Fe^{2+} as catalyst) (Figure 1), while 70% and

65% of COD and TOC removal was obtained with Ti/IrO_2-RuO_2/carbon-brush (optimal j = 11.03 mA cm^{-2} and 0.2 mM Fe^{2+}). This difference was attributed to the excellent oxidative properties of BDD, which is known to produce M($^{\bullet}$OH) on its surface via Eq. (4) unlike Ti/IrO_2-RuO_2, which is not considered as a M($^{\bullet}$OH) promotor [3].

$$M + H_2O \rightarrow M(^{\bullet}OH) + H^+ + e^- \qquad (4)$$

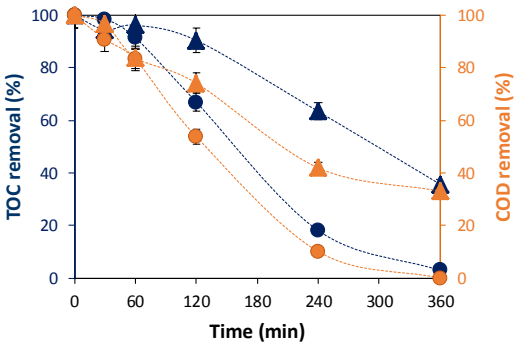


Fig. 1. TOC and COD evolution during the EF treatment using a BDD (●) and a Ti/IrO_2-RuO_2 (▲) anode. V = 500 mL, pH = 3.0, Fe^{2+} = 0.2 mM. COD_0 = 1230 ± 59 mg L^{-1}, TOC_0 = 430 ± 15 mg L^{-1}, BOD_0 = 170 ± 14 mg L^{-1}.

At this point, we must keep in mind that BDD electrodes are expensive and require a substantial investment cost unlike dimensionally stable anodes (DSA) like Ti/IrO_2-RuO_2, which are more robust and accessible [3]. However, in spite of the lower performance of Ti/IrO_2-RuO_2, the effluent's biodegradability (BOD_5/COD ratio) rose with treatment time, reaching the BOD_5/COD threshold of 0.4 for a biodegradable effluent after 2 h in both cases. This fact is of the utmost importance because the treatment could be completed by conventional biological means, representing significant energy/costs savings.

Overall, these findings demonstrated the great potential of EF for the treatment of complex pharmaceutical wastewater for reuse purposes. Conventional and inexpensive electrodes (carbon-brush and Ti/IrO_2-RuO_2) are capable of transforming recalcitrant organics into biodegradable compounds with significant reduction of COD and TOC, making EF an excellent pre-treatment option. Additionally, when higher mineralization yields are sought, BDD could be implemented, whose high oxidation power can degrade chemicals refractory to homogeneous $^{\bullet}$OH. The comprehensive characterization of this real wastewater and degradation pathways followed by the main organic and inorganic species will be provided in the full presentation.

References

(1) Yang, Y.; Ok, Y. S.; Kim, K.-H.; Kwon, E. E.; Tsang, Y. F. *Sci. Total Environ.* **2017**, 596, 303-320.
(2) Brillas, E.; Sire, I.; Oturan, M. A. *Chem. Rev.* **2009**, 109 (12), 6570-6631.
(3) Martínez-Huitle, C. A.; Rodrigo, M. A.; Sirés, I.; Scialdone, O. *Chem. Rev.* **2015**, 115 (24), 13362-13407.

Thermal Activation of Persulfate for Wastewater Depollution on Pilot Scale Solar equipment

Telegang Chekem C[1,2]*; Chiron S.*[1]*; Goetz V.*[2]*;*

(1) UMR HydroSciences 5569, IRD, Montpellier University, 15 Avenue Ch. Flahault, 34093 Montpellier cedex 5, France;

(2) PROMES-CNRS UPR 8521, PROcess Material and Solar Energy, Rambla de la Thermodynamique 66100 Perpignan, France.

Abstract:

This paper investigates on the degradation of pharmaceuticals residues in wastewater (WW), driven by persulfate (PS) advanced oxidation reactions on a solar thermal pilot. According to preliminary studies beforehand carried out on lab scale experiments, 65°C was identified as the right temperature necessary to enable both activation of PS oxidant and degradation of ten target molecules. On the solar pilot equipment, 95 % pollutant removal rate is achieved within 2 hours after the temperature has been raised up to the target value (65°C) in the treated effluent.

Keywords: Wastewater, Emerging contaminants, Persulfates, free radicals, Pilot.

Introduction

Advanced oxidation processes (AOPs) are based upon the formation of highly reactive free radicals species. Typically, free radicals catalyzed chain reactions readily make possible degradation and/or mineralization of a wide range of organic molecules. For many years since the discovery of free radicals potential for water decontamination, hydroxyl radicals (OH°) have been considered among other radicals, as the most attractive (Brienza et al., 2014; Telegang Chekem et al., 2018). The good performances achieved with the well-known Fenton reaction (Fe^{2+}-H_2O_2) raised OH° at the first place. However, the extreme acidic pH conditions required for achieving Fenton reaction now appear as a serious bottleneck for process vulgarization (Clarizia et al., 2017; Johnson et al., 2008).

More recently, sulfate radical has been extensively studied based upon a number of attractive advantages and papers in the literature show how successful they are towards degradation of a wide range of biorefractory organic pollutants. Sulfates free radicals are generated from several routes after in situ activation of commercial

persulfate (PS) ions dissolved in contaminated water (Cai et al., 2018; Matzek and Carter, 2016). UV mediated and transition metals catalyzed activation of persulfate is intensively reported to drive sulfate free radical reactions, sometime combined with a heat treatment to achieve higher performances (Amor et al., 2019). However, fewer research studies addressed direct heat activation of PS and the real advantages it could provide as compared to old existing AOPs. The few recent papers dealing with the issue showed how successful is the activation of persulfate towards a wide range of biorefractory organic pollutants in water (Cai et al., 2018; Yang et al., 2017), but the demonstration of the technique on real pilot equipment needs more investigation. On the other hand, regarding heat demand, energy efficiency of what could be the future real processes are definitely relevant.

This paper investigates on the capacity of a pilot equipment to run solar driven heat activation of PS for removal of water emerging contaminants found downstream wastewater (WW) plants in the south west of Europe. The main objective of the study is to achieve PS thermal activation on a pilot scale solar equipment dedicated to wastewater treatment. Preliminary experiments were first carried out on lab scale indoor experiments prior to outdoor pilot scale experimentations under real solar irradiation conditions.

Material and Methods

At the first place, preliminary experiments enable us to work on small WW volumes 500 mL) to understand first how experimental parameters could interfere with degradation rate of the target molecules. WW was used in this study to keep the pilot demonstration under “real life - like” experimental conditions. WW was collected downstream a WW treatment plant in Perpignan (south of France). Suspended materials were removed after an additional sand filtration and WW was kept at ambient for less than 2 days before usage. **Table 1** presents the average physicochemical composition of WW samples.

Table 1. Physicochemical properties of wastewater samples

MES ($g.L^{-1}$)	pH	Cond. ($\mu S.m^{-1}$)	TOC ($mg.L^{-1}$)	DCO ($mg.L^{-1}$)	NTK ($mg.L^{-1}$)	NGL ($mg.L^{-1}$)	SO_4^- ($mg.L^{-1}$)
8.5	7.4	669	12.2	28.1	7	9.2	

Table 2 presents the ten target molecules used for spiking WW samples, at the level of µg concentrations range i.e to keep close to naturally occurring concentrations. Commercial reagent of these target molecules were obtained from *Sigma Aldrich* at more than 98% purities, together with potassium iodide (99.5%) and sodium bicarbonate (99,7%). Potassium persulfate (99%) was purchased from *Acros Organics*. All the chemicals were analytical reagent grade.

Table 2. List of emerging contaminants used as target molecules

Family	Target Molecules
Nervous system stimulant	Caffeine (CAF)
Lipid-lowering agent	Bezafibrate (BZF)
Antihypertensives	Atenolol (ATN)
Anti inflammatory	Diclofenac (DCF)
	Ibuprofen (IBF)
	Niflumic acid (NUF)
	Tramadol (TRM)
Anticonvulsant lipid regulators	Carbamazepine (CBZ)
Antibiotics	Trimetoprim(TRI)
	Sulfamethoxazole (SFX)

Concentrations of pollutants were determined using an ultra high performance liquid chromatography - electrospray - orbitrap mass spectrometer (UHPLC-MS/MS, *Agilent 1290*), equipped with a C-18 analytical column under 0.2 $mL.min^{-1}$ flow rate of binary water/acetonitrile solvent mixture. Persulfate concentration was determined according to a new spectrometric method recently reported in the literature (Liang et al., 2008; Zhao et al., 2015). TOC measurements were performed with a TOC meter equipment (Shimadzu TOC-VCSH/CSN) after total and inorganic carbons have been determined.

For indoor lab scale experiments, flasks (1L) containing WW samples were placed into a lab thermal water bath set at a given temperature. This allowed to carry out experiments at different temperatures.

For pilot experimentations, **Figure 1** sets out with the picture of the solar pilot. The equipment is globally made up of two reservoirs (upper and lower), a thermal receiver, two pumps and a heat management system. The upper tank (1 m^3) is connected to the thermal receiver (3 x 2 m^2 irradiation surface) over a looping system, which allows pumping and recirculation of contaminated WW effluent.

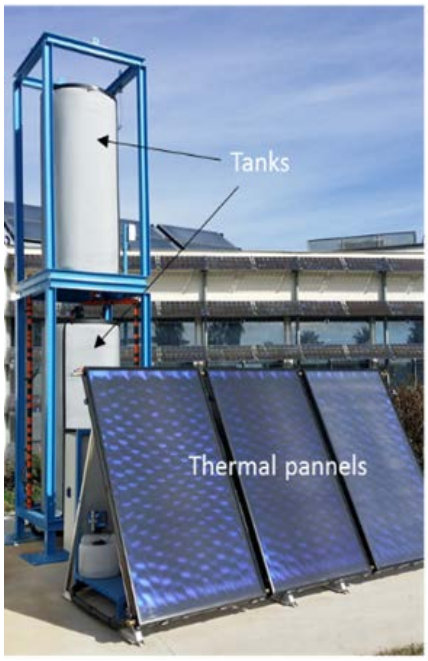


Figure 1. Wastewater treatment solar pilot in the platform of PROMES - Perpignan

PS oxidant was injected at a target temperature to drive pollutant degradation and WW samples were collected over time for determination of residual concentrations.

Results and Discussion

Figure 2 sets out with average concentrations kinetics profiles for lab indoor experimentation at different temperatures, with respect to the ten target pollutant molecules. At room temperature, less than 4 % removal rate is achieved after 5 hours reaction, suggesting the negligible degradation advancement. It's as from 65°C that pollutant disappearance rate becomes significant.

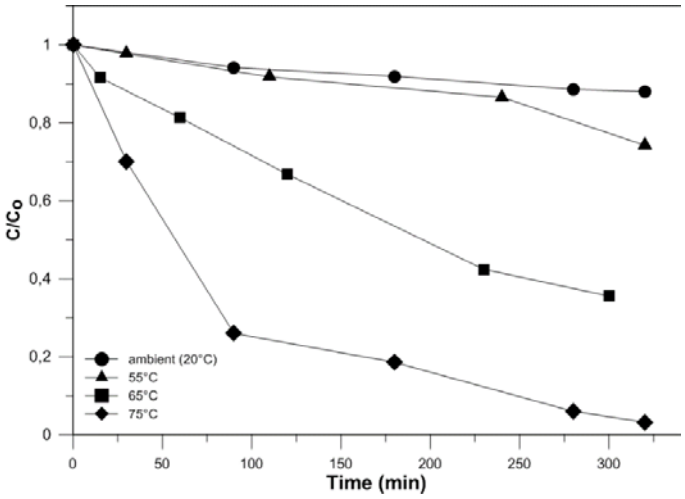
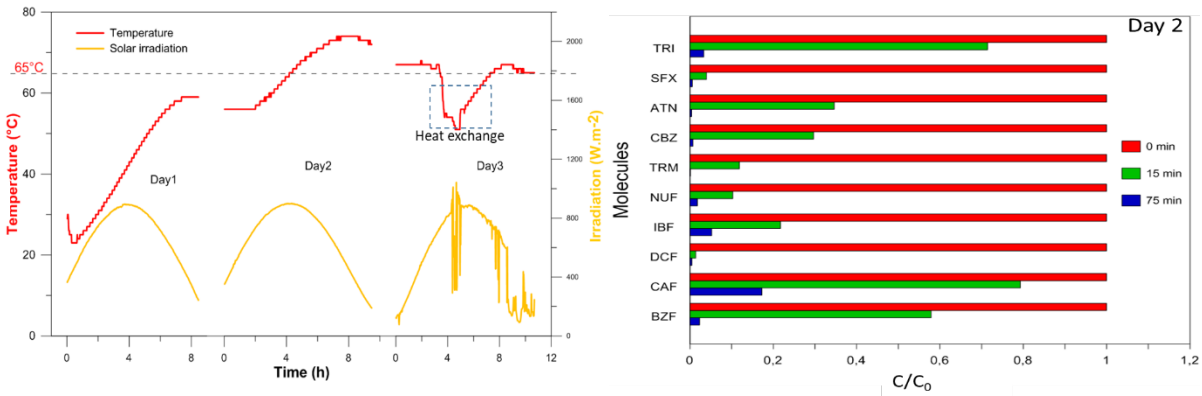


Fig. 2. Kinetic profiles of pollutant removal (average concentration) at different temperatures (PS concentration 200 µM)

This temperature was then identified as the target temperature to achieve on pilot experimentations, before PS oxidant is injected. If injected before this temperature, PS oxidant is degraded and consumed by the heated system, with negligible consequence on pollutant removal (result not shown).

Regarding outdoor pilot experiments, **Figure 3.a** shows the temperature profile of WW effluent (800 L) under solar irradiation over three successive days of the month of June in Perpignan.



(a) (b)

Figure 3. (a) Effluent temperature and solar irradiation in three successive days and (b) degradation kinetic profiles of individual target pollutants.

As it stands now, 02 days are needed for the pilot to raise the temperature of 800 L up to 65°C. In the future, this irradiation time could be shortened by increasing surface area of thermal panels. On the other hand, as soon as the effluent is spiked with PS oxidant, less than 02 hours are needed to remove up to 95 % of pollutants on day 2 (**Figure 3.b**). On day 3, a heat management system allows the pilot to run a new treatment circle within few hours after the new volume of 800 L contaminated water gets in the system.

Regarding total organics in the solution (results not shown), less than 10% initial TOC load is removed when at the meantime almost total degradation of target molecules is achieved. This suggests the selective action of sulfate free radicals as reported in a number of studies in the literature.

Conclusions

In this paper, persulfate is thermally activated on a solar pilot equipment to drive degradation of ten target molecules found in wastewater streams in the south west of Europe. A 800 L volume of WW contaminated by these pollutants is treated on a

solar pilot equipment, within 2 hours as from the target temperature (65°C) is achieved. The constructed thermal solar pilot is an attractive tool regarding environmental remediation, especially for WW treatment and reuse.

References

Amor, C., Rodríguez-Chueca, J., Fernandes, J.L., Domínguez, J.R., Lucas, M.S., Peres, J.A., 2019. Winery wastewater treatment by sulphate radical based-advanced oxidation processes (SR-AOP): Thermally vs UV-assisted persulphate activation. Process Saf. Environ. Prot. 122, 94–101.

Brienza, M., Mahdi Ahmed, M., Escande, A., Plantard, G., Scrano, L., Chiron, S., A. Bufo, S., Goetz, V., 2014. Relevance of a photo-Fenton like technology based on peroxymonosulphate for 17β-estradiol removal from wastewater. Chem. Eng. J. 257, 191–199.

Cai, J., Zhou, M., Yang, W., Pan, Y., Lu, X., Serrano, K.G., 2018. Degradation and mechanism of 2,4-dichlorophenoxyacetic acid (2,4-D) by thermally activated persulfate oxidation. Chemosphere 212, 784–793.

Clarizia, L., Russo, D., Di Somma, I., Marotta, R., Andreozzi, R., 2017. Homogeneous photo-Fenton processes at near neutral pH: A review. Appl. Catal. B Environ. 209, 358–371.

Johnson, R.L., Tratnyek, P.G., Johnson, R.O., 2008. Persulfate Persistence under Thermal Activation Conditions. Environ. Sci. Technol. 42, 9350–9356.

Liang, C., Huang, C.-F., Mohanty, N., Kurakalva, R.M., 2008. A rapid spectrophotometric determination of persulfate anion in ISCO. Chemosphere 73, 1540–1543.

Matzek, L.W., Carter, K.E., 2016. Activated persulfate for organic chemical degradation: A review. Chemosphere 151, 178–188.

Telegang Chekem, C., Goetz, V., Richardson, Y., Plantard, G., Blin, J., 2018. Modelling of adsorption/photodegradation phenomena on AC-TiO2 composite catalysts for water treatment detoxification. Catal. Today.

Yang, J.-F., Yang, L.-M., Zhang, S.-B., Ou, L.-H., Liu, C.-B., Zheng, L.-Y., Yang, Y.-F., Ying, G.-G., Luo, S.-L., 2017. Degradation of azole fungicide fluconazole in aqueous solution by thermally activated persulfate. Chem. Eng. J. 321, 113–122.

Zhao, L., Yang, S., Wang, L., Shi, C., Huo, M., Li, Y., 2015. Rapid and simple spectrophotometric determination of persulfate in water by microwave assisted decolorization of Methylene Blue. J. Environ. Sci. 31, 235–239.

Water reclamation using regenerated membranes for indirect potable reuse and irrigation of private gardens

A. Casadellà, Eurecat, Manresa, Spain; S. Casas, Eurecat, Manresa, Spain; A. Serra, Eurecat, Manresa, Spain; J. Ribera-Pi, Eurecat, Manresa, Spain; X. Martinez-Lladó, Eurecat, Manresa, Spain; S. Reyes, ACA, Barcelona, Spain; A. Pérez, ACA, Barcelona, Spain; Ll. Sala, CCB, Girona, Spain; A. Con, Aigües Costa Brava, Girona, Spain; J. Couso, Ajuntament Tossa de Mar, Tossa de Mar, Spain;

anna.casadella@eurecat.org

Abstract:

Water reclamation is of interest in regions with a seasonal demand and scarcity episodes (e.g. Costa Brava). Membrane technology is suitable as tertiary treatment but it is costly. Costs can be reduced with regenerated membranes that can be tailor-made for permeability (Lp) and rejection (R). End-of-life RO membranes were regenerated and lead to suitable ones for reclaimed water production for private irrigation: hybrid NF with R of BW-RO and hybrid UF with R of NF. They were tested with real effluent reaching both a similar Lp ($3.0 L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$) but different R of salts (UF: 90%, NF:96%) and organic matter (UF:95%, NF:97%). Trace organic pollutants were also monitored and R was mainly >90% proving these membranes as promising for water reclamation with high water quality requirements.

Keywords: regenerated membranes; water reclamation; trace organic pollutants

Introduction

Costa Brava is a touristic region located on the Mediterranean characterized by high seasonal demand and usual water scarcity episodes. It is also one of the first areas in the production of water reuse in Europe with 14 full-scale tertiary treatments that provide $4 hm^3$/year (2016) for golf course and agricultural irrigation, environmental uses, non-potable urban uses and, in a special case, indirect potable reuse. More uses are aiming to be implemented in the area so to increase the flexible use of reclaimed water and deal with the future scenarios of water demand, affected by the expected increase of tourism in the area. Indirect potable reuse through aquifer recharge and irrigation of private gardens are the uses being evaluated for a mid-term extension of water reuse in Costa Brava. These are the more stringent uses according to the Spanish RD1620/2007 and accordingly, advanced treatments such

as membrane treatments are likely to be needed to meet the required final qualities. This, in turn, will increase the operation costs of the reclamation system and it will also likely increase the final reclaimed water price. Commercial membranes, seawater reverse osmosis membranes (SW-RO) membranes, have standard properties in terms of permeability of water and rejection of salts which makes them easily classified (Mulder, 1991). However, these common membranes are not versatile, in other words, they cannot present, for example, a high permeability membrane and a high salt rejection. Project NEXTGEN focuses on the regeneration of end-of-life seawater reverse osmosis membranes (SW-RO) and they are evaluated to be used in the tertiary treatment schemes of Costa Brava instead of commercial membranes for reclaimed water production. The use of regenerated membranes can reduce the operation cost of the treatment scheme by reducing the cost of membrane acquisition, by operating at lower pressures than conventional membranes and at the same time, by reducing the environmental impact of reverse osmosis as the membranes are reused and not disposed to the landfill or incinerated (Gosh *et al.*, 2016). However, water quality produced and its associated risk associated needs to be assessed to ensure health safety.

Materials and Methods

Membrane regeneration and performance. End-of-life SW-RO membranes were provided by a desalination plant located in Spain. These membranes correspond to commercial spiral-wound 8” SW-RO membranes with the active layer made of polyamide (PA) and fabricated by Dow Filmtec. When new, these membrane elements provide a NaCl rejection of 99.8% and a permeability of 0.57 $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$ at 8% of recovery. To regenerate and test this end-of-life membranes, coupons of 140cm^2 where cut from the middle sheets of element. These coupons were then placed in flat-sheet cells made of methacrylate for regeneration or of stainless steel regarding if the aim was either regeneration or performance testing, correspondingly. For each coupon a standard test was performed to assess its performance, allowing to compare initial properties of delivered membranes with the properties of regenerated membranes. Standard tests used are based on the assessments manufacturers provide in their data sheets. These test consisted in assessing and comparing permeability and rejection of NaCl (2,000ppm), if compared with SW-RO, or of $MgSO_4$ (2,000ppm), if compared with nanofiltration (NF) at 25ºC, 15% recovery

and at 16 and 9 bar, correspondingly. After assessing membranes properties with the standard tests at a cross-flow velocity of 0.27m/s, regeneration was carried out. The process of regeneration was conducted in two steps: hydration and oxidation. The hydrating process was passive and oxidation consisted in recirculating an oxidative agent (OA) to increase their permeability and obtain the desired salt rejection. The effect of each of the regenerating steps on the membranes was measured with standard tests for, so permeability and rejection for NaCl and/or $MgSO_4$ were measured.

Effluent sampling and characterization. Representative water to evaluate the performance of the obtained membranes was collected after the secondary treatment, after the sand filter, in the wastewater treatment plant in Tossa de Mar (Costa Brava). Volume collected was integrated in a three-day integrated sample. Analytical characteritzation of the effluent during the study was carried out following methodology presented in **Table 1**.

Table 1. Analytical methods used to characterize the effluent under study.

Parameter	Methodology	Parameter	Methodology
pH, Conductivity	pH-meter, EC-meter	Plaguicides	GC-MS/MS & LC-MS/MS
Cations, Anions	IC (Dionex)	Pharmaceuticals	UPLC-MS/MS
Turbidity	2100Qis Turbidimeter	EDC	SPE-UPLC-MS/MS
Dissolved Organic Carbon (DOC)	3100 N/C, AnalytikJena	Watch List	SPE-UHPLC-MS/MS

Results and Discussion

Membrane coupons after being in contact with the OA solution for different doses changed their performance and achieved different permeability and rejection of salts as presented in **Figure 1**. The higher the dose of OA, the higher the permeability of the regenerated membranes as OA oxidized the polyamide active layer, and thus degraded (Xu, *et al.*, 2013) it allowing higher fluxes across the membrane. Following the reference marks of commercial membranes (dashed line), doses of OA between 0ppm·h (hydration only) and 6,000ppm·h produced regenerated membranes with a permeability close to SW and brackish water (BW) RO membranes. Higher doses of

OA, from 8,000 to 20,000 derived in membranes with a permeability close to nanofiltration (NF) and ultrafiltration (UF) membranes.

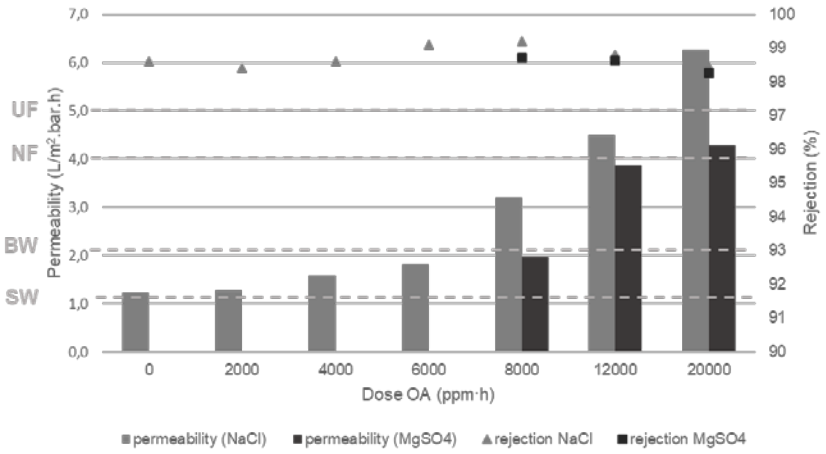


Figure 1. Permeability and rejection of the regenerated membranes. Estimated average permeability values of representative commercial membranes (dashed line).

Even though membranes presented variable permeabilities, rejection remained above 98% for both standard tests (NaCl and $MgSO_4$). Rejections referred to NaCl are standard for RO membranes: above 99.5% is characteristic of SW-RO membranes and, around 99.5% of BW-RO. Rejections referred to MgSO4 are standard for NF membranes being common around 98.5% (Filmtec^{TM}). Thus, the regenerated membranes produced can be classified, in terms of rejection, between BW and NF.

To sum up, the produced regenerated membranes are tailor-made hybrid membranes as they present permeabilities of NF and UF and rejections between BW and NF.

Performance for real wastewater (effluent of the secondary treatment) of two representative hybrid membranes regenerated at 8,000ppm·h (NF) and 12,000ppm·h (UF) were carried out and results are presented in Table 3. For the hybrid NF, a prior pre-filtration at 0.45µm was conducted to simulate real processes of UF as pre-treatment. Both membranes with real wastewater presented a Lp around $3.0 L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$ at 5bar for UF and at 10bar for NF. Characterization of the secondary effluent was conducted in terms of physicochemical parameters so rejections would stablish the quality of the produced water and subsequently compare this quality with legislation (RD1620/2007). Water derived from both regenerated membranes can be considered as reclaimed water and, in principle, it could be used for irrigation of

private gardens as it complies with legislation. However, quality for aquifer recharge has not yet been stated.

Table 2. Removal efficiency of the produced hybrid membranes.

	Effluent of secondary treatment		**Rejection hybrid UF (%)**	**Rejection hybrid NF (%)**
	Value	*units*		
Conductivity	1893	uS/cm	90,9	95,6
Turbidity	9,6	NTU	95,8	40,0
DOC	12,4	ppm	95,9	97,0
Cl^-	296	mg/l	91,6	97,6
SO_4^{2-}	90	mg/l	98,7	>99,6
Na^+	202	mg/l	90,0	94,3
Ca^{2+}	75,5	mg/l	90,3	97,2
Mg^{2+}	17,1	mg/l	90,0	96,5
NH_4^+	54,8	mg/l	80,5	83,4

In addition, and in order to evaluate a possible health and environmental risk of the application, organic pollutants were also characterized and their rejection monitored for the hybrid NF membrane (**Figure 2**). These compounds were found in the secondary effluent in concentrations in the order of tens and hundreds $ng \cdot L^{-1}$ and, after the membrane process, concentrations of most of the compounds monitored were found below the detection limit (10-1.0 $ng \cdot L^{-1}$). Rejection of the produced hybrid membrane is >90% for most of the organic pollutants with exception of several compounds (e.g. TCPP) which require further study to reject them. Given that the majority of compounds present a high rejection, tailor-made hybrid NF membranes are a satisfactory approach for the removal of organic pollutant compounds from secondary effluents for added value uses. However, legislation does not regulate the concentration of such compounds in treated wastewater, so a complete health and environmental risk assessment should be conducted case by case when discharged or further used as reclaimed water.

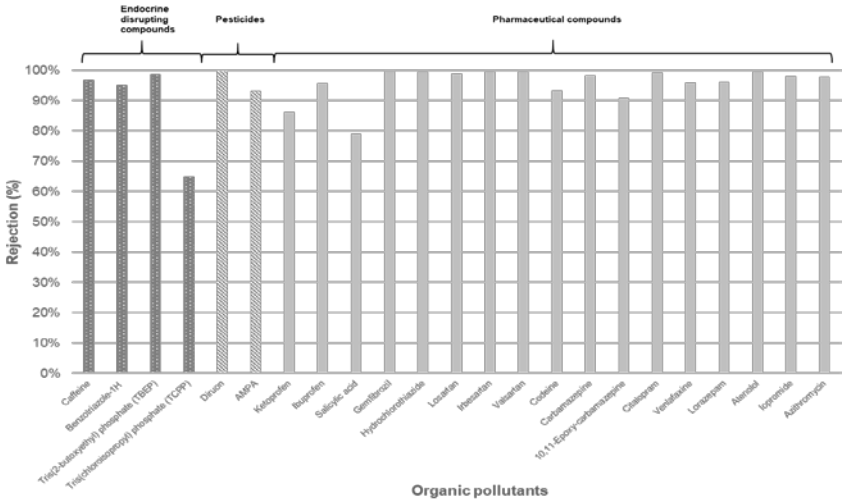


Figure 2. Removal efficiencies for trace organic pollutants of the NF hybrid membrane.

Conclusions

The process of oxidizing end-of-life RO membranes results in a new generation of membranes that can be classified as hybrid regenerated membranes between BW-RO, NF or UF with regard of the dose of OA applied. The application at lab-scale of hybrid NF and UF membranes for the treatment of secondary effluent derived into rejection of salts above 95% and 90%, correspondingly. Rejection of organic matter was very similar for both NF and UF, this being >96%. Rejection of trace organic contaminants were assessed with the hybrid NF membrane and it was >90% for most compounds. In conclusion, tailor-made regenerated membranes are a suitable option to possibly produce high-quality reclaimed water from secondary effluents. However, legislation is not yet clear on the required quality in terms of emerging compounds of reclaimed water and must be determined site by site depending on the risks considered.

References

Filmtec^{TM} Reverse Osmosis Membranes. Technical manual. DOW Water&Process and solution. Form No. 609-00071-0416.

Gosh, P.S., Matsuura, T., Ismail, A.F., Hilal, N. Recent trends in membranes and membrane processes for desalination. Desalination, 391 (2016) 43-60.

Mulder, M. Basic Principles of Membrane Technology. (1996) 2nd Ed. Springer, The Netherlands.

Xu J., Wang, Z., Wei, X., Yang, S., Wang, J., Wang, S. The chlorination process of cross-linked aromatic polyamide reverse osmosis membrane: New insights from the study of self-made membrane. Desalination, 313 (2013) 145-155.

Biodegradable ion-exchange resins for nutrient recovery from effluents of anaerobic membrane bioreactors

Yiwei Li[1], Qiqi Huang[2], Hefeng Zhang[2] and Yeyuan Xiao[1];

[1] Department of Civil and Environmental Engineering, Shantou University, China

[2] Department of Chemistry, Shantou University, China

Keywords: ion-exchange resins; nutrient recovery; anaerobic membrane bioreactors

Summary of key findings

Integration of an anaerobic membrane bioreactor (AnMBR) and ion-exchange using novel biodegradable ion-exchange resins was successfully applied to recover both energy and nutrients from municipal wastewater. The novel ion-exchange resins were synthesized from cellulose and chitosan for the recovery of ammonium-nitrogen and phosphate, respectively. The adsorption capacity of the two resins will be tested in batch tests (on-going). Then, the ratio of the two resins will be optimized to achieve the same breakthrough time of nitrogen and phosphorus in an ion-exchange column. The exhausted resins can be dried and used as a commercial fertilizer; this is a significant advantage over the conventional polymer- or mineral-based resins, which are regenerated or disposed of at high costs.

Background and relevance

Anaerobic membrane bioreactor (AnMBR) process is a promising technology to recover energy from wastewater, and has attracted lots of research interests these years. However, the extremely low, if any, removal of nutrients in AnMBRs necessitates a post-treatment process to make it feasible as a main-stream technology (Mai et al., 2018). A number of technologies have been tried to couple with AnMBRs to tackle this challenge, such as an Anammox process to convert ammonium to nitrogen, and a photobioreactor to recover both nitrogen and phosphorus as microalgal biomass (Mai et al., 2018). However, successful operation of a main-stream Anammox process remains a big challenge despite recent efforts in laboratory research. The huge operating costs associated with microalgal biomass processing make it impracticable for full scale wastewater treatment plants (WWTPs). Struvite precipitation has been successfully applied in full scale WWTPs to recover both nitrogen and phosphorus from anaerobic digestate (Huang et al., 2016); however, the low concentrations of nitrogen and phosphorus in effluents of AnMBRs, and the huge differences in nitrogen to phosphorus ratio from the stoichiometric

requirement have forbidden the use of struvite precipitation as a post process of AnMBRs. Hence, novel processes to couple with AnMBRs are urgently needed to turn wastewater into a real source of energy and nutrients.

In the present study, novel biodegradable ion-exchange resins were synthesized from cellulose and chitosan for the adsorption of ammonium and phosphate, respectively, from effluents of AnMBRs. The adsorption capacities of the two resins were tested in batch tests first, then the two resins will be mixed in an ion-exchange column to treat effluents from a laboratory AnMBRs. Unlike the typical ion-exchange resins which are disposed of or regenerated at high costs, the exhausted resins of the present study can be dried and used as a commercial fertilizer.

Results and discussion

The batch experiments to determine the adsorption capacity of the newly synthesized resins are still ongoing, and will be updated before the conference.

References

Huang, H., Zhang, P., Zhang, Z., Liu, J., Xiao, J., Gao, F., 2016. Simultaneous removal of ammonia nitrogen and recovery of phosphate from swine wastewater by struvite electrochemical precipitation and recycling technology. J. Clean. Prod. 127, 302–310. https://doi.org/10.1016/j.jclepro.2016.04.002

Mai, D.T., Kunacheva, C., Stuckey, D.C., 2018. A review of posttreatment technologies for anaerobic effluents for discharge and recycling of wastewater. Crit. Rev. Environ. Sci. Technol. 48, 167–209. https://doi.org/10.1080/10643389.2018.1443667

Solar photo-oxidation process: an innovative technology to partially mineralize three major pharmaceuticals to make them biodegradable.

REOYO-PRATS B. [1], PROMES-CNRS UPR 8521, PROcess Material and Solar Energy, Rambla de la Thermodynamique 66100 Perpignan, France ; JOANNIS-CASSAN C.[2,3], Université de Toulouse, INPT, Laboratoire de Génie Chimique, 4 Allée Emile Monso BP 44362, F-31432 Toulouse, France ; HAMMADI M. [1] ; DEZANI C.[1] ; GOETZ V.[1] ; CALAS-BLANCHARD C.[4], Centre de Phytopharmacie, CNRS UMR 5054, Université de Perpignan, 52 Avenue de Villeneuve, 66860 Perpignan, France ; LACORTE BRUGUERA S.[5], Department of Environmental Chemistry, IIQAB-CSIC, Jordi Girona 18-26, 08034 Barcelona, Catalonia, Spain ; PLANTARD G.[1] ; brice.reoyo@promes.cnrs.fr

Abstract:

Pharmaceuticals are not effectively degraded by classical wastewater treatment plants and represent an increasing threat to aquatic ecosystems. A solution consists in the implementation, directly at major sources of pharmaceuticals like retirement houses, of advanced treatments. This study determines how three major pharmaceuticals (carbamazepine, diclofenac and ibuprofen) were degraded by photocatalysis in different situations; elucidating cocktail, matrix and concentration effects in controlled conditions. The efficiency of a solar pilot is also verified.

Keywords: pharmaceuticals; photooxidation; cocktail, matrix and concentration effects.

Introduction

One of the latest and most important threat to freshwaters quality is pharmaceuticals which are increasingly used by our modern and aging societies (Boeckel et al., 2017). Pharmaceutical compounds end up in waste waters and are not effectively degraded by classical activated sludge treatments, meaning an important percentage of pharmaceutical molecules is actually directly released in the environment (Han Tran et al., 2018; Luo et al., 2014; Sousa et al., 2018). Some molecules are classified by the European Union as priority pollutants for their persistent or emerging characteristics (European Union Parlement, 2013) but their removal is still not mandatory as the advanced treatments needed are still expensive. Photocatalysis is a non-selective advanced oxidation process, yet able to treat such persistent organic pollutants (Bernabeu et al., 2011; Dalrymple et al., 2007; Miranda-garcía et al., 2010). In this paper, we will demonstrate how to optimize different parameters of the

photo-oxidation process in order to degrade three major pharmaceuticals (carbamazepine, dilofenac and ibuprofen). They have been tested independently and all together, in both tap water and treated wastewater from the waste water treatment plant of Perpignan city. Indeed, controlled conditions have been used to determine the impact of the cocktail effect (the three molecules mixed together *vs* one by one), the matrix effect (treated wastewater *vs* tapwater) and the concentration effect (high *vs* „real world“). This optimization aims at a better degradation of the three molecules by the photocatalysis process in anticipation of a coupling with a membrane bioreactor.

Material and Methods

Two pilots were built, an inside one of 2 L capacity using artificial then adjustable electronical UV light, and an outside one of 400 L capacity using natural UV light from the sun, all their characteristics are given in **Table 1**. The inside pilot allowed to precisely set and test different parameters (flux light density, catalyst concentration, treatment duration…) in controlled conditions before transposing the process to the real-world external pilot (**Table 1**). The maximum flux density (85 W/m²) has been chosen for this study in order to faster and easier follow answers in the degradation phenomena.

Tab. 1. Detailed characteristics of both pilots.

	Internat pilot	External pilot
UV light type	Artificial	Solar
Flux density (W/m²)	0-85	0-60
Total volume V_t (L)	2	300
Irradiated volume V_i (L)	2	70
Ratio V_t/V_i	1	4.3
Irradiated shapes	Cuboid	Tubes
Irradiated projected surface (m²)	0.1	2.9

Ibuprofen (IBU), diclofenac (DCF) and carbamazepine (CBZ) are the three pharmaceutical molecules chosen for this study as they are vastly encountered in freshwaters (Reoyo-Prats et al., 2017; Sousa et al., 2018), show some toxicity characteristics as well as different biodegradability levels (Brandhof and Montforts, 2010; Xia et al., 2017). Titan dioxide (TiO_2) has been chosen in its photospheres form (40 µm glass microspheres) as it floats and is therefore easier to separate from the treated water. Firstly, high concentrations of 10 mg/L were used for the three compounds and followed by UHPLC in our laboratory. Secondly, smaller concentrations of 400 µg/L for IBU and 50 µg/L for CBZ & DCF were followed by LC-MS/MS at COFRAC accredited laboratory Groupe Carso. These smaller “real world

concentrations" have been chosen accordingly to a 2015 wastewater analyses report from the geriatric St Joan establishment.

Results and Discussion

As the solar energy is intermittent (cycles of day and night, seasons, variable weather conditions), results for both exterior and interior were expressed as a function of the accumulated UV energy received Q_{UV} (kJ/L) by the reactor per volume of solution to be treated: $Quv = \frac{S}{Vt}\int_0^t I(t)dt$ where S is the surface of the collector (m²), Vt the total volume of the solution treated (L), and I the incident flux density (W/m²) over time t (s) (Elatmani et al., 2013).

High concentrations

Good degradation of the three pharmaceuticals has first been verified in the best-case scenario: each molecule alone, at high concentration (C_0 = 10 mg/L) and in tap water. The removal of each molecule followed a first order law $\left(\frac{dC}{dQuv} = kC_0\right)$, with DCF being the fastest to be degraded, followed by IBU and then CBZ (**Fig. 1**). Degradation of IBU has been followed in all cases scenario (**Fig. 2**) : in tap water versus in treated wastewater and alone versus mixed with the two other molecules. Slower degradations were always observed when the molecule was mixed than alone, traducing the cocktail effect ; but also when the elluent was treated wastewater instead of tap water, traducing the negative impact of matrix effect on their photocatalysis degradation (Choi et al., 2014; Kanakaraju et al., 2014).

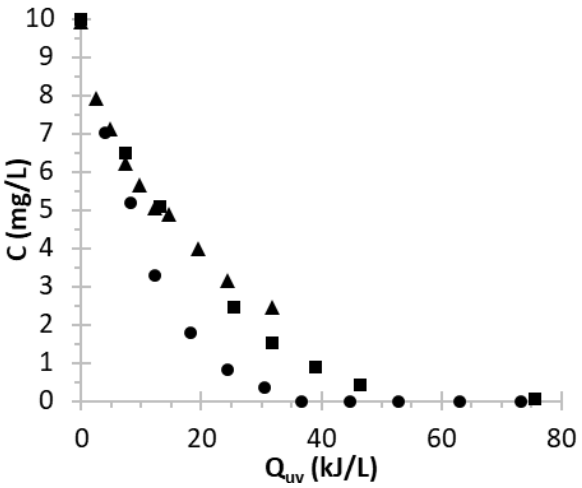


Fig. 1. Degradation of CBZ (▲), DCF (●) and IBU (■) in tap water at 85 W/m² flux

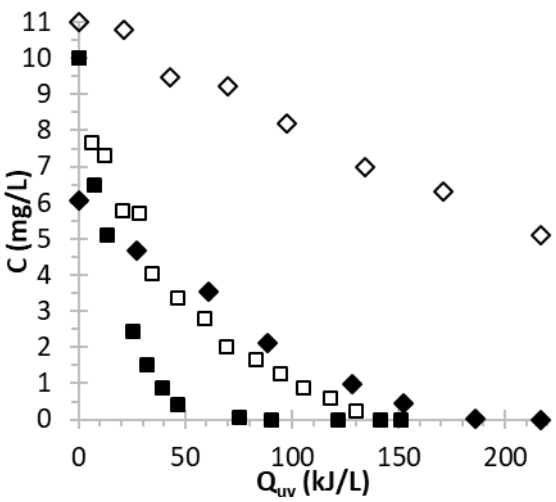


Fig. 2. Degradation of IBU at 85 W/m² flux density in tap water when alone (■)

density.

and mixed with CBZ & DCF (□), as well as in treated wastewater when alone (◆) and mixed with CBZ & DCF (◇).

The degradations of CBZ and DCF have also been studied in the same way, and kinetic coefficients k (in milligram of compound treated by kilojoule of received radiation) have been determined for the three molecules (**Tab. 2**). The highest values for each compound was reached for the molecule alone in tap water and in the order previously stated: DCF had the highest kinetic coefficient with 0.3318 mg/kJ, followed by IBU with 0.2933 mg/kJ and CBZ with 0.2898 mg/kJ. Besides, DCF always showed the highest k values in each case scenario, being therefore an easier pharmaceutical compound to treat by photocatalysis like other study had already shown (Bernabeu et al., 2011).

Tab. 2. Kinetic coefficients k (mg/kJ) in each case scenario for each molecule (in dark color) as well as their ratios Tap Water / Treated WasteWater (TWW) and Alone / Mixed (in light color) for high experimental initial concentrations.

	k (mg/kJ) for experimental high concentrations								
	Alone			Mixed			Ratio Alone / Mixed		
	CBZ	DCF	IBU	CBZ	DCF	IBU	CBZ	DCF	IBU
Tap water	0.2898	0.3318	0.2933	0.1966	0.2283	0.1384	1.5	1.5	2.1
TWW	0.0746	0.1503	0.0393	0.0269	0.0461	0.0280	2.8	3.3	1.4
Ratio Tap Water / TWW	3.9	2.2	7.5	7.3	5.0	4.9			

Concerning the ratios between kinetic coefficients (**Tab. 2**), on average for the three compounds: in tap water, it took 1.7x more time to remove the same initial concentration of molecule when it was alone than when it was mixed, while in treated wastewater it took 2.5x more time. For each compound alone, it took 4.5x more time to get degraded in treated wastewater than in tap water, while this factor was 5.7x when each compound was mixed with the two others. Therefore, at these initial experimental high concentrations, cocktail effect had actually less impact on CBZ, DCF and IBU removal than matrix effect.

Real world concentrations

Real world initial concentrations (C_0 = 400 µg/L for IBU and 50 µg/L for CBZ & DCF) have been tested, treatment still worked in these conditions. Kinetic coefficients have

been determined (**Tab. 3**) the same way as previously and were always smaller than the ones for high initial concentrations (**Tab. 2**). Similar tendencies between high and low initial concentrations had been shown for DCF (Achilleos et al., 2010; Kanakaraju et al., 2014).

Tab. 3. Kinetic coefficients k (mg/kJ) in each case scenario for each molecule (in dark color) as well as their ratios Tap Water / Treated WasteWater (TWW) and Alone / Mixed (in light color) for real world concentrations.

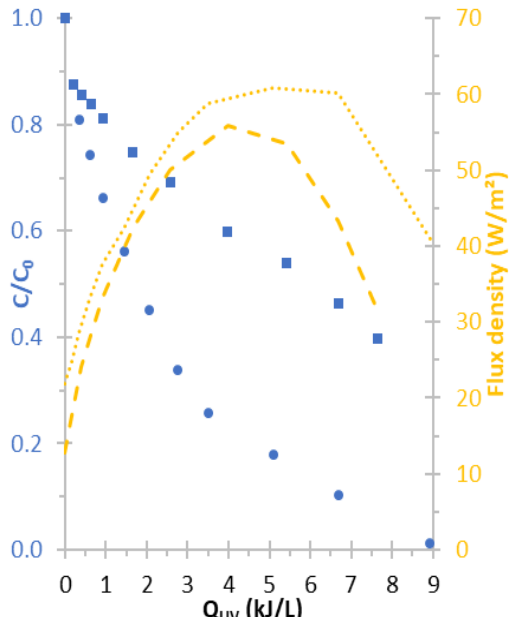
	k (mg/kJ) for real world concentrations								
	Alone			*Mixed*			*Ratio Alone / Mixed*		
	CBZ	*DCF*	*IBU*	*CBZ*	*DCF*	*IBU*	*CBZ*	*DCF*	*IBU*
Tap Water	*0.0014*	*0.0023*	*0.0277*	*0.0024*	*0.0009*	*0.0145*	*0.6*	*2.5*	*1.9*
TWW	*0.0006*	*0.0013*	*0.0173*	*0.0009*	*0.0005*	*0.0076*	*0.7*	*2.6*	*2.3*
Ratios Tap Water / TWW	*2.5*	*1.8*	*1.6*	*2.9*	*1.9*	*1.9*			

For each molecule alone in tap water, a proportionality seemed to be verified between initial concentrations ratios and k values ratios with a magnitude of 1 to 2. However, as soon as the conditions got complexified, behaviors were totally different with no proportionality. Globally the ratios {Alone / Mixed} and {Tap water / Treated WasteWater} are much smaller with real world concentrations (**Tab. 3**) than with high experimental concentrations (**Tab. 2**), which can be surprisingly interpreted as: cocktail and matrix effects had less impact on CBZ, DCF and IBU degradation when they were dosed at smaller initial concentrations.

Fig. 3. Degradation in relation to respective solar flux density in tap water (● / **.**) versus treated wastewater (■ / **-**).

Transposition to natural solar conditions

Degradation has been tested in both tap water and treated wastewater in the transposed external pilot. Promising results have been obtained after 7 h of treatment with the total removal in tap water under 50 W/m² average solar flux density and more than 60 % of removal in treated wastewater under 40 W/m² average solar flux density (**Fig. 3**).



Conclusions

This paper showed that both our photocatalytic pilots works great for the removal of all the considered molecules and in all cases scenarios. On the one hand, the controlled conditions allowed us to verify the globally negative impact of cocktail and matrix effects as well as initial concentrations on the degradation rates.

Acknowledgment

This study has been funded by the Sudeo “Innovec’Eau” project (http://innovec-eau.univ-perp.fr, 2018).

References

Achilleos, A., Hapeshi, E., Xekoukoulotakis, N.P., Mantzavinos, D., Fatta-kassinos, D., 2010. Factors affecting diclofenac decomposition in water by UV-A / TiO 2 photocatalysis 161, 53–59.

Bernabeu, A., Vercher, R.F., Santos-juanes, L., Simón, P.J., Lardín, C., Martínez, M.A., Vicente, J.A., González, R., Llosá, C., Arques, A., Amat, A.M., 2011. Solar photocatalysis as a tertiary treatment to remove emerging pollutants from wastewater treatment plant effluents. Catal. Today 161, 235–240.

Boeckel, T.P. Van, Gandra, S., Ashok, A., Caudron, Q., Grenfell, B.T., Levin, S.A., Laxminarayan, R., 2017. Global antibiotic consumption 2000 to 2010 : an analysis of national pharmaceutical sales data. Lancet Infect. Dis. 14, 742–750.

Brandhof, E. Van Den, Montforts, M., 2010. Ecotoxicology and Environmental Safety Fish embryo toxicity of carbamazepine , diclofenac and metoprolol $. Ecotoxicol. Environ. Saf. 73, 1862–1866.

Choi, J., Lee, H., Choi, Y., Kim, S., 2014. Heterogeneous photocatalytic treatment of pharmaceutical micropollutants : Effects of wastewater effluent matrix and catalyst modifications Applied Catalysis B : Environmental Heterogeneous photocatalytic treatment of pharmaceutical micropollutants : Effects of wastewater effluent matrix and catalyst modifications. "Applied Catal. B, Environ. 147, 8–16.

Dalrymple, O.K., Yeh, D.H., Trotz, M.A., 2007. Review - Removing pharmaceuticals and endocrine-disrupting compounds from wastewater by photocatalysis. J. Chem. Technol. Biotechnol. 82, 121–134.

Elatmani, K., Plantard, G., Sacco, D., Aitichou, I., Goetz, V., 2013. Innovative photocatalytic media optimized for solar-powered remediation: Application to pyrimethanil treatment. Mater. Sci. Semicond. Process. 16, 1117–1124.

European Union Parlement, 2013. DCE 2013/39/EU. Official Journal of European Union, European Union.

Han Tran, N., Reinhard, M., Yew-hoong Gin, K., 2018. Occurrence and fate of emerging contaminants in municipal wastewater treatment plants from different geographical regions-a review. Water Res. 133, 182–207.

Kanakaraju, D., Motti, A.C.A., A, B.B.D.G., 2014. Photolysis and TiO 2 -catalysed degradation of diclofenac in surface and drinking water using circulating batch photoreactors 51–62.

Luo, Y., Guo, W., Ngo, H.H., Nghiem, L.D., Hai, F.I., Zhang, J., Liang, S., Wang, X.C., 2014. A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. Sci. Total Environ. 473–474, 619–641.

Miranda-garcía, N., Maldonado, M.I., Coronado, J.M., Malato, S., 2010. Degradation study of 15 emerging contaminants at low concentration by immobilized TiO 2 in a pilot plant 151, 107–113.

Reoyo-Prats, B., Aubert, D., Sellier, A., Roig, B., Palacios, C., 2017. Dynamics and sources of pharmaceutically active compounds in a coastal Mediterranean river during heavy rains. Environ. Sci. Pollut. Res.

Sousa, J.C.G., Ribeiro, A.R., Barbosa, M.O., Pereira, M.F.R., Silva, A.M.T., 2018. A review on environmental monitoring of water organic pollutants identified by EU guidelines. J. Hazard. Mater. 344, 146–162.

Xia, L., Zheng, L., Zhou, J.L., 2017. Chemosphere Effects of ibuprofen , diclofenac and paracetamol on hatch and motor behavior in developing zebra fi sh (Danio rerio). Chemosphere 182, 416–425.

Modelling and predicting the potential application of new waste-derived activated carbons for controlling pharmaceutical compounds in conventional wastewater treatment

Rui M.C. Viegas; Elsa Mesquita*; Margarida Campinas*; Ana S. Mestre**; Ana P. Carvalho**; Maria João Rosa**

** Water Quality and Treatment Laboratory, Urban Water Division, Hydraulics and Environment Department, LNEC – National Civil Engineering Laboratory, Lisbon, Portugal; rviegas@lnec.pt*

*** Centro de Química e Bioquímica and Centro de Química Estrutural, Faculdade de Ciências, Universidade de Lisboa, Portugal*

Abstract:

This paper addresses the potential application of new waste-derived powdered activated carbons for PhC removal in urban wastewater treatment plants with conventional activated sludge during the secondary treatment, using bench-scale tests to assist PAC adsorption demonstration at pilot and full scales. The results of PhC adsorption in mixed liquor and secondary effluent are used to model and simulate PAC addition into the bioreactor vs. in a post-secondary step, and to elucidate the impact of the biomass on PAC adsorption efficiency. The modeling projections show the benefits of PAC dosing in the bioreactor, with only a slightly higher dose of PAC being needed when compared to its dosing in a post-secondary step but no additional investment needed.

Keywords: Adsorption; modeling; pharmaceutical compounds; waste-derived activated carbons; wastewater treatment

Introduction

Sustainable water services demand a circular economy-driven operation of wastewater treatment plants (WWTPs), enabling water reuse and using renewable materials. LIFE Impetus project (2016-2019) aims at demonstrating feasible improvement measures to control pharmaceutical compounds (PhCs) in urban WWTPs with conventional activated sludge treatment (CAS), using resource efficient processes and low capex solutions, i.e. chemical enhancement with new waste-based powdered activated carbons (PACs). This paper addresses the potential application of new waste-derived PACs for PhC removal in CAS-WWTPs during the

secondary treatment, using bench-scale tests to assist PAC adsorption demonstration at pilot and full scales. PAC full scale application is emerging (Boehler et al. 2012, Zietzschmann et al. 2019) though direct application to CAS reactor (Streicher et al., 2016) lacks in practice to fully understand its advantages (high contact times and PAC concentration due to sludge recirculation) and limitations (PAC blocking by the biomass in the mixed liquor). The results of PhC adsorption in mixed liquor and secondary effluent are used to model and simulate PAC addition into CAS reactor vs. in a post-secondary step, and to elucidate the impact of the biomass on PAC adsorption efficiency.

Materials and Methods

A new carob-based PAC was prepared by steam activation (Mestre et al. 2014) of the solid recovered from the carob pulp acid effluent washed until neutral pH. PAC textural and surface chemistry (i.e. the point of zero charge, pH_{PZC}) properties and morphology (Mestre et al. 2014) were assessed. PhCs were selected for their occurrence in the case study WWTPs and their diversity in properties: diclofenac/DCF (anionic relatively hydrophobic), carbamazepine/CBZ (neutral hydrophobic) and sulfamethoxazole/SMX (anionic hydrophilic). Adsorption isotherms assays (5-20 mg/L PAC) of these PhCs spiked (100 µg/L) in mixed liquor and in clarified mixed liquor were conducted. The water inorganic and dissolved organic matrices were characterised using standard methods of analysis and the dissolved organic matter (DOM) was further fractionated according to charge and hydrophobicity (Table 1). The PhCs were quantified by HPLC-DAD (Viegas et al. 2018).

Table 1 Characterisation of the inorganic and dissolved organic matrices of the WWTP mixed liquor

pH	**EC**	**DOC**	**A_{254}**	**A_{436}**	**SUVA**	**vHB**	**sHB**	**cHL**	**nHL**
	mS/cm	mg C/L	cm^{-1}	cm^{-1}	L/(mg.m)	mg C/L	mg C/L	mg C/L	mg C/L
7.0	2.47	4.1	0.21	0.02	5.1	2.5	0.9	1.0	0.3

SUVA = A_{254}/DOC; vHB - very hydrophobic, sHB - slightly hydrophobic, cHB - charged hydrophilic and nHF - neutral hydrophilic organic matter

Results and Discussion

The carob-derived PAC is a 50/50 micro-mesoporous material with alkaline character, with a mixture of fibers and nonspecific shape particles (Table 2 and Figure 1). The WWTP mixed liquor DOM is predominantly hydrophobic (Table 1), thus of high adsorption competing nature.

Table 2 Carob-derived PAC nanotextural characterisation and pH_{PZC}

A_{BET} m^2/g	V_{total}[a] cm^3/g	V_{meso}[b] cm^3/g	$V_{\alpha\ total}$ cm^3/g	$V_{\alpha\ super}$ cm^3/g	$V_{\alpha\ ultra}$ cm^3/g	pH_{PZC}
762	0.56	0.28	0.28	0.21	0.07	8.0

[a] Evaluated at p/p^0 = 0.975 in the N_2 adsorption isotherms at - 196 ºC
[b] Difference between V_{total} and $V_{\alpha\ micro}$

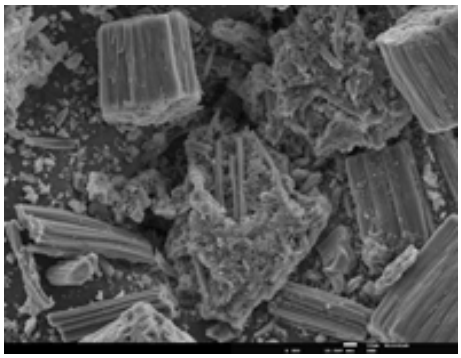


Figure 1 SEM micrograph of carob-derived PAC

The adsorption results were modelled with the Freundlich isotherm equation (equation 1) (Viegas et al. 2014):

$$q_e = K_F \cdot C_e^{1/n} \qquad \text{(equation 1)}$$

where q_e and C_e are the solid-phase and liquid-phase concentrations in equilibrium, respectively, and K_F and 1/n are the Freundlich isotherm capacity and exponent constants, respectively.

The parameters obtained are presented in Table 3. The results showed that the adsorption capacity follows the trend CBZ > DCF > SMX (Figure 2). Further, the particulate matter (mixed liquor vs. clarified mixed liquor data) slightly reduces the PAC capacity towards the hydrophobic DCF (19%) and CBZ (9%) and does not affect its capacity towards the hydrophilic SMX (Table 3).

Table 3 Adsorption Freundlich isotherms parameters of the target PhCs

PhC	water	KF (µg/mg)(µg/L)$^{(1/n)}$	1/n
DCF	C MXL	0.16	0.66
	MXL	0.13	
CBZ	C MXL	0.80	0.40
	MXL	0.73	
SMX	C MXL	0.13	0.61
	MXL	0.14	

C MXL – Clarified mixed liquor; MXL – Mixed liquor

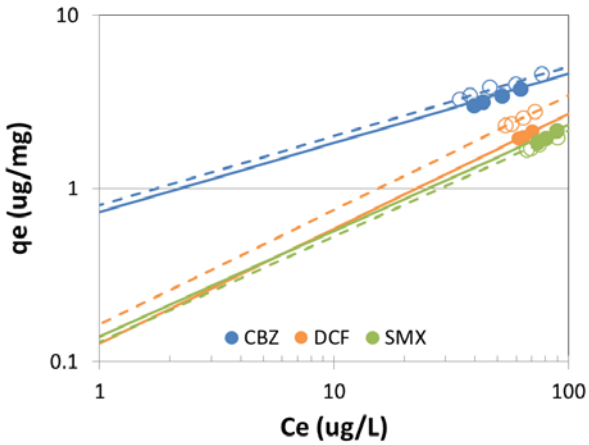


Figure 2 Adsorption isotherm data and Freundlich modelling in the mixed liquor (filled symbols, solid lines) and in the clarified mixed liquor (open symbols, dashed lines)

Assuming the PAC is recycled in both dosing options and that a hidraulic retention time of 30-45 min is provided (Meinel et al. 2016), the PAC full capacity and adsorption equilibrium are achieved and thus PhC removal is given by the adsorption isotherm (equation 1) and by the mass balance equation:

$$C_0 \cdot \mathrm{V} = C_e \cdot \mathrm{V} + q_e \cdot \mathrm{M} \qquad \text{(equation 2)}$$

where C_0 is the initial liquid-phase concentration, V is the solution volume and M is the PAC mass.

Numerical solutions of system of Eq. (1) and Eq. (2) allow predicting the PAC removal efficiency towards the PhCs in their naturally occurring concentrations. Figure 3 shows the target PhC removal as a function of the PAC dose, for the PhC median values recorded during monitoring campaigns, from the WWTP mixed liquor, and from the clarified mixed liquor.

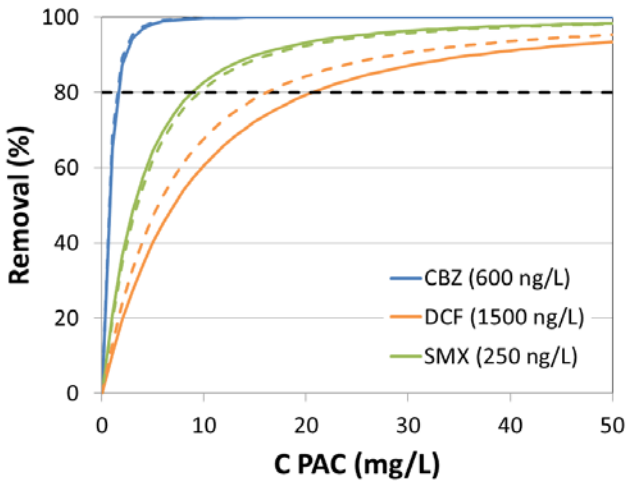


Figure 3 Target PhC removal as a function of the PAC concentration from the mixed liquor (solid lines) and from the clarified mixed liquor (dashed lines)

The projections show that to achieve the same removal of the target PhCs only slightly higher PAC concentrations are required if the PAC is dosed in the bioreactor, e.g. 21 mg/L are required to achieve 80% removal of diclofenac vs. 16 mg/L if the PAC is dosed in a post-secondary step. Nevertheless, this latter option requires dosing coagulant for minimizing PAC particles discharge with the treated water, which, according to our experimental data, is not needed when dosing PAC to the mixed liquor. Further, it requires additional investment in a PAC contactor and in a separation process, e.g. clarifier and/or filter. As so, PAC dosing in the bioreactor is more cost-effective when compared to PAC dosing in a post-secondary step. This approach and these results assisted the operation of the pilot prototypes installed at the project WWTPs, aiming at minimizing its dosing and the full-scale PAC dosing performed.

Conclusions

The lab-scale adsorption results allowed predicting the removal efficiency of the PAC towards the three PhCs in full scale. The modeling projections show that a 30% higher dose of PAC is needed if dosing in the bioreactor than if dosing in a post-secondary step to achieve the same removals. Given the additional investment and the coagulant dosing to prevent PAC particles occurrence in the treated water required in this latter option, PAC dosing in the bioreactor is more cost-effective.

Further adsorption assays have been carried out with different waste-based PACs, namely with pine and pine nut wastes, which showed to outperform high-performing commercial carbons.

Acknowledgments

The authors acknowledge European Union LIFE Programme funding under Grant Agreement LIFE14 ENV/PT/000739 - LIFE Impetus and FCT Portugal for financial support to CQB (UID/MULTI/00612/2019). ASM thanks FCT for her Grant (SFRH/ BPD/86693/2012). Industrial Farense is acknowledged for the carob pulp effluent.

References

Boehler M., Zwickenpflug B., Hollender J., Ternes T., Joss A. and Siegrist H. (2012) Removal of micropollutants in municipal wastewater treatment plants by powder activated carbon. Water Science & Technology, 66.10, 2115-2121.

Meinel F., Sperlich A. and Jekel M. (2016) Pilot-scale study of powdered activated carbon recirculation for micropollutant removal. Water Sci. Technol. 74, 927-934.

Mestre A.S., Pires R.A., Aroso I., Fernandes E.M., Pinto M.L., Reis R.L., Andrade M.A., Pires J., Silva S.P. and Carvalho A.P. (2014) Activated carbons prepared from industrial pre-treated cork: Sustainable adsorbents for pharmaceutical compounds removal. Chemical Engineering Journal 253, 408-417.

Streicher J., Ruhl A.S, Gnirß R. and Jekel, M. (2016) Where to dose powdered activated carbon in a wastewater treatment plant for organic micro-pollutant removal. Chemosphere 156, 88-94.

Viegas R.M.C., Campinas M., Costa H. and Rosa M.J. (2014) How do the HSDM and Boyd's model compare for estimating intraparticle diffusion coefficients in adsorption processes. Adsorption 20, 737-746.

Viegas R.M.C., Mesquita E., Campinas M., Almeida C.M.M and Rosa M.J. (2018). Designing a PAC/NF advanced process for controlling pharmaceutical compounds in reclaimed water. *In* Sanitation Approaches & Solutions and the Sustainable Development Goals. Eds. J.S. Matos, M.J. Rosa. ERSAR, EWA, APESB, CERIS. Lisbon, pp. 69-82.

Zietzschmann F., Dittmar S., Splettstößer L., Hunsicker J., Dittmann D., Meinel F., Rößler A., Metzger S., Jekel, M. and Ruhl A.S. (2019) Fast empirical lab method for performance projections of large-scale powdered activated carbon re-circulation plants. Chemosphere 215, 563-573.

CoRe Water: from WWTP to a sustainable water factory

Kees Roest[1]; Lex van Dijk[2]; Annie Polman[2]; Hans Ramaekers[3]; Alexander Hendriks[3]; Emile Cornelissen[1]

[1]KWR Watercycle Research Institute, Nieuwegein, The Netherlands

[2]BLUE-tec, Renkum, The Netherlands

[3]Royal HaskoningDHV, Amersfoort, The Netherlands

Sewage is thickened by a factor of 20 with membrane filtration. The concentrated stream (1 of the 20 parts) is purified in several steps, the remaining 19 parts are released as pure water. The CoRe Water concept represents a highly innovative approach to the treatment of wastewater. Aims are to reuse of water & materials, reduce GHG & medicines emissions and stimulate modular construction.

Introduction

Scarcity of water is a key driver for reuse of wastewater in many places around the world. Meanwhile, current wastewater practice is challenged to improve on reduction of greenhouse gas emissions, removal of organic micro-pollutants (including pharmaceuticals) and on recovery potential of valuable compounds. This is where the CoRe Water concept comes in: Concentration, Recovery and Reuse.

The challenge in this project is to work on both sustainability and cost-effectiveness of sewage treatment and on better effluent quality (read removal of organic micro-pollutants (OMP; including pharmaceuticals), nitrogen and phosphate). With the innovative purification concept CoRe Water wastewater is first concentrated before it is further treated. In this way, sewage water can be efficiently and efficiently purified with a higher purification efficiency (N, P & OMP) & optimal recovery of resources such as nutrients, energy and especially water: from wastewater treatment plant to sustainable water factory.

Technology

The pre-concentration of wastewater is done with a new technology based on the principle of Forward Osmosis (FO). This is the key step in the production of clean water without nutrients, (pathogenic) micro-organisms and OMP and a concentrated

wastewater stream that can be treated more energy-efficient and from which resources are easier to recover. Due to substantial flow and quality variations, municipal wastewater is a challenging application for FO technology. Presently we are up-scaling the process in three subprojects using pilot research and adjoining laboratory research on different scale sizes for the extraction of water, energy and raw materials. In doing so, we first and foremost investigate the technology of FO itself, but also pay attention to anaerobic treatment, nutrient extraction and removal of micro-pollutants. The possible application of the raw materials is also included in the study.

Solution

The aim is to obtain sufficient information about the technical and economic potential of the CoRe Water concept to assess whether it is a fully-fledged new alternative for the treatment of sewer wastewater and to have sufficient insight into both the overall energy balance and the economic feasibility of the concept. We also obtain insight into the possibilities for reusing water, energy and raw materials (applications) from the concentrate of the FO.

As a first step, the municipal wastewater is concentrated by a factor of 20 applying FO. The concentrated stream (1 part of the 20) is then biologically treated – first anaerobically, then aerobically. In this way the maximum amount of energy and valuable components is recovered, while making the removal of OMP manageable. A key element is concentration of wastewater early in the process, because:

- As a general rule in water technology, the more concentrated the liquid stream, the more efficient treatment processes are.
- The concentrate can be treated anaerobically, which converts organics into methane.
- Recovery of valuable compounds (e.g. nutrients) and energy from the concentrate are favored.
- OMP (e.g. pharmaceuticals) are managed more efficiently.
- The emission of greenhouse gases (esp. N_2O) is significantly reduced.
- And last but not least: the clean water flow can be reused in high-end applications.

The remaining 19 parts of the original wastewater are released as pure water of demiwater quality, which is suitable for reuse in a number of applications. With CoRe Water we're now truly making the step from WWTP to water factory!

Acknowledgement

The CoRe Water project is a collaboration by water boards Limburg, Vallei & Veluwe and Rijn & IJssel, BLUE-tec, Royal HaskoningDHV and KWR Watercycle Reseach Institute. This activity is co-financed with PPS-funding from the Topconsortia for Knowledge & Innovation (TKI's) of the Dutch Ministry of Economic Affairs and Climate.

Non-potable reuse – getting squeezed out in favor of potable reuse?

Summary:

Non-potable (NP) reuse can diversify water supply portfolios. Many applications (e.g., landscape irrigation) are only applicable seasonally and require dual distribution systems. Expanding indoor NP reuse (e.g., toilet flushing, urban agriculture) have risks the industry must take seriously. This presentation summarizes key opportunities in NP reuse and highlights the need to balance benefits and risks of NP and potable reuse practices.

Abstract:

Water reclamation and reuse have taken on increased importance in the management of water supply and wastewater, industries as global water supplies become increasingly strained with climate variability exacerbating the issue. Alternative and efficient water options, such as reuse of reclaimed water, are increasingly needed. The US Environmental Protection Agency (USEPA) 2012 Guidelines for Water Reuse (EPA Guidelines) highlight a broad range of opportunities for using reclaimed water and provide guidance for matching the end use of this resource with the appropriate treatment technologies.

There are a wide variety of untapped "low hanging fruit" – non-potable reuse projects to help diversify communities' water supply portfolios. Many of these applications (such as landscape irrigation), however, only offer seasonal demands while requiring the costs to install and maintain dual distribution systems. Thus, while many communities are expanding indoor uses of non-potable reclaimed water, including toilet flushing and urban agriculture, along with potable reuse of highly purified water, to address the need to provide year-round use of reclaimed water, the benefits and risks of these practices must be considered.

Indoor uses of non-potable reclaimed water are predominantly accidental cross-connection with potable supplies and opportunistic premise plumbing pathogens such as Legionella. With a backdrop of a 400% increase in Legionella outbreaks in the U.S. since 2001 (not linked to reclaimed water), the water reuse industry must take this seriously to avoid any outbreaks linked to reclaimed water.

Additionally, there is a growing body of evidence that shows that there is a need to understand the risks (both acute and chronic) associated with various types of potable reuse. While overall, there have been relatively few health-based studies evaluating the risks associated with potable reuse, several recent risk assessments have bene focused on various types of potable reuse, including: unplanned (or *de facto*), indirect potable reuse (IPR) and direct potable reuse (DPR).

All of the recent studies point to the potential for planned potable reuse to be "safer" than *de facto* practices; however, there is substantial variability in the results of these risk assessments that is not well understood. This calls for the need to further evaluate the risk scenarios, and assumptions, so that risks results can be translated to inform the decision-making in implementation of reuse practices. While the current results reported in the literature indicate that predicted risks associated with planned potable reuse scenarios may belower than those for *de facto* or even non-potable reuse scenarios, site specific data from case studies on *de facto*, planned indirect potable reuse, and direct potable reuse will be presented to further highlight this consideration.

This presentation will provide an overview of the key opportunities remaining in non-potable reuse as well as the challenges that remain, including premise plumbing issues, salinity and nutrient management, and regulation and implementation of decentralized systems. These constraints may further drive communities towards potable reuse, which has been practiced globally since the early 1960's as an effective solution to numerous water resource challenges.

Can chlorine disinfection control the biofouling of reverse osmosis membrane used for municipal wastewater reclamation?

Yun-hong Wang[1], Xin Tong[1], Yuan Bai[1], Xue-hao Zhao[1], Nozomu Ikuno[1], Yin-hu Wu[1] (presenting author), Hong-ying Hu[1, 3]

1 Environmental Simulation and Pollution Control State Key Joint Laboratory, State Environmental Protection Key Laboratory of Microorganism Application and Risk Control (SMARC), School of Environment, Tsinghua University, Beijing 100084, PR China;

2 Kurita Water Industries Ltd., Nakano-ku, Tokyo 164-0001, Japan;

3 Shenzhen Environmental Science and New Energy Technology Engineering Laboratory, Tsinghua-Berkeley Shenzhen Institute, Shenzhen 518055, China

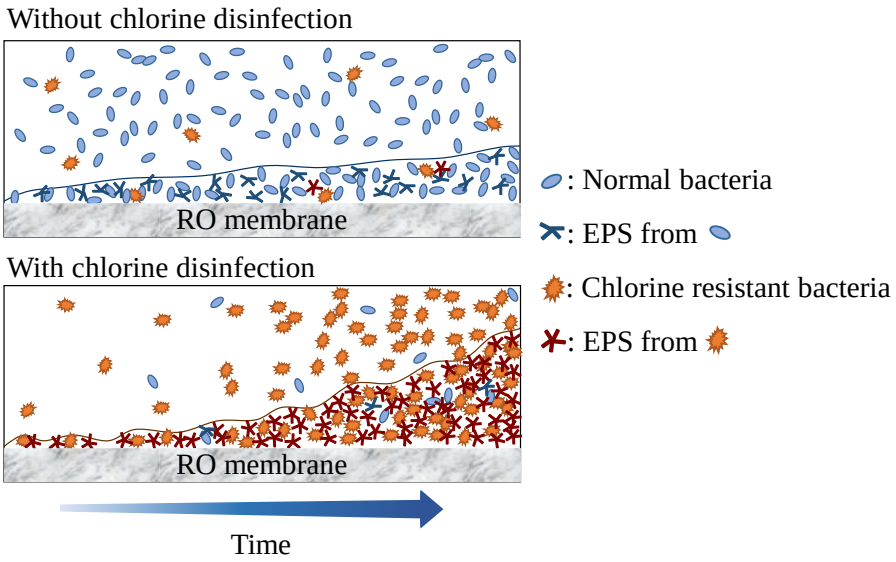


Fig. 1 The difference in the biofouling of reverse osmosis membrane between groups with and without chlorine disinfection

Background Reverse Osmosis (RO) process is now used to produce high-quality reclaimed water from municipal wastewater. In RO system, membrane fouling, especially biofouling, is an inconvenient truth which could result in declining of product water quality and increasing of energy consumption. In municipal wastewater reclamation, chlorine disinfection is the most commonly-used process to inactivate microorganism.

Although chlorine disinfection inactivates most bacteria in wastewater, some chlorine-resistant bacteria could still survive and the microbial community structure changes significantly after chlorine disinfection. Could the change of microbial community structure affect the biofouling of RO membrane? Is it positive impact or negative?

Methods In order to answer these questions above, the effect of chlorine disinfection on the biofouling potential of RO membrane was investigated using a laboratory cross-flow RO system. MBR effluent was disinfected with different dosage of chlorine, and then used as the feed water for the RO system. The operational status of the system was recorded to represent the fouling process, namely normalized flux and salt rejection efficiency. After the operational period, the foulants on the RO membranes were analyzed systematically. Furthermore, we also investigated the properties of extracellular polymeric substances (EPS) produced by the remaining bacteria after chlorine disinfection.

Results and discussion Chlorine disinfection could significantly inactivate the bacteria in MBR effluent. However, in the operation of the RO system, with the increase of chlorine dosage the flux reduction became more and more severe after a period of operation. The final normalized flux after 21 days was 0.27, 0.26, 0.20, and 0.21 with the chlorine dosage of 0, 1, 5, 15 mg/L, respectively.

After the operation, CFU test and ATP test showed that the numbers active bacteria in the foulants with different chlorine dosage were on the same level. However, the thickness of the foulants increased significantly with the chlorine dosage, and more EPS could be observed by scanning electron microscope.

The microbial community structure analysis revealed that the abundance and species number of chlorine-resistant bacteria increased significantly with the increase of chlorine dosage. These remaining bacteria were found to produce more EPS with higher molecular weight, which could be the main cause of severe RO membrane fouling.

Conclusions Chlorine disinfection could aggravate the biofouling of RO membrane due to the change of microbial community structure.

Acknowledgments This study was supported by Key Program of the National Natural Science Foundation of China (No. 51738005).

Factors Affecting Chlorine Stability in Recycled Water Distribution System: How Much Do We Know?

Arumugam Sathasivan, Bal Krishna KC, George Kastl, Que Thanh Trinh, and Andrzej Listowski*[b]

School Engineering, Western Sydney University, Australia; Sydney Olympic Park Authority, Australia.

Abstract

Reuse of treated wastewater in non-potable uses can reduce the demand for drinking water. Shortages of drinking water are experienced on a wider scale and the need for recycling a higher proportion of treated wastewater is increasing. Better disinfection is needed to protect the public from exposure to potential pathogens. This paper describes the stability of chlorine in recycled water. Chlorine was highly unstable and is present predominantly as combined chlorine. Repeated re-dosing or the removal of organics by coagulation improved the chlorine stability and decreased the concentration of combined chlorine, but better improvement is needed. Chlorine instability was probably due to the nitrogenous organic compounds in recycled water. Potential pathways to this goal are discussed.

Keywords: Recycled water, Water reuse, Chlorine decay, Organic nitrogen, Coagulation

Introduction

Recycled water is increasingly used to cope up with the consequences of climate change and increased population and increased industrial/agricultural activities or urbanisation associated with progressive economic development in every country. Many countries including Australia are planning to increase recycled water use (Paul et al., 2019). Recycled water is used for different non-potable purposes such as toilet flushing, car washing, landscape irrigation, industries, commercial use, groundwater recharge. In water-stressed countries or cities, recycled water is used for direct or indirect potable reuse.

To protect the exposed public from microbial pathogens and to prevent excessive regrowth of microbes and hence discoloration events in the recycled water system, disinfectants – mostly chlorine - are added. Many countries have formulated appropriate regulation around minimum disinfectant residual and maximum faecal coliforms. For example, in New South Wales, Australia total chlorine should be > 0.1 mg/L at the customer taps.

The Water Reclamation and Management Scheme at Sydney Olympic Park (SOP) is one of those systems where chlorine is added but experiences difficulty in maintaining steady chlorine residuals within 40 km long pipeline. Caboolture system in Brisbane also experiences the same issue. Although these water utilities are addressing the instability through re-chlorination, it is important to understand the factors affecting chlorine stability in them.

Various factors can affect chlorine decay namely inorganic and organic compounds. Inorganic compounds include ammonia, nitrite, other reductive compounds such as dissolved sulphide, $Fe^{2+,}$ and Mn^{2+}. Organic compounds affecting chlorine decay include carbonaceous organic carbon (Jabari Khopei et al., 2011), nitrogenous organic compounds (Taras, M.J, 1953), including soluble (Bal Krishna et al, 2012) and insoluble microbial products which are essentially proteins (Herath et al., 2018).

This study reports the results of investigations surrounding the factors affecting the chlorine stability in the SOP recycled water supply systems. Secondary effluent from SOP was collected and chlorination and re-chlorination experiments were conducted. In secondary effluent from SOP was also coagulated with ferric chloride to remove organic carbon in an effort to improve the chlorine stability. Implications of results and possible pathways to improve chlorine stability are discussed.

Material and Methods

Water samples were collected from the Sydney Olympic Park (SOP). The SOP system mines sewage and produces recycled water by treating sewage and combine it with stormwater. The domestic wastewater (2.2 ML/day) is treated using a sequencing batch reactor followed by UV disinfection. Stormwater is collected from the drainage system, treated using the wetlands and stored in a 300 ML an open pit. Stormwater and wastewater are pumped into a buffer tank for the final treatment.

Then the mixture of water is treated using the microfiltration (MF) followed by reverse osmosis (RO) membrane filter. Chlorine (10-12 mg-Cl_2/L) is dosed at a chlorine contact tank where water retention time is ~ 1 hr. The chlorinated water is stored at 8 ML storage reservoir for ~ 3 days prior to supply through the distribution system.

The samples were collected from various locations of treatment processes and nine points (DS-1 to DS-9) in the distribution system. The digit represents the sampling location number. Total and free chlorine residuals were measured at the sampling locations immediately after the collection of the samples which were transported to the laboratory and stored at 4 ^{o}C.

The treated and raw water samples were placed in polyethylene bottles and dosed with chlorine and incubated at 23 ^{o}C. In the raw water samples, once the total chlorine residuals dropped below 0.1 mg/L, chlorine was re-dosed.

Coagulation: To test the ability of coagulation to improve chlorine stability, $FeCl_3$ was added and pH was maintained at 5.5-6.0 (Kastl et al., 2004). The samples were filtered through 0.45 µm filter paper for chlorine stability test.

Analytical methods: Free chlorine and total chlorine residuals were measured in accordance with the DPD colorimetric method using a HACH colorimeter. Nitrogenous species (NH_3-N, NO_2-N, and NO_3-N) were measured by Gallery™ Automated Photometric Analyser (Thermo Scientific) following the manufacturer protocols. DOC concentrations were measured using a TOC-L instrument (Shimadzu, Japan).

Results and Discussion

Chlorine residuals measured at various locations of the SOP recycled water distribution system: In the treated water sample (prior to chlorination) of SOP, DOC, NH_3-N, NO_2-N, NOx-N, total nitrogen, and pH were 8.4 mg/L, 0.1 mg/L, 0.02 mg/L, 2.0 mg/L, 2.62 mg/L, and 7.5 unit, respectively. Treated water contained low concentrations of ammonia and nitrite which are known chlorine demanding inorganic nitrogen.

Both total and free chlorine residuals dropped in the storage reservoir and along the distribution pipelines (Figure 1). Average total chlorine and free chlorine residuals drop in the storage reservoir were 1.22 mg/L and 1.39 mg/L, respectively. In the

distribution system, total chlorine and free chlorine residuals were in the range of 0.06-1.10 mg/L and 0.04-0.47 mg/L, respectively. The difference between total and free chlorine residuals increased in the majority of sampling locations while in the distribution system when compared with the inlet and outlet of storage reservoir (Figure 1). The differences could be the result of organic chloramines formation.

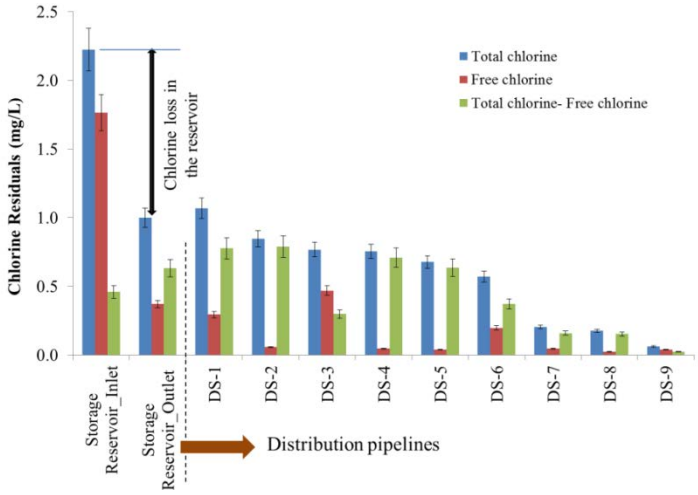


Figure 1: Chlorine (total and free) residuals measured at the inlet and outlet of the storage reservoir and from the various locations of the distribution pipelines.

A rapid drop of chlorine residual was noted in the sample until the 2nd dosing of chlorine (Figure 2) and upon the 3rd chlorine dose, better stability was observed. A rapid loss of chlorine demonstrated the chlorine demand was not satisfied in the bulk water. High chlorine dose may improve stability, but it may increase unwanted chlorinated by-products in the recycled water.

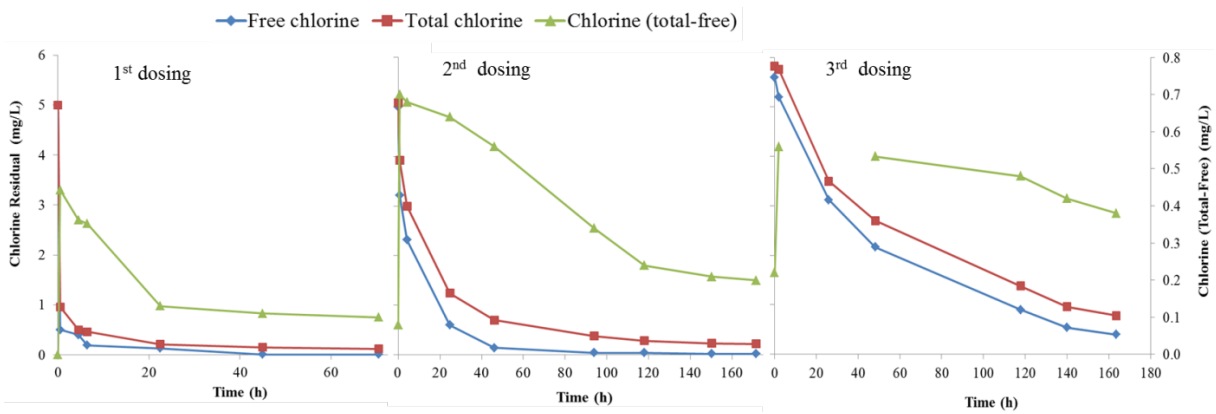


Figure 2: Chlorine (total and free) decay pattern at repeated chlorination in the samples collected prior to chlorination from the SOP recycled water distribution system

Organic chloramine residuals (total-free) were high in the repeated chlorine dosing sample although stability increased with the repeated dose of chlorine (Figure 2).

Since known chlorine demanding inorganic compounds were minimal in the treated water samples, coexisting carbonaceous and nitrogenous organics were removed by coagulation. Even after reducing DOC concentrations substantially (~50%), only a slight improvement in chlorine stability was noted (Figure 3).

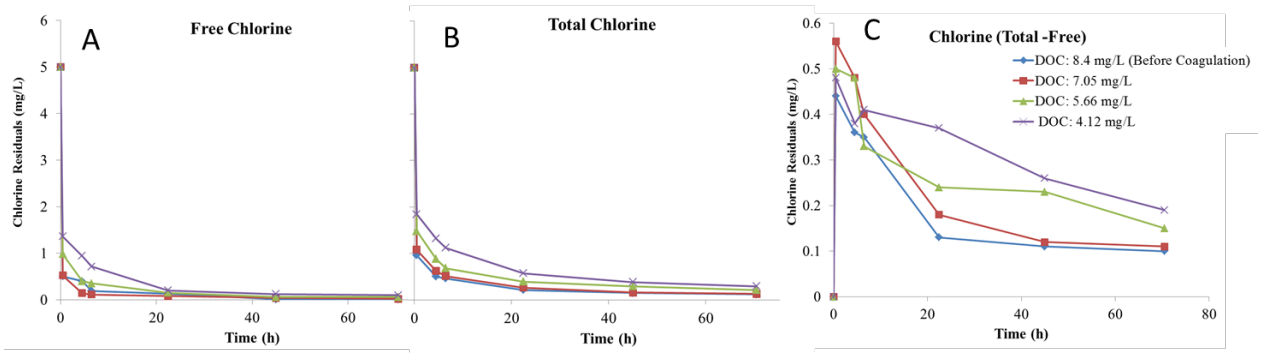


Figure 3: Chlorine (total and free) decay pattern in the treated water collected prior to chlorination from the distribution system of SOP

Organic chloramines are formed as a result of the reaction between chlorine and nitrogenous organic compounds, e.g., amino acid and proteinaceous compounds (Lee and Westerhoff 2009). Proteinaceous organic compounds have been shown to demand up to 38 mg-Cl_2/L for every mg of nitrogen (Taras, 1953). The increase of organic chloramine and quick decay of chlorine in the pipelines could be also the result of the additional reaction between chlorine and biofilms (pipe walls). Although not directly measured, organic nitrogen can explain the reason for the phenomena. Organic nitrogen may either exist in smaller molecules (<2 kDa) and or possess positive charge preventing the organic nitrogen from being removed by coagulation at pH 5.5-6.0.

Organic nitrogen in the recycled wastewater should be characterized and various means of removing them should be attempted. Coagulation may be performed at higher pH (> the isoelectric point) or zeolite could be used. Ozonation followed by biologically activated carbon could be used. In a completely different approach, even chloramination could be attempted.

Conclusions

Better disinfection is needed to protect the public from exposure to potential pathogens in recycled water. Chlorine was highly unstable and was present predominantly as combined chlorine. Repeated re-dosing or the removal of organics by coagulation improved the chlorine stability and decreased the concentration of combined chlorine, but better improvement is needed. Chlorine instability was probably due to the nitrogenous organic compounds in recycled water. Potential pathways such as attempting chloramination, altering treatment conditions to target organic nitrogen are discussed.

References

Bal Krishna, K C, A. Sathasivan, D Sarker (2012) Evidence of soluble microbial products accelerating chloramine decay in nitrifying bulk water samples, Water Research, 46 (13), 3977-3988

Herath, B. S, A.,Torres, A. Sathasivan, (2018) Effects of feed water NOM variation on chloramine demand from chloramine-decaying soluble microbial products during rechloramination. Chemosphere, 212, 744-754.

Kastl, G., A. Sathasivan, I Fisher, J van der Leeuwen (2004) Modeling DOC removal enhanced coagulation, Journal of American Water Works Association, 96(2), 79-89.

Kohpaei, A. J., A. Sathasivan, (2011). Chlorine decay prediction in bulk water using the parallel second order model: An analytical solution development. Chemical Engineering Journal, 171(1), 232-241.

Lee, W., P. Westerhoff, (2009) Formation of organic chloramines during water disinfection–chlorination versus chloramination. Water research, 43(8), 2233-2239.

Paul, R., S. Kenway, P. Mukheibir (2019) How scale and technology influence the energy intensity of water recycling systems - An analytical review, Journal of Cleaner Production, 215,1457-1480

Taras, M. J. (1953). Effect of free residual chlorination on nitrogen compounds in water. Journal (American Water Works Association), 45(1), 47-61.

Urban water reclamation with resource recovery as key potential to close resource loops in Munich, Germany

M.Sc. Mohammed Al-Azzawi, Dr. Daphne Gondhalekar, Prof. Dr.-Ing. Jörg E. Drewes, Chair of Urban Water Systems Engineering,
Technical University of Munich, Germany

As demand for resources such as water, energy and food continues to grow worldwide, cities urgently need to implement measures to conserve resources. Integrated urban planning using water reclamation with resource recovery can significantly support water and energy conservation as well as food security. Using Munich, Germany as a case study city, this paper discusses drivers and barriers to operationalization.

Introduction

With on-going economic growth, demand for resources such as water, energy and food continues to grow worldwide, especially in cities. This pattern of over-consumption has contributed to environmental degradation and climate change. Cities urgently need to implement measures to close resource loops at the latest by 2030 to avert disastrous climatic change and realize the SDGs. Integrated urban planning utilizing the Water-Energy-Food (WEF) Nexus approach can help cities exploit potential synergies between climate change mitigation and adaptation approaches to act on climate change more effectively. Further, with the rapid expansion of cities due to population growth and urbanization, the traditional method of a centralized wastewater collection and treatment is becoming a burden; expensive maintenance is required for the aging plants and piping infrastructure, as well as the extra capital required for expanding the capacity to cover demand from population growth, and meet new regulations for tighter control over certain pollutants such as Trace organic chemicals (TorCs). Herein, urban water reclamation with resources recovery is a key synergy opportunity. A range of technology options for this exists, but so far only few cities worldwide have been able to implement these at larger scales, often because many cities have insufficient capacities to address this issue comprehensively. This paper presents experiences of water reclamation with resource recovery from different geographical and cultural settings, to discuss main drivers and barriers to operationalization of urban water reclamation with resource

recovery. Further, it discusses how water reclamation with resource recovery could be envisioned and operationalized in the city of Munich, Germany. This study aims to show that one alternative to conventional wastewater infrastructure systems may be small, neighborhood scale, decentralized systems and treatment plants. These can be customized according to the required treatment targets (e.g. industrial, commercial, or municipal neighborhood), are easily accessible for maintenance, and they eliminate the need for lengthy pipe networks as is currently the case with traditional approaches.

Methods

The method employed in this study is assessing the economic feasibility of the current situation in the city of Munich. By taking an example of the densely populated, centrally located Maxvorstadt neighborhood and comparing the costs associated with the existing infrastructure there to a proposed decentralized solution derived from studying various case studies from around Europe.

Results

The study finds that the existing centralized treatment method is more expensive than the proposed decentralized concept as it entails a lengthy pipe network that constantly needs maintenance and expansions, as well as the upgrades and maintenance performed on the aging treatment plants themselves. Furthermore, resources such as nutrients, biogas, and rainwater are not being recycled and utilized effectively. As such, the current paradigm could be replaced by a decentralized system at a lower cost and better resources recovery efficiency, thus, propagating a more sustainable future in the face of resources scarcity and climate change.

There are many challenges with the current city models: (1) Water is being treated to a drinking water level and then being used for everything, from drinking to washing and flushing the toilets. This is a waste of highly purified water, and thus a waste of energy and money being spent to treat it. (2) Pumping costs and the energy required are very high due to the length of the supply water network as well as the sewage network, as both originate from and converge to a central treatment plant respectively. (3) The energy budget for treating wastewater is high due to the usage

of aerobic biological treatment. (4) The treated sewage water is then released back to the rivers downstream which means resources such as organic matters and nutrients are leaving the system as waste. (5) Due to the old age of most centralized sewage treatment plants, they cannot cope with the changes and discoveries that happened in the past few decades, therefore rivers are slowly being polluted with substances that are typically not removed in such plants, such as micropollutants like pharmaceuticals, microplastics and body care products... Etc. (6) Also due to their old age, most treatment plants and their associated pipe networks are in constant need of expensive large scale maintenance and upgrades to keep functioning according to new regulations, as well as regular expansions to keep up with the increased population past their original design capacities, not to mention expensive maintenance and expansions to the piping network.

However, after centuries of utilizing and investing in the traditional paradigms, is it even feasible to make a paradigm shift and abandon an existing and functioning centralized treatment plant in favor of an ideal futuristic solution? Perhaps not all at once, change is always a gradual and a slow process. And by making changes in the right places, such a decentralized approach could end up saving energy and money in the long run, while reducing load on an aging infrastructure to avoid expensive upgrades and expansions.

The suggested decentralized system aims also to reduce the footprint on the environment and increasing cities' resiliency in the face of climate change by employing a near closed loop concept, where some of the water and nutrients are recycled and reused, rainwater is harvested and used, and biogas is generated to recover and generate energy from the system.

Below are the most interesting points found by this study about the existing and proposed systems in Maxvorstadt:

- The proposed system's capital costs can be easily recuperated in a little over one year as a result of cost effectiveness.
- The cost of treating wastewater using the decentralized system is around 40% of the current costs incurred by the users if the whole life cycle analysis is taken into account and around 56% of the cost if only the named treatment cost is taken, without including even extra costs from rainwater discharge.
- Energy generation potential of the system was not very large, it covered only 2.26% of the electrical demand and 0.82% of the heating demand inside the

neighborhood. However, it is still an energy positive system and helps to save on costs and reduce the CO2 footprint of the neighborhood.

- Saving on water consumption as a result of rainwater reuse as service water still offered a large saving even in a city like Munich with an abundance of water resources. It is also worth noting that the water harvested was only from roofs with an inclination less than 15 °. Utilizing even more roofs and more rainwater could help reduce water consumption even further, although, for purposes other than toilet flushing, there should be some sort of treatment for the rainwater to avoid health issues.
- Using reclaimed wastewater for urban agriculture has several benefits, as it is rich in nutrients, and offers resiliency in the face of climate change where Summers are expected to be more dry by as soon as 2050 (Gondhalekar & Ramsauer, 2016).
- The problems associated with storing reclaimed agricultural water as well as applying it to the land were mitigated by the use of post-treatment and polishing steps in the form of a Nitrifying tricking filter and a slow sand filter to further reduce COD and Total Nitrogen concentrations which would cause bacterial growth during storage and over nitrification of the soil otherwise.
- A multiple barriers approach to eliminating pathogens as well as the COD that causes regrowth is employed in the system, so as to ensure the safety of the people coming in contact with the urban agricultural areas as well as to protect the groundwater.
- An extra benefit of decentralizing Maxvorstadt as well as rainwater harvesting, is preventing 4.65 Million m3/year from entering the sewage network. Munich utilizes a rather large mixed sewage network with flood retention basins, this extra capacity can help protect the city against urban flooding. And in the distant future if the centralized system were to be fully retired, this immense sewer network can be used mainly for flood prevention. Which would be a valuable defense against the increased flood risks as a result of climate change which is set to increase rainfall in Winters by 2050 (Gondhalekar & Ramsauer, 2016).
- A densely packed neighborhood like Maxvorstadt is a prime candidate for relieving the centralized treatment capacity of the city. Which would have the future advantages already mentioned in the previous points.

- However, another advantage that can be realized even today is instead of upgrading the central plants to increase their efficiency to meet new regulations and challenges, the lowered load because of decentralization would allow the operators of the centralized plants to simply increase hydraulic and solids retention times of the system to get a better effluent quality.

This is a very preliminary feasibility study, but it shows at the very least that such a system shows some promise. Further investigations are needed, followed by a small-scale pilot project and more detailed cost analysis would reveal more about the accuracy of the calculations and assumptions made in this study, as well as the challenges and opportunities not covered here.

Conclusion

Integrated urban planning can support cities to significantly improve water, energy and food security. This is a “window of opportunity” in cities with existing old infrastructures, as well as in cities aiming to build large-scale infrastructure. Particularly climate change related water scarcity is a driver that can enable water reclamation with resource recovery. In Munich however, existing institutional and legal barriers need to be considered, and a lack of capacity of the local government may hamper a comprehensive approach. Research is needed on how to adapt existing technologies. Nonetheless, “products” of decentralized water reclamation with resource recovery can create a revenue stream that can serve as the foundation for a novel governance approach.

Wastewater Disinfection: Performic acid compared to conventional treatment processes

Regina Gnirss, Carsten Lüdicke, Berliner Wasserbetriebe, Berlin;
Hans-Christoph Selinka, Umweltbundesamt, Berlin

Key words: wastewater disinfection, indicator organisms, performic acid, UV radiation, ozonation, membrane filtration,

Since the 1970s, the EU Bathing Water Directive (EU-BWD [1], revised in 2006) requires Members States to monitor and assess the bathing water for at least two parameters of faecal bacteria. In addition, they must inform the public about beach management through so-called bathing water profiles. These profiles have to contain information on the kind of pollution and sources that affect the quality of the bathing water and are a risk to bathers' health, such as waste water discharges.

In Berlin, River Spree and Havel fulfill the criteria as bathing waters. However, during the summer season the flow is as low as 15 and 30 m^3/sec, respectively and urban impact increases. Wastewater Treatment plant effluent, discharging into this rivers, must be disinfected in order to keep the requirements of the EU-BWD. To choose the most efficient treatment, different wastewater disinfection processes have been tested in large-scale. The chemical disinfection using performic acid, UV radiation and ozonation show a significant 3-4 log removal of E.coli and enterococci faecali. These clearly indicate that all disinfection processes are able to achieve “good quality” as mentioned as guide value in BWD. Membrane filtration, using a nominal pore size of 0.2 µm, even achieved E.coli and Enterococci faecali near or below the detection limit of 1 cfu/100 ml. Performic acid could not effect a sufficient reduction either for the viruses or for parasites such as cryptosporidien. The three other processes showed themselves in principle suitable for the elimination of phages/viruses to certain extend. However, an optimization must take place for each process on large scale to determine the design parameters. Additionally, dual media filtration plus UV radiation proved itself to be continuously effective for virus and pathogen removal.

[1] Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC

Golf Courses Irrigation with Reclaimed Water: a Risk Approach

Salgot, M., and Folch, M., Soil Science Unit and Water Research Institute, University of Barcelona, Barcelona, Spain

Abstract:

Golf courses are one of the main users of reclaimed water in arid and semiarid countries and the islands. Nevertheless, this practice must guarantee the safety of the users and other stakeholders.

In order to guarantee the safety when reusing reclaimed water in golf courses, several systems can be applied. Apart from the comparison of analytical results and standards, proactive methods are starting to be used: e.g. HACCP (Hazard Analysis and Critical Control Points) or SSP (Sanitation Safety Planning).

Three golf courses irrigated with reclaimed water have been controlled, and evaluated according to the methods indicated.

The results show that the risk of using reclaimed water in the facilities is acceptable and the methods employed are useful for controlling the practice in an adequate way.

Keywords: reclaimed water; water reuse; golf courses; golf; wastewater reclamation

Introduction

In Catalonia, Spain, as in other places around the world, is compulsory, when available, to use reclaimed wastewater for golf courses irrigation. In addition, reclaimed water reuse is usually subject to rules and regulations, mainly in the form of standards. Nevertheless, given the practical limitations of the standards, other approaches are appearing in the reuse field all over the world, namely risk approaches based on the WHO guidelines (2006). Later on, the European Union launched the Circular Economy (Com 2015) initiative, which includes a clear mandate to reuse wastewater. The same year, the WHO (2015) published the “Sanitation Safety Planning”, adding on the safety idea to regulate reclaimed water use of all the mentioned documents.

The golf is an agricultural and ludic activity, intense and skilled, that can provide important social and economic benefits. In the golf courses, the crop/ lawn, is being used at the same time that is being generated.

Wastewater reuse in golf courses

Apart from the applicable rules, in the specific case of reuse in golf courses is indispensable to know the characteristics of any course where irrigation water is reclaimed wastewater. Since the course is a system modified to obtain a maximum yield of the crop; soils, vegetation and management have been adapted to the reuse practice, apart from the implementation of adapted species and varietals of grass (Salgot et al., 2012).

It is estimated that a standard golf course uses for irrigation the same volume of water that an identical surface with a crop of lucerne; however, the profitability by hectare of the golf course ifs 5 to 20 times more. In terms of water, a golf course located in Mediterranean climate uses for irrigation an average of 1,60 Hm^3 of water/ha and year for 18 holes, from 20 to 54 ha of surface. Also from the economic point of view, it is calculated that the tourism of golf has around 5 times more productivity that the classical sun and beach tourism (Díaz et al., 2016).

The application of reclaimed water must have as a compulsory objective the absence of risks in the real time reuse (safety). The classical method of risk evaluation is focused in the comparison of the analytical results with the water quality fixed in standards. With this method, what is obtained is the history of the quality of the water, which does not allow quick responses in case of deficient quality – not complying with the standards - of the irrigation water. Modern approaches (WHO, 2015) did not abandon the standards but went further on developing the risk concept, which can be applied in a preventive way.

Application of Risk Assessment to golf courses

To overwhelm the indicated problem, methods of risk management have been developed by the WHO (2006, 2009), ISO (2015) or other international instances, but

for this project the Sanitation Safety Planning (SSP) approach has been used (WHO, 2015, which include the HACCP approach).

The SSP approach uses a modular system to analyse the facilities and its associated areas. The six modules are: 1) Preparation of the SSP; 2) Description of the reuse system; 3 Identify the dangerous events, analyse the measures of control and the risks related to reclaimed water contact; 4) Develop and establish a plan of progressive improvement; 5) Control the measures of analysis and verify his performance; and 6) Develop programs of support and perform a revision of the planning. If there are changes, is necessary to restart the procedure in the point 2 (loop).

The work has been performed in two directions: the first one is the preparation of a handbook for reclaimed water use in golf courses (Salgot et al. 2017), including the basic description of a golf course, the description on how to apply the SSP and a guide (protocol) to perform an inspection of any course with regular characteristics

The second part of the work, described in this paper, is the application of the system to two golf courses in the Girona province and one in Barcelona province (Spain), quoted GC1, GC2 and GC3 respectively. The working team has been defined, diagrams have been elaborated and checked in the course Figure 1,2; analytical work has been performed for the parameters indicated in the Spanish RD 1620/2007; the points 1 to 6 defined in the SSP have been followed. The Critical Control Points (CCP) have been established and at present, the baseline of the 3 courses is clear and allowed further work.

After the analysis of the data gathered, three diagrams were constructed.Like the one in (Figure 1,2).

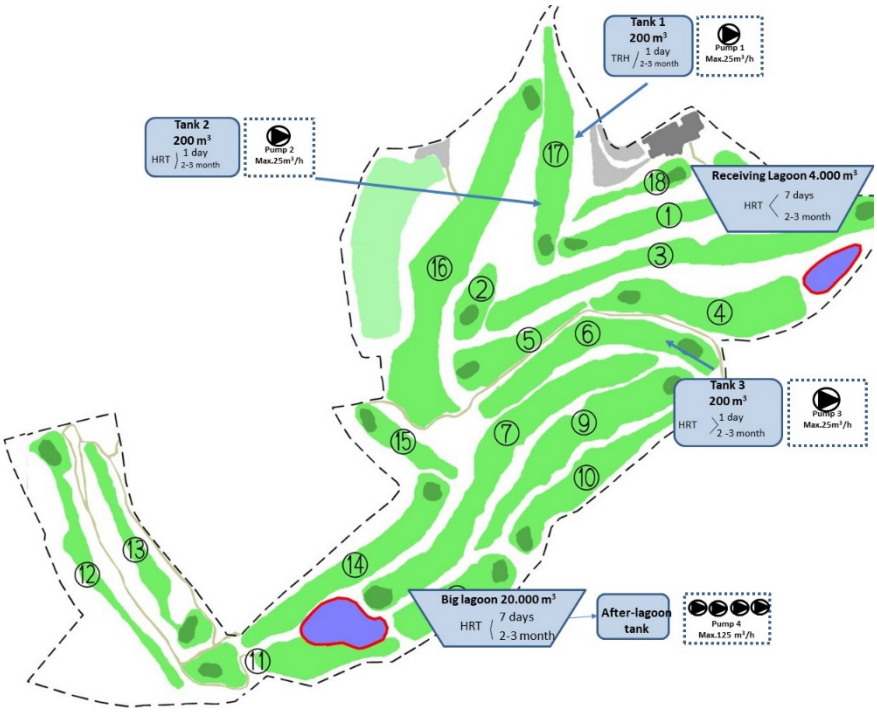
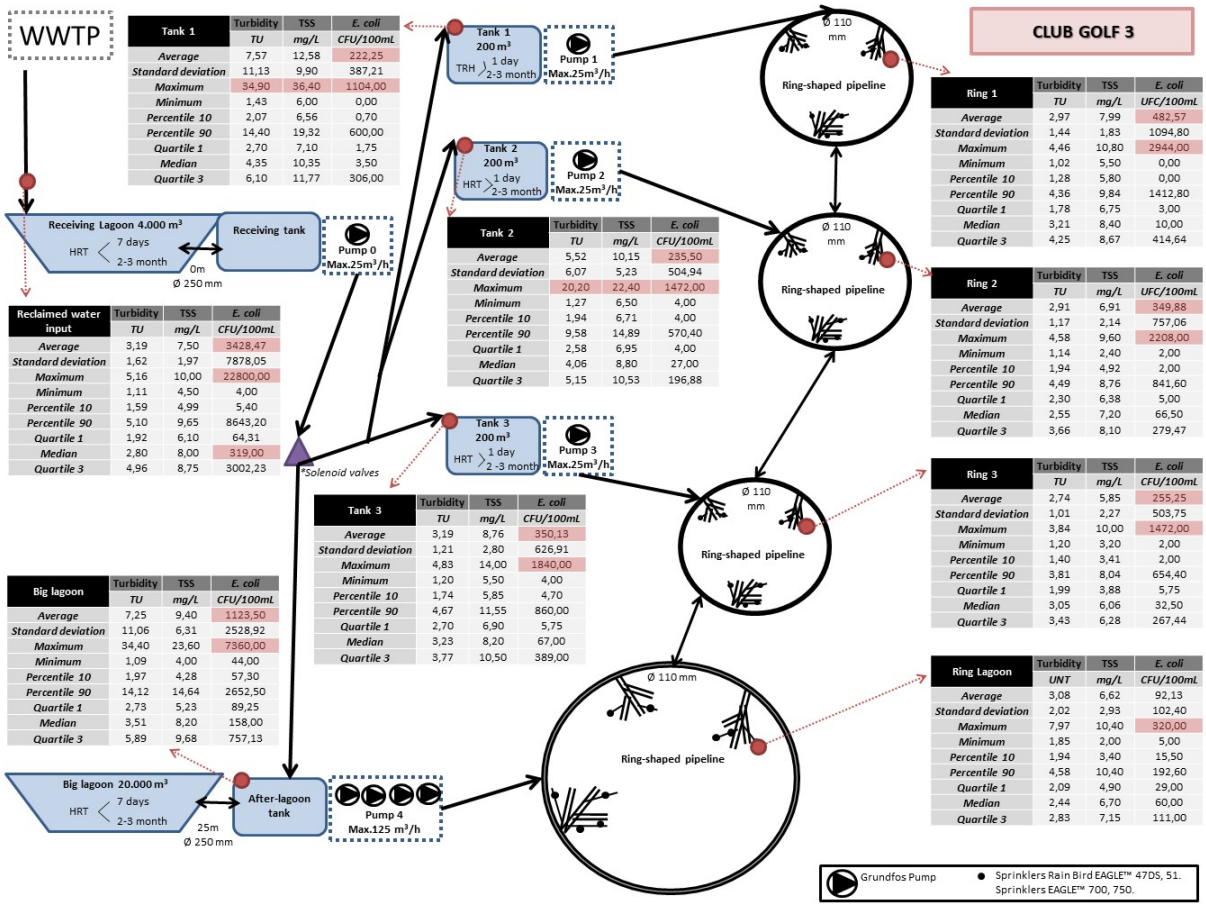


Figure 1 Diagram of one of the golf courses evaluated (CG3)

The results are indicated in the Figure 2



Tank 1	Turbidity	TSS	E. coli
	TU	mg/L	CFU/100mL
Average	7,57	12,58	222,25
Standard deviation	11,13	9,90	387,21
Maximum	34,90	36,40	1104,00
Minimum	1,43	6,00	0,00
Percentile 10	2,07	6,56	0,70
Percentile 90	14,40	19,32	600,00
Quartile 1	2,70	7,10	1,75
Median	4,35	10,35	3,50
Quartile 3	6,10	11,77	306,00

Reclaimed water input	Turbidity	TSS	E. coli
	TU	mg/L	CFU/100mL
Average	3,19	7,50	3428,47
Standard deviation	1,62	1,97	7878,05
Maximum	5,16	10,00	22800,00
Minimum	1,11	4,50	4,00
Percentile 10	1,59	4,99	5,40
Percentile 90	5,10	9,65	8643,20
Quartile 1	1,92	6,10	64,31
Median	2,80	8,00	319,00
Quartile 3	4,96	8,75	3002,23

Big lagoon	Turbidity	TSS	E. coli
	TU	mg/L	CFU/100mL
Average	7,25	9,40	1123,50
Standard deviation	11,06	6,31	2528,92
Maximum	34,40	23,60	7360,00
Minimum	1,09	4,00	44,00
Percentile 10	1,97	4,28	57,30
Percentile 90	14,12	14,64	2652,50
Quartile 1	2,73	5,23	89,25
Median	3,51	8,20	158,00
Quartile 3	5,89	9,68	757,13

Tank 2	Turbidity	TSS	E. coli
	TU	mg/L	CFU/100mL
Average	5,52	10,15	235,50
Standard deviation	6,07	5,23	504,94
Maximum	20,20	22,40	1472,00
Minimum	1,27	6,50	4,00
Percentile 10	1,94	6,71	4,00
Percentile 90	9,58	14,89	570,40
Quartile 1	2,58	6,95	4,00
Median	4,06	8,80	27,00
Quartile 3	5,15	10,53	196,88

Tank 3	Turbidity	TSS	E. coli
	TU	mg/L	CFU/100mL
Average	3,19	8,76	350,13
Standard deviation	1,21	2,80	626,91
Maximum	4,83	14,00	1840,00
Minimum	1,20	5,50	4,00
Percentile 10	1,74	5,85	4,70
Percentile 90	4,67	11,55	860,00
Quartile 1	2,70	6,90	5,75
Median	3,23	8,20	67,00
Quartile 3	3,77	10,50	389,00

Ring 1	Turbidity	TSS	E. coli
	TU	mg/L	UFC/100mL
Average	2,97	7,99	482,57
Standard deviation	1,44	1,83	1094,80
Maximum	4,46	10,80	2944,00
Minimum	1,02	5,50	0,00
Percentile 10	1,28	5,80	0,00
Percentile 90	4,36	9,84	1412,80
Quartile 1	1,78	6,75	3,00
Median	3,21	8,40	10,00
Quartile 3	4,25	8,67	414,64

Ring 2	Turbidity	TSS	E. coli
	TU	mg/L	UFC/100mL
Average	2,91	6,91	349,88
Standard deviation	1,17	2,14	757,06
Maximum	4,58	9,60	2208,00
Minimum	1,14	2,40	2,00
Percentile 10	1,94	4,92	2,00
Percentile 90	4,49	8,76	841,60
Quartile 1	2,30	6,38	5,00
Median	2,55	7,20	66,50
Quartile 3	3,66	8,10	279,47

Ring 3	Turbidity	TSS	E. coli
	TU	mg/L	CFU/100mL
Average	2,74	5,85	255,25
Standard deviation	1,01	2,27	503,75
Maximum	3,84	10,00	1472,00
Minimum	1,20	3,20	2,00
Percentile 10	1,40	3,41	2,00
Percentile 90	3,81	8,04	654,40
Quartile 1	1,99	3,88	5,75
Median	3,05	6,06	32,50
Quartile 3	3,43	6,28	267,44

Ring Lagoon	Turbidity	TSS	E. coli
	UNT	mg/L	CFU/100mL
Average	3,08	6,62	92,13
Standard deviation	2,02	2,93	102,40
Maximum	7,97	10,40	320,00
Minimum	1,85	2,00	5,00
Percentile 10	1,94	3,40	15,50
Percentile 90	4,58	10,40	192,60
Quartile 1	2,09	4,90	29,00
Median	2,44	6,70	60,00
Quartile 3	2,83	7,15	111,00

Figure 2: Water flow chart and results obtained in the GC3, for every control point

Finally, an analysis of the changes in protocols, forced by the appearance of the new EU regulation, will be performed. Nevertheless, the new EU regulation is not definitive at present (March 2019) and only the characteristics that are supposed to remain are considered.

The CCPs of the golf courses are defined and are relative to the advanced reclamation treatments as well as to the storage and distribution systems of the fields.

Conclusions

Golf courses have been developed during the last decades in many areas around the Mediterranean basin. Due to the water resources deficits in the area the irrigation of the courses with reclaimed water is now common.

In the Mediterranean, the development of the golf practice has been associated with the tourism of quality but also with the complaints of many environmental activists.

The scientific study of golf reveals the level of water consumed by the courses and an assessment of the positive and negative economic and social impacts of the practice.

The HACCP/SSP methods are adequate to assess the risk related to reclaimed water reuse in the golf courses.

References

Alcalde, L.; Gawlik, B. (2018). Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge - Towards a water reuse regulatory instrument at EU level. http://dx.doi.org/10.2760/804116

COM (2015). Circular Economy. Closing the loop. An EU action plan for the Circular Economy. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. European Commission, Brussels, Belgium.

Consorci de la Costa Brava, Universitat de Barcelona, Aigües de la Costa Brava (2018). Manual de reutilización de agua regenerada en campos de golf. Girona, Spain. In press.

Díaz, A., Priestley, G., Salgot, M. (2016). Agua para el desarrollo del turismo: una relación desde el nexus agua-cambio climático. International Conference on Regional Science. Santiago de Compostela, Spain

RD 1620/2007, de 7 de diciembre, por el que se establece el régimen jurídico de la reutilizaicón de las aguas depuradas. BOE núm. 294 de 8 de diciembre de 2007.

Salgot, M., Prestley, G., Folch, M. (2012). Golf course irrigation with reclaimed water in the Mediterranean: a risk management matter. Water, 4: 389-429

WHO (2006). Guidelines for the safe use of wastewater, excreta and greywater. Volume 2: Wastewater use in agriculture. World Health Organization, Geneva, Switzerland

WHO (2009). Water safety plan manual (WSP manual). Step-by-step risk management for drinking-water suppliers. World Health Organization, Geneva, Switzerland

WHO (2015). Sanitation safety planning. Manual for safe use and disposal of wastewater, greywater and excreta. World Health Organization, Geneva, Switzerland

Determining the standard of nitrogen and phosphorus concentration in reuse of wastewater in scenic water based on microalgal growth potential

*Guo-Hua Dao [1], Cheng Yang [2], Hong-Ying Hu [1,2,]**

[1] *Environmental Simulation and Pollution Control State Key Joint Laboratory, School of Environment, Tsinghua University, Beijing 100084, PR China*

[2] State Environmental Protection Key Laboratory of Microorganism Application and Risk Control (SMARC), Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, PR China

Reuse of secondary wastewater in scenic water bodies could serve as an effective approach to alleviate freshwater resource shortage, while, excessive nitrogen and phosphorus in secondary effluents was an ineluctable problem, so as to prevent possible issues of eutrophication. Therefore, it is necessary to set a standard of nitrogen and phosphorus for reclaimed water reused in scenic water. However, up to now, there are less research about the potential of algal bloom caused by reclaimed water. Meanwhile, no research has focused on the nitrogen and phosphorus control strategies for reclaimed water. In this study, we evaluated the growth potential of a mixed microalgae collected from scenic water body in reclaimed water with different concentration of nitrogen and phosphorus and the relationship between microalgal biomass and nutrition level were also analyzed.

The results showed that the microalgal growth potential were different in the reclaimed water with different concentration of nutrition, increasing with the concentration of nutrition (Fig. 1). The results of Monod-Droop model show that the risk of algal bloom could be controlled by limiting the concentrations of nitrogen and phosphorus in a certain extent (Fig. 2). Such as, when the N/P=30, the nitrogen less than 0.9 $mg \cdot L^{-1}$ and the phosphorus less than 0.07 $mg \cdot L^{-1}$ were safe extent (The algal bloom biomass standard is 84 $mg \cdot L^{-1}$). Furthermore, the results of model sensitivity showed that when the concentration of phosphorus is less than 0.1 mg L^{-1}, reducing nitrogen concentration will be a good way to control the microalgal growth potential. On contrary, when the concentration of nitrogen more than 1 mg L^{-1}, reducing phosphorus concentration is a good choice (Fig. 3).

Reasonable control the concentration of nitrogen and phosphorus is beneficial to the safe and efficient utilization of reclaimed water in scenic water.

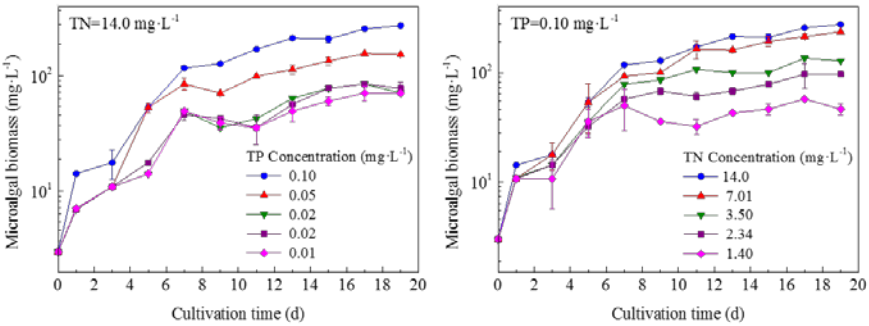


Fig. 1 The growth characteristic of mixed microalgae in reclaimed water with different concentration of nitrogen and phosphorus.

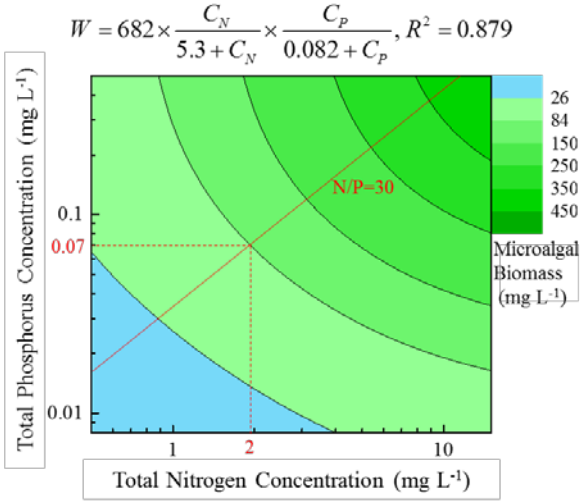


Fig. 2 The relationship between microalgal biomass and nutrition.

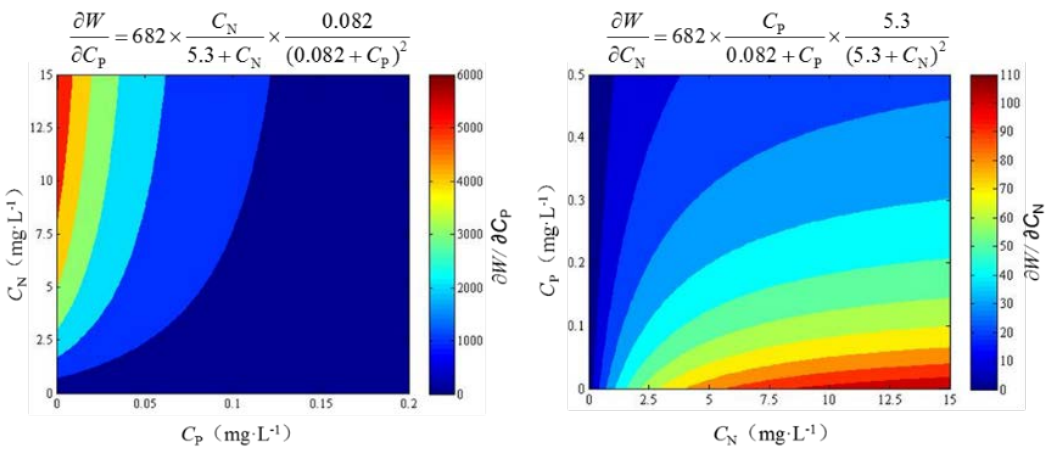


Fig. 3 The model sensitivity.

The Role of Ceramic Membranes in in Improving Water Recyling

Jonathan Clement, Abcoude,The Netherlands; Gilbert Galjaard , Almere, The Netherlands; Nanostone Inc

Over the past 2 decades many water treatment schemes for indirect and direct potable reuse. Nearly all these schemes include reverse osmosis (RO) preceded by polymeric micro-filtration (MF). In the water industry this has become an all too conventional combination for approaching the problem. The polymeric MF systems are severely underperforming as to expectations with most system having a membarne lifetime < 4 years and rapid fouling limiting productivity.

Ceramic membranes because of their ability to recover permeability, resistance to fouling, tolerance of high solids loading due to the large channels, and the ability for direct contact with ozone. In addition ceramic membranes have been shown to retain their permeability for 20 years. The direct contact with ozone creates an enhancement of fluxes by a factor of 2 while providing enhanced oxidation,

Pilot studies have been conducted to test ceramic membranes at 3 different sites with secondary effluent to evaluate the feasibility of ceramic membranes with and without ozone. Data will be presented on the operation of the pilot trails that will illustrate the benefits and feasibility of the approach

Conditioning of super-concentrate brines from industrial water recycling for salt recovery

T. Hogen, M. Kieselbach, S.-U. Geißen, J. Wellmann
Technische Universität Berlin, Berlin, Germany
tobias.hogen@tu-berlin.de

Introduction

State-of-the-art industrial water reuse inherently leads to the production of brine containing inorganic salts and non- or hardly degradable organic compounds. The emerging disposal of brine in local sewage systems or in some areas even directly into water bodies is conceivably leading to ecologic impact especially in regions with high local water stress. In consequence, some governments, local authorities and operators of WWTPs are reacting with stricter disposal limits for the discharges. Starting with the USA in the 1970es, this has led to a growing application of zero liquid discharge (ZLD) technologies (Tong & Elimelech, 2016). On top of legal boundaries, companies are getting aware of sustainability in production as a growing marketing driver. L'Oreal e.g. has committed to reduce its water consumption from 2005 to 2020 by 60% which shall inter alia be achieved by implementing the "dry factory" (L'Oreal, 2017). Non-selective ZLD ends in the production of large amounts of solid waste streams that - depending on its compositions and regional prospects - is stored locally or deposed in landfill (Tong & Elimelech, 2016). From sustainability point of view[1], the development should tend to reuse all resources, including pure water as well as all dissolved components.

The HighCon research project

As a systematic approach to develop and demonstrate alternative, advanced and sustainable ways for brine treatment and disposal, the research project HighCon has been raised. The project comprises the development of new technologies and processes to utilize brine as source for the recycling of inorganic salts (Geißen, 2018). Using holistic methods, the aim of the project is to deliver solutions for defined reference industries looking at recycling water yield, energy efficiency, salt production and reduction of waste streams.

[1] This takes also into account the high energy consumption of conventional ZLD technologies.

Two main concentrate treatment process variants have been defined. Lab and prototype tests for the technologies membrane bioreactor (MBR), nanofiltration (NF), reverse osmosis (RO), electrodialysis (ED), electrodialysis metathesis (EDM) and membrane distillation (MD) have been conducted locally by the project partners. The focused methods of crystallization are low-temperature distillation (LTDis) and multi-effect-humidification (MEH) as they provide robust process designs that are able to cope with high salinity, scaling potential and other extraneous substances that could be contained in the concentrates. One key aspect is the demonstration of industrial application at defined demonstration sites of the following associated project partners:

Clariant Produkte Deutschland GmbH, DEK Deutsche Extrakt Kaffee GmbH, MEWA Textil-Service AG & Co. Management OHG and L'OREAL PRODUKTION DEUTSCHLAND GmbH & Co. KG.

As brines from industrial water recycling are mixtures of multiple components, it can be extremely inefficient to separate salts[2] with sufficient purity just by thermal crystallization. In consequence of that, the processes developed in the HighCon project include pre-concentration of the brine and pre-selection of ions and organic matter via membrane technologies before entering the thermally driven last process steps. In context of the research project, the intermediate product between pre-concentration and crystal precipitation is called super-concentrate (> 8 weight-% salt).

The HighCon demonstration plant and method of testing

In the first demonstration phase, the pre-concentration process chain has been installed directly at a coffee producing site (DEK Berlin). The influent for the demonstration plant has been the effluent of the MBR which is part of the existing conventional wastewater treatment. A side-stream has been fed into a temporarily installed RO which provided the first water recycling stage. The RO brine has been fed to a NF. The NF permeate - expected to be low concentrated in multivalent ions and organic matter - is the influent for an ED in the tested process variant. The ED concentrate has finally been fed to a MD leaving this last treatment step as super-concentrate to be later processed by one of the selective crystallization technologies MEH or LTDis.

[2] Strongly depending on the brine source and composition

This demonstration setup has been operated for approx. 2 month of daily operation while the stream compositions have been systematically analyzed. The characteristic values like recovery rate and ion-specific rejection rates have been calculated as steady-state operation average values. In addition, a lot of operational experience has been received of the technologies interacting with each other.

Results and discussion

Table 1 shows an extract of the water and dissolved solids balance for the first HighCon demonstration process. The process streams are abbreviated as feed (F), permeate (P), diluate (D) or concentrate (C) stream. The displayed load of each stream is referring to the influent (RO-F).

Table 1: Water and dissolved solids balance of the 1st demonstration test

	RO-F	RO-C	NF-P	NF-C	ED-C	MD-C
H2O	100%	36%	18%	18%	2%	0%
DOC	100%	100%	0%	100%	0%	0%
TIC	100%	99%	20%	79%	16%	16%
Cl-	100%	99%	49%	50%	40%	40%
PO4-P	100%	99%	25%	74%	20%	20%
SO42-	100%	99%	1%	98%	1%	1%
Ca2+	100%	100%	5%	95%	4%	4%
K+	100%	99%	30%	70%	24%	24%
Mg2+	100%	100%	7%	92%	6%	6%
Na+	100%	99%	35%	65%	29%	28%
TDS (Salts)	100%	99%	30%	70%	24%	24%
TDS (Total) [g/kg]	1	3	1	4	12	48
Subsequent Operation		NF	ED	Chemical Treatment	MD	Crystallization

It can be stated that the separation of dissolved organic carbon (DOC) from the inorganic ions via NF is nearly complete with a rejection factor of about 100%. Also the rejection of multivalent ions can be considered as effective - this selectivity leads to a simplified ion matrix in the super-concentrate which is beneficial for subsequent selective crystallization. Adding up the permeates/diluates of RO, ED and MD, the water recovery rate of 81% is adequate but offers still potential for improvement.

The NF concentrate contains, besides 18% of the water and the DOC load, the major share of the multivalent and some monovalent ions. A separate (physical or chemical) treatment for the NF concentrate with the aim to raise overall ions and water recovery rate and to reduce the waste stream has been investigated in lab scale - with promising results in part.

The effect of MD is the increase of the residual concentration without showing ion specific sensitivity. In consequence of that, the solids load is almost unchanged from

feed to concentrate. As it can be seen by the TDS (Total) value, the MD concentration rate was approx 4:1.

It can be concluded that the overall salt recovery rate achieved in the first HighCon process demonstration is still subject to optimization. As shown in Table 1, the overall inorganic TDS load in the super-concentrate is 24% of the influent which is considered as not satisfying. Concerning the monovalent ions, the specific recovery rate can reach up to 40% (for chloride) which looks more promising but still needs further improvement.

The total TDS was 4.8 weight% what is below the target of at least 8 weight-% according to the project-internal definition of super-concentrate. The consequence is an operation of ED and especially of the MD in concentration ranges that have been lower than originally designed.

Two major improvement potentials have been identified:

- The used RO pilot device is designed operated as once-through configuration leading to the comparable low recovery rate of 64%. An optimized configuration is estimated to achieve rates of at least 70%.
- The MBR effluent which is enriched of carbonates causes a high scaling potential in subsequent treatment stages. In consequence the recovery rate was limited to 50% to handle the scaling process. Recent results from the second demonstration phase show that the NF recovery rate can be raised to 80% with standard pretreatment e.g. acidifying.

A recalculation of the water and solids balance with improved RO and NF recovery rates indicated that the salt recovery rate of the whole process chain can be improved from 24% to 33%, the monovalent ion recovery rate could improve by 10-20%.

Conclusion and outlook

The first demonstration of the HighCon process chain from MBR to super-concentrate has been successfully conducted, delivering extensive operational data and practical operation experience. The major fields of improvement are the increase of the overall salts recovery rate and the treatment of the NF concentrate. The increase of the RO and NF recovery ratios have been identified as easy-to-handle levers for process improvement. In the next demonstration phase, RO concentrate from the cosmetics industry is treated under consideration of the lessons learned

from the first demonstration phase. It is planned to firstly launch the crystallization of the super-concentrate in pilot scale. Dates and figures from the lab- and demonstration phases will finally be used to set up the process chain for each covered industry including also energy- and economic evaluation as well as LCA.

Acknowledgements

First we would like to thank the Federal Ministry of Education and Research (BMBF) and the Projektträger Karlsruhe (PTKA) which enabled funding and execution of the HighCon project as part of the program "Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)".

As the presented results are condensed extracts based on the contributions of numerous project partners, our special thanks are given to:

DEK Deutsche Extrakt Kaffee GmbH Berlin

Andreas Stern, Richard Kurth

DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V.

Dennis Becker

Deukum GmbH

Hans-Jürgen Rapp

DVGW Research Centre at Engler-Bunte-Institute of Karlsruhe Institute of Technology

Florencia Saravia, Annika Bauer

Fraunhofer Institut für Solare Energiesysteme ISE

Vinay Narayan Hegde, Emily Discepola, Daniel Winter,

Joachim Koschikowski, Joachim Went

MEWA Textil-Service AG & Co. Management OHG

Diana Wolf

SolarSpring GmbH, Freiburg

Rebecca Schwantes, Jakob Seger

Technische Universität (TU) Berlin

Max Wimmer, Maximilian Wirjatijasa

Terrawater GmbH

Nicolas Heyn

Wehrle Umwelt GmbH

Miriam Weissroth

References

Geißen, S.-U. (2018). Konzentrate aus der Abwasserwiederverwendung. *wwt 9/2018*.

L'Oreal. (2017). *2017 PROGRESS REPORT: Sharing Beauty With All - The L'Oréal Sustainability Commitment.* L'Oreal.

Tong, T., & Elimelech, M. (2016). The Global Rise of Zero Liquid Discharge for Wastewater Management: Drivers, Technologies, and Future Directions. *Environmental Science & Technology*.

Experimental Results on Brine Treatment with Special Configuration of Membrane Distillation

Vinay Narayan Hegde1, Fraunhofer ISE1, Freiburg1, Germany1; Dr. Daniel Winter, Fraunhofer ISE2, Freiburg2, Germany2; Rebecca Schwantes3, Solar Spring3, Freiburg3, Germany3; Dr. Joachim Went4, Fraunhofer ISE4, Freiburg4, Germany4; vinay.narayan.hegde@ise.fraunhofer.de

Abstract:

Sustainable desalination and zero liquid discharge (ZLD) can solve the problems associated with water supply and wastewater management. Membrane distillation is one among the promising and emerging technology to address desalination and ZLD. The main idea of this work is to test experimentally a special configuration of membrane distillation (MD) for treating brine. Feed Gap Air Gap Membrane Distillation (FGAGMD) setup is used to treat the brine (may be from industrial wastewater, water treatment plants, desalination plants etc.) to produce the solution near the saturation point or super saturation. Characterization on the performance parameters is done with a lab scale experimental setup. Operation temperature, feed flow rate and salinity are found to be the main influencing parameters on the performance. From the experiments it is confirmed that FGAGMD configuration can treat the brine up to saturation and over saturation. Later the concentrate output from the MD can be used to realize ZLD.

Keywords: FGAGMD; ZLD

Introduction

One of the main challenges in the current scenario of globalization and climate change is water supply and wastewater management. For industrial scale seawater desalination plants, brackish water and inland desalination plants the disposal problem becomes more serious. Using ZLD concept for desalination can give the solution to the problems associated with wastewater or brine disposal [1].

Membrane Distillation is an emerging membrane-based technology for desalination and industrial effluent treatment. Also, the salt rejection rate is nearly 100%, producing water at high purity, independent of feed concentration [2, 3]. Chmielewski [4] in his master thesis worked on an analysis of MD to treat high concentrated saline solution and the results show that MD can be effectively used to treat the water until the concentration of 250 g/kg which is the saturation limit of most of the salt

solutions. Several researchers mentioned that MD has huge potential for treating high salinity brine due to its intrinsic suitability [1, 5–11]. Advantages of MD include, possibility to use low grade energy such as solar thermal heat or waste heat, operating temperature is between 5°C to 80°C, driving force for water separation is temperature difference, less potential for fouling and scaling of the membrane than in pressure driven membrane separation [6, 12]. The results from a techno-economic analysis of MD and MVC by Schwantes et.al., shows that MD is around 40% more cost effective than conventional MVC for ZLD system of capacity 100m^3/day, and that it can be nearly 75% more cost effective if the free of costs waste heat is used [13]. So, due to the capability of harnessing low-grade energy, primary energy demand, operating cost, and greenhouse gas footprint of ZLD can be reduced significantly. However, in common MD configurations like direct contact MD (DCMD), air gap MD (AGMD) and permeate gap MD (PGMD) feed and permeate handling is an issue if the feed and permeate are of corrosive, toxic and hazardous in nature.

It is possible to overcome the issues with treating high salinity, corrosive and harmful brine with Feed Gap Air Gap Membrane Distillation (FGAGMD) configuration FGAGMD configuration consists of 4 channels namely, evaporator channel, condenser channel, air gap and feed channel. In FGAGMD feed is exempted from heating and cooling function, hence normal tap water can be used in evaporator and condenser channels which reduces the risk and cost of heat exchangers and hydraulics.

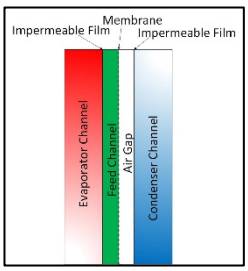


Figure 1. Schematic of FGAGMD

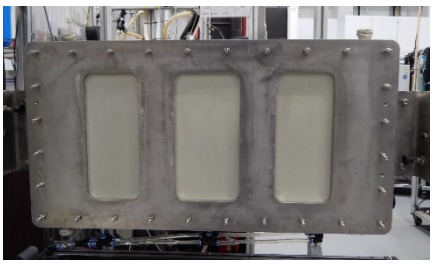


Figure 2. Assembled FGAGMD module

Figure 1 illustrates the configuration of FGAGMD. Evaporator and condenser channels are separated with an impermeable thin polymer film from functional fluids such as feed and permeate respectively. Feed and permeate are separated by a microporous hydrophobic membrane.

Material and Methods

A multi-purpose membrane distillation test rig for flat sheet membranes is developed for laboratory scale measurements and characterisation of membrane parameters. The test rig offers active membrane area of 670×310 mm^2 for the MD process. FGAGMD module configuration is assembled using appropriate channel plates and channel spacers. For the experimentation, commercially available membrane and spacer materials are selected. The membrane has a pore diameter of 0.2 μm and voidage of 80%, spacers used in thermostat channels, air gap have 2 mm thickness, and 80% voidage with rhombus shape, spacer in the feed channel is 1mm thick and has parallelogram shape voidage with 80% of voidage space. The assembled FGAGMD module (Figure 2) is integrated into a test facility with necessary hydraulic connections, controls, sensors and data acquisition system. An insulation box is also provided to prevent heat loss to the ambient.

Effect of bulk mean temperature or temperature level, flow rate of feed V_f (flow velocity c_f) and salinity of the feed S_f are chosen for evaluation of the performance. The evaporator inlet temperature T_{ei}, condenser outlet temperature T_{co} and feed inlet temperature T_{fi} are controlled by a proportional integral (PI) controller. The flow rate in thermostat cycle V_t is fixed at 160 l/h (or flow velocity $c_t = 0.08\, m/s$). The conductivity of feed and distillate are monitored continuously. The performance parameters selected for comparison are flux through the membrane j_M, evaporation efficiency of the membrane η_{ee} and thermal efficiency η_{th} of the system. η_{ee} is the ratio of latent heat transfer to the total heat transfer through the membrane and η_{th} is defined as the ratio of the latent heat through the membrane to the total heat supplied by the evaporator channel.

Results and Discussion

The results obtained at different mean temperature of evaporator inlet and condenser outlet temperatures (temperature level) $\bar{T}_{ei-co}$ for tap water and NaCl solution with concentration of 100 g/kg are shown in Figure 3.

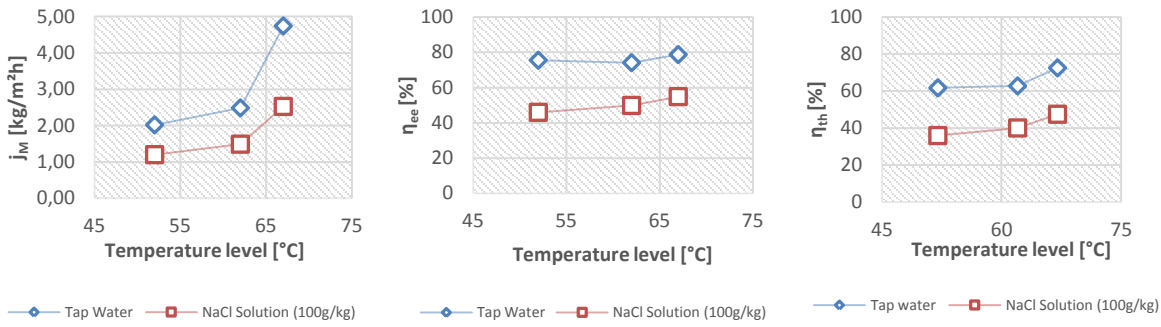


Figure 3. Influence of temperature: V_f = 10 l/h (c_f= 0.0075 m/s), V_t= 160 l/h (c_t= 0.08 m/s)

The transmembrane flux follows the increase in temperature as same as vapor pressure. The transmembrane flux at temperature level of 52°C (T_{ei}=60°C, T_{co}=44°C) is found to be 2.019 kg/m^{2}h for tap water. At temperature level of 67°C (T_{ei}=80°C, T_{co}=54°C) flux doubles and reaches maximum of 4.741 kg/m^{2}h. The relative increase is calculated as 135%. The evaporation efficiency and thermal efficiency slightly increase with increase in temperature due to more losses through the membrane and to the ambient.

The influence of feed flow velocity on performance parameters is presented in Figure 4. The results show that there is a decrease in performance of MD with increase in the feed flow rate starting from the minimum possible feed flow rate. The reduction in flux for tap water and saline water is counted as 38.9% and 45.4% respectively. The main reason behind this reduction in flux is due to low retention time of feed in the channel for higher flow velocities. In addition, the evaporator is not capable of supplying enough heat to the feed at higher flow rate as the surface area available for conductive heat transfer from evaporator to the feed through the film is limited and as a result bulk mean temperature of the feed reduces.

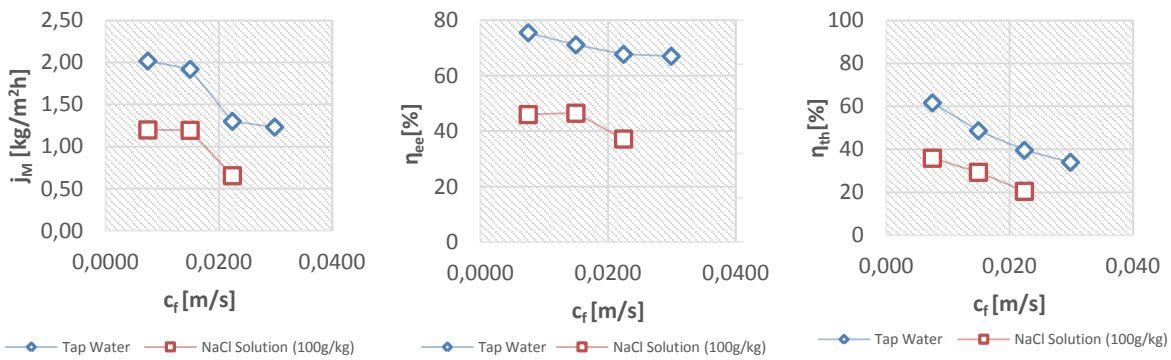


Figure 4. Influence of feed flow: V_t= 160 l/h (c_t=0.08 m/s), $\overline{T}_{ei-co}$=52°C, ΔT_{ei-co}= 16°C, T_{fi}= 50°C.

η_{ee} decreases with increase in feed flow rate. The decrease in η_{ee} can be attributed the reduction in transmembrane flux. Also, a huge amount of heat transferred from evaporator to the feed channel is carried out of the module with feed itself as sensible heat. Thermal efficiency (η_{th}) accounts for all the losses from the module and hence thermal efficiency decreases with increase in feed flow rate.

The salinity of the solution has a negative influence on vapor pressure of the solution. Since driving force for MD process is difference in vapor pressure between hot side and cold side of the membrane, the performance of the MD reduces with increase in salinity. Figure 5 illustrates performance parameters at different level of salinity.

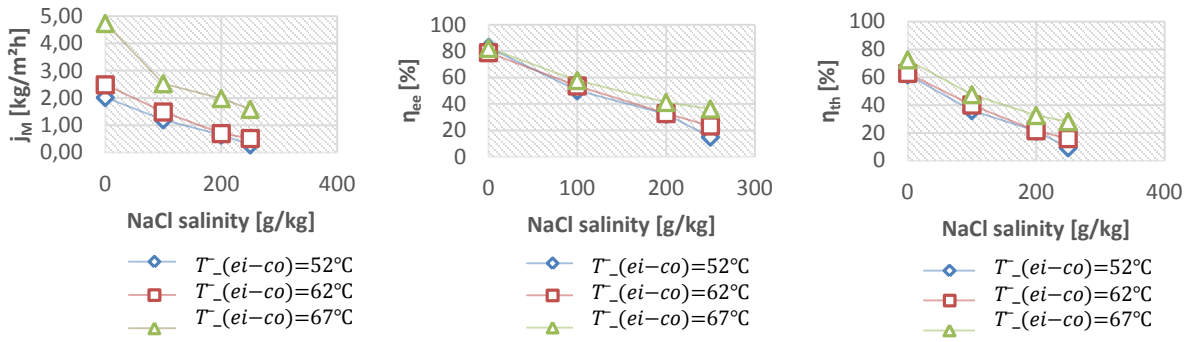


Figure 5. Influence of salinity: V_t= 160 l/h (c_t = 0.08 m/s), V_f= 10 l/h (c_f= 0.0075 m/s)

The percentage decline in flux for feed with zero salinity to 250 g/kg salinity at $\bar{T}_{ei-co}$ of 52°C, 62°C and 67°C are 86.03%, 79.28% and 66.57% respectively. The responsible factors for decrease in flux with salinity increase are decrease in the vapor pressure, possibility of localised back diffusion and blocking of membrane pores by salt precipitation.

Conclusions

Sustainable water supply and wastewater management are the key factors to address water scarcity and healthy eco system. Zero liquid discharge not only reduces the problems with the wastewater management, it also improves water recovery rate. However, current technologies to obtain zero liquid discharge are expensive and energy intensive which makes ZLD non-economic and unsustainable. Membrane distillation is found to be suitable technology to treat high saline brine. Feed gap air gap membrane distillation (FGAGMD) configuration is developed in order to overcome the issues with DCMD, AGMD and PGMD.

Influence of temperature level on flux follows the vapor pressure increase with temperature. Increase in feed flow rate has negative impact on flux, evaporation and thermal efficiencies. However, minimum flow rate is recommended in all flow

channels to have enough turbulence for proper mixing and maintaining optimum temperature. With increase in salinity, flux rapidly decreases. There is a reduction of evaporative efficiency and thermal efficiency with increase in salinity and the decrease trend is similar to the reduction in flux. From the experiments, it is found to be FGAGMD can be capable of working with near saturated solutions and can produce salt crystals from the solution. In order to protect the membrane and flow channels from blockage by the precipitated salt crystals, external crystallizer or crystal separator is recommended.

References

[1] C. J. Gabelich, P. Xu, and Y. Cohen, “Concentrate Treatment for Inland Desalting,” vol. 2, pp. 295–326.

[2] D. Winter, J. Koschikowski, and M. Wieghaus, “Desalination using membrane distillation: Experimental studies on full scale spiral wound modules,” *Journal of Membrane Science*, vol. 375, no. 1-2, pp. 104–112, 2011.

[3] Z. S. Tai *et al.,* “An Overview of Membrane Distillation,” pp. 251–281.

[4] J. Chmielewski, “Analysis of the Membrane Distillation Process for the Treatment of High Salinity Brines,” Master of Science, Hochschule Offenburg, Fraunhofer ISE, Freiburg, 2015.

[5] Daniel Winter, “Membrane Distillation - a Thermodynamic, Technological and Economic Analysis,” Doctoral Thesis, Department of Mechanical and Process Engineering, University of Kaiserslautern, Germany, Fraunhofer ISE, Freiburg, 2014.

[6] J. Morillo *et al.,* “Comparative study of brine management technologies for desalination plants,” *Desalination*, vol. 336, pp. 32–49, 2014.

[7] K. Nakoa, K. Rahaoui, A. Date, and A. Akbarzadeh, “Sustainable zero liquid discharge desalination (SZLDD),” *Solar Energy*, vol. 135, pp. 337–347, 2016.

[8] S. Lee *et al.,* “Hybrid desalination processes for beneficial use of reverse osmosis brine: Current status and future prospects,” *Desalination*, 2018.

[9] G. U. Semblante, J. Z. Lee, L. Y. Lee, S. L. Ong, and H. Y. Ng, “Brine pre-treatment technologies for zero liquid discharge systems,” *Desalination*, vol. 441, pp. 96–111, 2018.

[10] Mohamed Khayet and Takeshi Matsuura, *Membrane Distillation Membrane Distillation, Principles and Applications*, 2011.

[11] E. Drioli, A. Ali, and F. Macedonio, *Membrane Operations for Process Intensification in Desalination*, 2017.

[12] J. Minier-Matar, A. Hussain, A. Janson, F. Benyahia, and S. Adham, “Field evaluation of membrane distillation technologies for desalination of highly saline brines,” *Desalination*, vol. 351, pp. 101–108, 2014.

[13] R. Schwantes, K. Chavan, D. Winter, C. Felsmann, and J. Pfafferott, “Techno-economic comparison of membrane distillation and MVC in a zero liquid discharge application,” *Desalination*, vol. 428, pp. 50–68, 2018.

Concentration of reverse osmosis concentrate from incineration leachate using membrane distillation coupled with a pre-treatment process

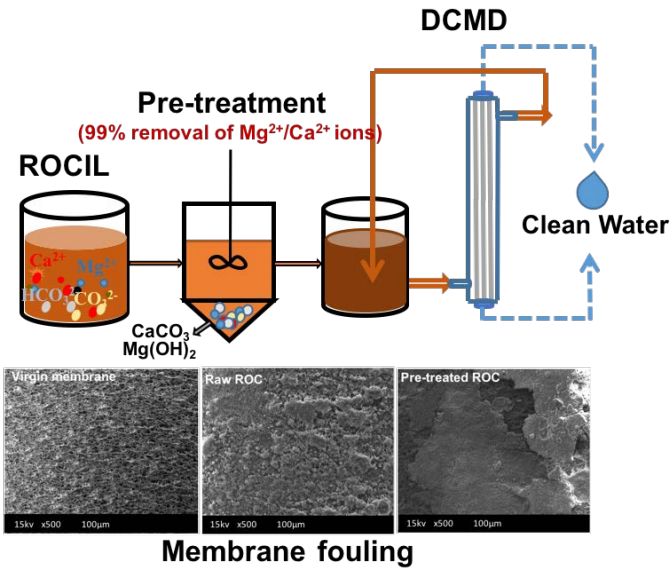
*Jinyu Shi, Yan Dang, Dan Qu, Dezhi Sun**

Beijing Key Laboratory for Source Control Technology of Water Pollution, Engineering Research Center for Water Pollution Source Control and Eco-remediation, Beijing Forestry University, Beijing, 100083, China.

Abstract

Reverse osmosis is frequently used to process biologically treated leachate from municipal solid waste incineration plants. However, the RO process produces a large amount of leachate concentrate, which adds up to be about 10–15% of the volume of the original leachate. The reverse osmosis concentrate (ROC) containing extremely high concentrations of monovalent and divalent metal ions (e.g. Na^+, K^+, Ca^{2+} and Mg^{2+}), some refractory organic pollutants (e.g. humic substances) and trace toxic compounds needs further treatment. In this study, a lab-scale direct contact membrane distillation (DCMD) coupled with chemical precipitation as a pre-treatment process was applied to treat the ROC. The results shown that 99% of calcium and magnesium ions, 34.5% of the color and 17.4 % of the COD were effectively removed by adding of NaOH/PAM chemicals, thus significantly improving the treatment efficiency of DCMD and slowing down membrane fouling mainly caused by $Mg_5(CO_3)_4(OH)_2{\cdot}4H_2O$ and $CaCO_3$ scaling on the membrane surface. During the long-term operation of DCMD treating the pre-treated ROC, the ROC was concentrated 20 times, and the amount of permeate obtained accounted for 95% of the ROC volume. Nearly all of the inorganic ions (>99.9%) and organic matter with molecular weight between 0.7–5.2 kDa (>99%) were trapped in the DCMD feed solution, and the permeate had a low conductivity in the range of 5–80 μS/cm and only a small amount of organics (e.g. aromatic protein-like constituents) was detected throughout each run, which can be used directly for in-plant circulating cooling system. At the end of MD, a strong interactions occurred due to the accumulation of humic substances and metal ions (i.e., Ca^{2+}, Mg^{2+}, Zn^{2+}, Cu^{2+}, Na^+, K^+ etc.)

in feed solution, which thus leaded to more severe inorganic and organic scaling deposited on the membrane surface, even the membrane pores, but wetting phenomenon was not serious for the distillate concentration was still at a very low level.



ACKNOWLEDGEMENT

This research was financially supported by the National Natural Science Foundation of China (No.51678051).

AUTHOR INFORMATION

Jinyu Shi. Email: Shijyup@163.com

Yan Dang. Email: yandang@bjfu.edu.cn

Dan Qu. Email: qudana@163.com

Corresponding author:

*Dezhi Sun. Email: sdzlab@126.com; sundezhi@bjfu.edu.cn

Transformation of organic matters in reverse osmosis concentrate from a municipal wastewater reclamation plant

Zi-bin Xu[1] (presenting author), Wen-long Wang[1], Qian-yuan Wu[2], Hong-ying Hu[1,3]

1 Environmental Simulation and Pollution Control State Key Joint Laboratory, State Environmental Protection Key Laboratory of Microorganism Application and Risk Control, School of Environment, Tsinghua University, Beijing 100084, PR China;

2 Key Laboratory of Microorganism Application and Risk Control of Shenzhen, Graduate School at Shenzhen, Tsinghua University, Shenzhen 518055, PR China;

3 Shenzhen Environmental Science and New Energy Technology Engineering Laboratory, Tsinghua-Berkeley Shenzhen Institute, Shenzhen 518055, PR China

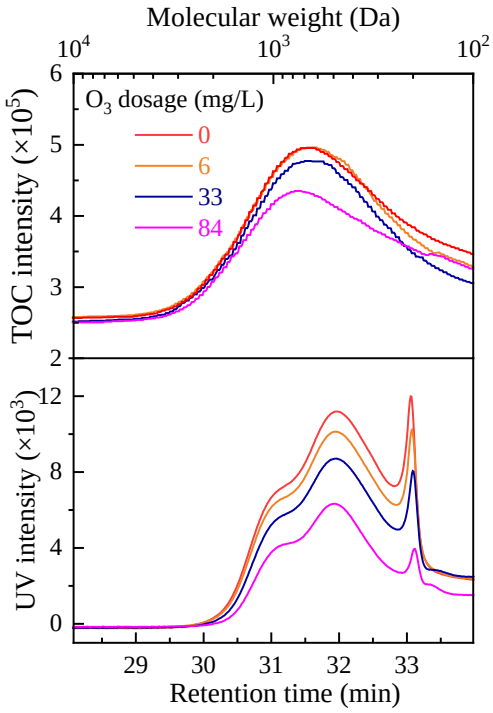


Fig.1 TOC and UV intensity changes in organic matters under different molecular weight of ROC as ozone dosage increased. For comparisons of different detector results, all data was plotted based on molecular weight axis, while the retention time axis worked for UV-results.

Abstract

Water reclamation is a potable way to solve the problem of water scarcity which the whole world is facing with. Membrane technology is widely used in obtaining reclaimed water. Reverse osmosis (RO) process is found extensively in practical wastewater treatment as the demand of reclaimed water with high-quality water is

increasing in recent years. However, it produces RO concentrate (ROC) which is hard to deal with because of high concentration of organic matters. Due to its low biodegradability, in this study, ozonation was selected as treatment method for ROC of municipal wastewater reclamation plant in Beijing, and the removal of organic matters was investigated. The results showed that instantaneous ozone demand for ROC was 1.96 mg/L, indicating part of organic matters in ROC can react with ozone in less than 5 seconds. Ozone consumption per minute reduced as ozone dose increased from 0 mg L^{-1} to 84 mg L^{-1}, showing that the reaction between organic matters in ROC transformed into ozone-resistance substances gradually. During ozonation, although TOC was hard to remove, COD, BOD_5 was partially removed, and biodegradability expressed by BOD_5 to COD increased a little, indicating that the structure of organic matters were transformed by ozonation, and only a little of them transformed into biodegradable substances. To further investigate the transformation of organic matters during ozonation, changes of UV absorbance and fluorophore in excitation emission matrix fluorescence spectrum were studied. UV absorbance was reduced significantly with removal percentages 76.4% and 86.9% at wavelength of 254 nm and 270 nm as ozone dose reached 84 mg L^{-1}, showing that most of the chromophores in organic matters were eliminated through ozonation. Meanwhile, tryptophan-like proteins, fulvic acid-like substances, aromatic proteins, soluble microbial by-product-like substances, and humic-like substances were removed efficiently as their fluorophore removal percentages in EEM spectra were 71.6%, 76.2%, 68.8%, 85.2% respectively, but it was hard to remove tyrosine-like proteins with its removal percentage 7.4%. That was attributed to their different reactivity with ozone based on their structure. Furthermore, to investigate the transformation of different molecular weight organic matters, an online high performance size exclusion chromatography combined with UV detector and TOC detector (HPSEC-UV and HPSEC-TOC) machine was used. HPSEC-UV analysis showed that the molecule weight of organic matters with chromophores was less than 3000 Da, and ozone showed effective removal to UV absorbance of all those substances. HPSEC-TOC analysis showed that the molecule weight of organic matters in ROC was under 4000 Da, and ozone had capacity in reducing TOC of organic matters whose molecular weights were around 1000 Da. All the results above demonstrated that ozonation was a potable way to deal with organic matters in municipal wastewater ROC, but further treatment for ozone-resistant substances was needed.

Developing Biological Surrogates for Monitoring Treatment Performance of Onsite Non-Potable Water Systems

Nichole Brinkman, Scott Keely, Emily Wheaton, Michael Jahne, Jay Garland, U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH, USA; brinkman.nichole@epa.gov

Abstract:

Monitoring onsite non-potable water reuse systems (ONWS) to ensure treatment strategies sufficiently remove pathogens is a challenge. Pathogens and fecal indicators are difficult to routinely measure in source water. Microbes endogenous to ONWS that consistently occur at high titers and mimic pathogen removal with treatment could be surrogates to verify log reduction targets. Analysis of graywater revealed that *Staphylococcus*, *Corynebacterium*, *Zoogloea and Acidovorax* are abundant members and candidate surrogates for treatment performance indicators for enteric bacteria. Similarly, crAssphage, pepper mild mottle virus and the bacteriophage genes g23 and MCP were detected in ONWS source water at concentrations amenable to be treatment performance indicators for removal of enteric viruses.

Keywords: onsite non-potable water system, monitoring, treatment efficacy

Introduction

There is a continued need to implement alternative water usage strategies as the demand for water increases and freshwater supply diminishes. Fit-for-purpose water reuse strategies seek to meet user needs in a cost-effective, yet sustainable manner to provide quality water to end-users while conserving water resources. Onsite non-potable water systems (ONWS) utilize locally collected wastewater (i.e., graywater, rainwater and stormwater) that is treated on-site for use in proximally-located non-potable applications, like irrigation and toilet flushing. Wide spread application of ONWS has been hindered by potential exposure risks to pathogens from improperly treated recycled water. To address these and other ONWS concerns, an independent advisory panel of technical experts, public health officials and industry partners produced a guidance document "Risk-Based Framework for the

Development of Public Health Guidance for Decentralized Non-Potable Water Systems," outlining management practices, treatment requirements and monitoring strategies to ensure protection of public health (Sharvelle et al., 2017).

The ONWS risk-based framework outlines log reduction targets (LRT) for enteric pathogens in a variety of water sources and end-use scenarios. The LRTs are based on an acceptable level of risk of 10^{-4} or 10^{-2} infections per person per year. The LRT for enteric bacteria and indoor use (toilet flushing and clothes washing, including the potential for accidental ingestion) of locally treated wastewater and graywater ranges from 1.5-6, while the range is 4-8 for enteric viruses (Sharvelle et al., 2017). Once an ONWS is operational, treatment performance should be monitored to ensure that systems are operating sufficiently and consistently to meet LRTs. As indicated in the ONWS framework, online sensors can be used to continuously monitor water quality to assess treatment unit functionality. Additionally, field verification studies are recommended, both at ONWS initiation and specified intervals, to ensure treatment meets intended LRTs through direct measurement of the removal of microorganisms. Ideally, field verification of ONWS LRTs would be performed by direct measurement of enteric pathogens, but the numerous pathogens of interest and their low and sporadic occurrence makes them unreliable for verifying LRTs. Likewise, fecal indicator organisms, which are routinely used in water quality applications, may not occur at consistent and appropriate levels in ONWS source water to verify LRTs (Sharvelle et al., 2017). Challenge testing with an appropriate surrogate is a proposed method for field verification, but complexity, cost and relevance of lab-derived surrogates can prohibit this approach (Aldelman et al., 2016; Zimmerman et al., 2016). Alternatively, non-pathogenic microorganisms present in the source water can be used as surrogates to monitor pathogen removal. An appropriate endogenous surrogate would consistently occur at concentrations greater than the LRT in source water and mimic reference pathogen removal rates for a given unit process. In this review, we highlight our research efforts to identify and verify alternative endogenous biological surrogates for use in ONWS field verification studies to monitor treatment performance.

Bacterial Surrogates for Monitoring Treatment Performance of ONWS

Microbiome analysis of graywater revealed varying composition of the bacterial community depending on the source. Freshly collected graywater from industrial laundry washers contained an abundance of genera associated with human skin (i.e., *Staphylococcus*, *Corynebacterium*, *Micrococcus*, etc.) while graywater from sinks and showers were dominated by genera that are associated with water infrastructure (i.e., *Zoogloea*, *Acidovorax*, *Acinetobacter*, etc.) (Keely et al., 2015). Furthermore, storage of graywater from sink and shower sources resulted in a stable assemblage of bacteria that was distinct from graywater sourced from laundry and sinks/showers and dominated by the genera *Desulfovibrio*, *Tolumonas* and *Laribacter*. The predominant genera described in the various graywater sources are candidate surrogates for ONWS treatment indicators.

The abundant bacterial members of freshly collected laundry water were quantified to determine concentrations relative to LRTs established for indoor use of graywater (Zimmerman et al., 2014). For comparison, fecal indicator bacteria (*E. coli*, *Enterococcus*, total *Bacteroides* spp. and human-specific *Bacteroides*) were also quantified. Analysis by qPCR showed that the fecal indicator bacteria were not consistently detected in graywater and when present, concentrations averaged approximately 1-3.4 $\log_{10}$ gene copies/100 ml. On the other hand, genes corresponding to the skin associated bacteria *Staphylococcus*, *Propionibacterium*, *Corynebacterium* and *Pseudomonas* were detected in all samples. *Staphylococcus* was detected at the highest average concentration of approximately 6.5 log10 gene copies/100 ml, followed by *Propionibacterium*, *Corynebacterium* and *Pseudomonas* at 5.7, 5.4 and 4.3 log10 gene copies/100 ml, respectively.

The LRT for enteric bacteria at the 10^{-4} infections per person per year benchmark for graywater reuse is 3.5. The average concentrations of fecal indicator bacteria in freshly collected graywater do not meet this threshold. On the other hand, the targeted skin associated bacteria, *Staphylococcus*, *Propionibacterium*, *Corynebacterium* and *Pseudomonas* were detected at average concentrations that exceed the LRT and are candidate surrogates for treatment process indicators of enteric pathogens in ONWS.

Viral Surrogates for Monitoring Treatment Performance of ONWS

The abundance of bacteriophage in municipal wastewater and reclaimed water (10^8-10^{10} virus like particles per milliliter) (Rosario et al., 2009) make them candidates as endogenous surrogates for viral pathogens in ONWS. Viral metagenomic analysis of municipal wastewater and reclaimed water show viruses of the order *Caudovirales* dominate the communities while the ssDNA viruses, such as *Microviridae*, comprise a smaller proportion (Rosario et al., 2009; Tamaki et al., 2012). Abundant members of bacteriophage communities in graywater have not yet been explored, but these analyses should be conducted utilizing procedures that mitigate inherent biases to specific virus types so that abundant viruses are accurately identified (Brinkman et al., 2018).

Viral signature genes, homologous conserved genes in closely related bacteriophages, are also being explored as potential viral surrogates. Using this approach, we quantified genes that encode a capsid protein of some members of *Caudovirales* (g23) and *Microviridae* (MCP) in 3 ONWS utilizing PCR assays previously described (Filee et al., 2005; Hopkins et al., 2014). In 2 different graywater ONWS, MCP concentrations ranged 2.6-5.6 $\log_{10}$ PCR units/L while g23 concentrations ranged from 4-7.6 $\log_{10}$ molecules/L. In a blackwater ONWS, MCP and g23 gene quantities ranged from 4.6-5.9 $\log_{10}$ PCR units/L and 3.1-6.9 $\log_{10}$ molecules/L, respectively.

Recently, crAssphage (crAv) and pepper mild mottle virus (PMMoV) have been shown to be associated with human fecal contamination and occur in muncipal wastewater in high concentrations (Stachler et al., 2017; Kitajima et al., 2014). Since they occur in high concentrations, they were also explored as potential virus surrogates in 3 ONWS using previously described PCR assays (Stachler et al., 2015; Zhang, et al., 2006). In 2 different graywater ONWS, crAv concentrations ranged 2.8-5.8 $\log_{10}$ molecules/L while PMMoV concentrations ranged from 3.6-7.7 $\log_{10}$ molecules/L. In the blackwater ONWS, crAv and PMMoV gene quantities ranged from 7.3-8.9 and 7.8-9.2 $\log_{10}$ molecules/L, respectively.

Given the concentrations of the targeted genes in the various ONWS, g23 and MCP could meet the LRT of 4 to accomodate 10^{-2} infections per person per year benchmark for indoor reuse of graywater. Likewise, PMMoV and crAV could meet the LRT of 6.5 to meet 10^{-2} infections per person per year benchmark for indoor use of recycled blackwater. None of the targeted genes consistently achieved the

concentrations needed to meet the LRT for the 10^{-4} infections per person per year benchmark for indoor reuse of graywater or blackwater.

Ongoing and Future Work

Current studies are focused on examining the 16S microbiome of several ONWS to determine whether a core group of bacterial genera are common among systems. Future work will examine the viral community of graywater to identify abundant members that could meet the LRT for the 10^{-4} infections per person per year benchmark. In addition, newly identified viral surrogates and infrastructure-associated bacteria will be quantified to assess potential as candidate surrogates. Once candidate surrogates are identified, their removal through ONWS treatment will be compared to removal of reference pathogens.

References

Adelman MJ, Phelps M, Hadacek RT, Slosser OR, Calvet S, Oppenheimer J, Borchardt JH (2016) *Required C x T Value for 5-log Virus Inactivation at Full Scale.* Journal of the American Water Works Association, 108: E18-E26.

Brinkman NE, Villegas EN, Garland JL, Keely SP (2018) Reducing inherent biases introduced during DNA viral metagenome analyses of municpal wastewater. PLOS ONE 13: e0195350

Filee J, Tetart F, Suttle CA, Krisch HM (2005) Marine T4-type bacteriophages, a ubiquitious component of the dark matter of the biosphere. Proceedings of the National Academy of Scinces 102:12471-6

Hopkins M, kailasan S, Cohen A, Roux S, Tucker KP, Shevenell A, Agbandje-McKenna M Breitbart M (2014) Diversity of environmental single-stranded DNA phages revealed by PCR amplification of the partial major capsid protein. International Society of Microbial Ecology Journal 8: 2093-103

Kitajima M, Iker BC, Pepper IL, Gerba CP (2014) Relative abundance and treatment reduction of viruses during wastewater treatment process – identification of potential viral indicators. Science of the Total Environment 488-489: 290-6

Keely SP, Brinkman NE, Zimmerman BD, Wendell D, Ekeren KM, DeLong SK, Sharvelle S, Garland JL (2015) Characterization of the relative importance of human- and ingrastructure-associated bacteria in grey water: a case study. Journal of Applied Microbiology 119:289-301

Rosario K, Nilsson C, Lim YW, Ruan Y, Breitbart M (2009) Metagenomic analysis of viruses in reclaimed water. Environmental Microbiology 11:2806-20.

Sharevelle S, Ashbolt N, Clerico E, Hultquist R, Leverenz H, Olivieri A (2017) Risk-based framework for the development of public health guidance for Decentralized Non-Potable Water Systems. Prepared by the National Water Research Institute for the Water Environment & Reuse Foundation. Alexandria, VA. WE&RF Project No. SIWM10C15

Stachler E, Kelty C, Sivaganesan M, Li X, Bibby K, Shanks OC (2017) Quantitative crAssphage PCR assays for human fecal pollution measurement. Environmental Science and Technology 51: 9146-54

Tamaki H, Zhang R, Angly FE, Nakamura S, Hong P, Yasunaga T, Kamagata Y Liu W (2012) Metagenomic analysis of DNA viruses in a wastewater treatment plant in tropical climate. Environmental Microbiology 14: 441-52.

Zhang, T, Breitbart M, Lee W, Run J, Wei CL, Soh SWL, Hibberd ML, Liu ET, Rohwer F, Ruan Y (2006) RNA Viral Community in Human Feces: Prevalence of Plant Pathogenic Viruses. PLoS Biology 4: e3

Zimmerman BD, Ashbolt NJ, Garland JL, Keely S, Wendell D (2014) Human mitochondrial DNA and endogenous bacterial surrogates for risk assessment of graywater reuse. Environmental Science and Technology 48: 7933-8002

Zimmerman BD, Korajkic A, Brinkman NE, Grimm AC, Ashbolt NJ, Garland JL (2016) A spike cocktail approach to improve microbial perfomranc montiroing for water reuse. Water Environment Research 88: 824-7

Monitoring emerging contaminants in wastewater reuse systems by fluorescence EEM

Massimiliano Sgroi, Università degli Studi di Catania, Catania, Italy; Tarun Anumol, Agilent Technologies Inc., USA; Federico G. A. Vagliasindi, Università degli Studi di Catania, Catania, Italy, Gregory Korshin, University of Washington, Seattle, USA; Shane Snyder, University of Arizona, USA; Paolo Roccaro, Università degli Studi di Catania, Catania, Italy.

Introduction

Water utilities routinely monitor chemical and microbiological parameters, but only periodically through grab sampling programs, and at a frequency that would not provide early warning of a contamination event or any treatment process malfunctioning. In the present study, the use of fluorescence excitation emission matrix (EEM) are demonstrated to be very useful to monitor contaminants of emerging concern (CEC) in different wastewater treatment processes employed for wastewater reclamation and reuse.

Methods

Analysis for CEC was performed according to the procedure reported by Anumol et al. (2015). Fluorescence data were obtained by using several methods (Sgroi et al., 2017a), including Fluorescence regional integration (FRI), peak picking, and parallel factor analysis (PARAFAC). The investigate processes included biological activated sludge systems, packed bed adsorption reactor, and advanced oxidation processes. The monitoring of CEC in natural stream receiving treated wastewater is also explored.

Results and discussion

CEC monitoring in biological activated sludge reactors

Several full scale wastewater treatment plants were investigated. Their size ranged from 5000 population equivalent (p.e.) up to more than 400000 p.e. The activated sludge reactors were operated under different conditions (e.g. carbon removal, carbon + nutrient removal, carbon + nutrient removal with final filtration). The peak index defined by $\lambda ex/\lambda em$= 245/440 nm and the PARAFAC component with wavelength of the maxima $\lambda ex/\lambda em$= 245, 350/450, both identified as humic-like fluorescence, were found remarkably well correlated with CEC such as atenolol,

naproxen andgemfibrozil that were moderately removed (51–70% average removal) (Sgroi et al., 2017a).

CEC monitoring in adsorption reactors

Using rapid small-scale column testing, the breakthrough of dissolved organic matter (DOM) and CEC during granular activated carbon (GAC) filtration of different water qualities was investigated. Different correlation models to predict CEC breakthrough in different water qualities was related to its adsorption during GAC processes. Particularly, correlations between CEC removals and the microbial humic-like PARAFAC component removals were independent of water quality (Sgroi et al., 2018).

CEC monitoring in advanced oxidation processes

Alternative advanced oxidation processes (AOP), including ozonation, chlorination, H_2O_2/UV, Cl_2/UV, O_3/UV, H_2O_2/O_3/UV and Cl_2/O_3/UV, were investigated at pilot plant in order to remove CEC. Very strong correlations were found between CEC removal and total fluorescence abatement. Such correlations depended on the type of AOP employed.

CEC monitoring in natural streams receiving treated wastewater

Correlations between CEC and fluorescence indexes were observed along wastewater impacted streams that are used for irrigation in agriculture. Changes of the fluorescence indexes that correspond to a group of humic-like fluorescing species were determined to be highly correlated with the concentrations of recalcitrant contaminants such as sucralose, sulfamethoxazole and carbamazepine. Changes of the fluorescence indexes related to tyrosine-like substances were well correlated with the concentrations of ibuprofen and caffeine, anthropogenic indicators of untreated wastewater discharges (Sgroi et al., 2017b).

References

Anumol T., Snyder S.A., 2015. Rapid analysis of trace organic compounds in water by automated online solid-phase extraction coupled to liquid chromatography–tandem mass spectrometry, Talanta 132, 77.

Sgroi, M., Roccaro, P., Korshin, G.V., Greco, V., Sciuto, S., Anumol, T., Snyder, S.A., Vagliasindi, F.G.A., 2017a. Use of fluorescence EEM to monitor the removal of emerging contaminants in full scale wastewater treatment plants. J. Hazard Mater. 323, 367-376.

Sgroi, M., Roccaro, P., Korshin, G.V., Vagliasindi, F.G.A., 2017b. Monitoring the behavior of emerging contaminants in wastewater-impacted rivers based on the use of fluorescence excitation emission matrixes (EEM). Environ. Sci. Technol. 51, 4306-4316.

Sgroi, M., Anumol, T., Roccaro, P., Vagliasindi, F.G.A., Snyder, S.A., 2018. Modeling emerging contaminants breakthrough in packed bed adsorption columns by UV absorbance and fluorescing components of dissolved organic matter. Water Research, 145, 667-677

Information and communication technology (ICT) for optimized water reuse solution combining natural-engineered treatment systems in coastal area

Marie PETTENATI[1], Géraldine PICOT-COLBEAUX[1], Loic THOMAS[2], Axel AUROUET[2], Charlotte THIERION[2], Aubery WISSOCQ[2], Matthieu BAÏSSET[3].

1 BRGM, Orléans, France, m.pettenati@brgm.fr; 2 GeoHyd/Anteagroup, Olivet, France ; 3 Imageau, Montpellier, France.

A solution for short and long-term environmental management of water reuse has been developed combining both online monitoring and modeling for aquifer recharge with soil aquifer treatment. The ICT tool dedicated to optimize reuse in coastal area threaten by saline intrusion, is able to provide web services to address operational, strategic and executive management for better decision-making.

Groundwater in coastal environments are threaten by saline intrusion due to the vicinity of the seashore combined with a potential overexploitation due to seasonal touristic increase of population. Managed aquifer recharge (MAR) system can be used in this case in order to create a hydraulic barrier against salt-water intrusion and create a “freshwater” reservoir for various water supply[1,2]. Non-conventional water source such treated wastewater can be used in order to recharge the aquifer not only to enhance groundwater quantity but also groundwater quality when combined with Soil-Aquifer-Treatment (SAT). The technology has also gained increasing attention as natural water treatment and water reuse application, for irrigation[3,4] and, increasingly for Indirect Potable Reuse (IPR)[5]. However, this water can contain chemicals, both endogenous and anthropogenic and can potentially enter the aquifer environment from surface systems. It is a challenge to ensure the system

[1] Dillon, P. (2005) Future management of aquifer recharge. Hydrogeol J. 13 (1), 313-316.
[2] Dillon, P., Stuyfzand, P., Grischek, T., Lluria, M., Pyne, R.D.G., Jain, R.C., Bear, J., Schwarz, J., Wang, W., Fernandez, E., Stefan, C., Pettenati, M., et al. (2018). Sixty Years of Global Progress in Managed Aquifer Recharge. Hydrogeology Journal https://doi.org/10.1007/s10040-018-1841-z.
[3] Lazarova, V. Emsellem, Y., Paille, J., Glucina, K., Gislette, P. (2011) Water quality management of aquifer recharge using advanced tools. Water Sci. Technol. 64 (5): 1161–1168.
[4] Kazner, C., Wintgens, T. & Dillon, P. (Eds.). (2012). RECLAIM WATER - Advances in Water Reclamation Technologies for Safe Managed Aquifer Recharge. London UK: IWA Publishing. ISBN 9781843393443
[5] Grützmacher G. et al., (2013) Managed aquifer recharge in line with European groundwater legislation DEMEAU Report.

performance and efficiency in this natural and complex environment where the operator can have only a partial control on the treatment process. The use of subsoil natural systems (soil and aquifer) for water treatment requires a stringent monitoring and modelling to detect and foresee any adverse effects and risks for the concerned water bodies (e.g. contaminant flow beyond the confined injection-pumping perimeter). In the context of H2020 AquaNES project, we demonstrate into a unified platform the performance of innovative water quality real time monitoring and modelling technology linked to data management and communication, to optimize the management of water reuse on Agon-Coutainville site[6] (France, Basse-Normandie). These aspects are crucial for an integrated water management since real time monitoring allows a «day to day» action (early warning, rapid action etc…) and modelling allows long-term predictions. Agon-Coutainville is one of the older seaside resort of the Manche department where a combined natural engineered treatment systems (cNES) was provided both for golf irrigation reuse and avoiding direct discharge to the sea (health issues). The wastewater treatment plant combines pre-treatment using activated sludge and reed bed sand dune filtration. In this coastal area, groundwater quality and quantity are spatially and temporally linked with the natural environment (tides, natural recharge, rivers…). A set of groundwater online monitoring probes (water level, salinity, temperature…) was implemented at various distance from the sea and a transient hydrosystem model was built integrating the SAT/MAR system and saline intrusion hydrodynamics. Finally, a WWTP-SAT/MAR ICT system which is a site-specific decision support system (DSS), was established for Agon-Coutainville site in order to evaluate in real-time the system performance and to select system optimization options leading to an optimal management of water reuse for the operator.

[6] Pettenati, M., Picot-Colbeaux, G., Togola, A., Lopez, B., Devau, N. Thomas, L., Aurouet, A., Baïsset, M. (2017) Advanced monitoring- modelling communication tool for optimising Soil Aquifer Treatment (SAT) system design & operation in AquaConSoil, Jun 2017, Lyon, France.

Demonstrating Real-Time Collection System Monitoring for Enhanced Source Control in Potable Reuse

Eva Steinle-Darling, Carollo Engineers, Inc., Austin, USA; Gina Dorrington, Ventura Water, El Paso, USA; Nancy Nye, El Paso Water, Ventura, USA; Penny Carlo, Carollo Engineers, Inc., Sacramento, USA; Andrew Salveson, Carollo Engineers, Inc., Walnut Creek, USA

Summary Description

This research project is filling a critical gap in source control and potable reuse practice by demonstrating, at the full scale, the capability of commercially available monitoring platforms to identify, evaluate, and trigger responses to dumping events within the wastewater collection system, thus protecting the downstream water reclamation facilities, receiving waters, and future potable users.

Abstract

Within the United States, the Water Research Foundation and its predecessor organizations have sponsored studies that successfully defined many key concepts associated with advanced treatment for potable reuse, including establishing water quality goals, appropriate treatment approaches, engineered storage, monitoring and critical control points, and even operator training. However, our potable reuse research has not yet looked significantly beyond the advanced treatment train.

Recognizing this limitation, we are now looking to the next step and examining the source water for potable reuse more closely: the raw wastewater entering the treatment system. Regulators agree with this need, as California's State Water Resources Control Board (State Board) Expert Panel has identified source control as one of six key areas needing increased focus for potable reuse. Some forward-thinking utilities are already beginning to implement Enhanced Source Control Programs (ESCPs), which implement a "water first" prioritization and aggressively target industrial dischargers with enhanced local limits and sampling requirements.

Existing source control efforts rely on laborious and expensive sampling programs that can miss dumping events because these occur only intermittently. Those

challenges are exacerbated in ESCPs for potable reuse. Thus, the critical next step in the evolution of enhanced source control is developing the ability to monitor the water quality within the wastewater collection system cost-effectively and in real time.

Funded by The Water Research Foundation under project No 17-30, this research is demonstrating the ability of commercial monitoring platforms to monitor water quality within collection systems through six-month trial deployments of small pilot sensor networks at El Paso Water in Texas and Ventura Water in California, two utilities moving ahead with direct potable reuse projects. The pilot networks consist of three sensor stations that monitor bulk water quality parameters such as conductivity, pH, temperature, and dissolved oxygen, and are supplemented by sensors that measure the full UV-visible spectrum absorption of the water to provide measures of organic content and inorganic nitrogen species, and photoionization detector to sample for volatile organic carbon compounds (VOCs) in the airspace of sewers to provide warning of potential VOC slug discharges. Grab samples are collected to serve as a calibration dataset for the sensor algorithms, that differentiate between "baseline" or normal conditions, and "events" that trigger automated collection of a grab sample for analysis and potential enforcement action.

This research project, once complete, will thus fill a critical gap in source control and potable reuse practice by demonstrating, at the full scale, the capability of minimally modified commercially available monitoring platforms to automatically identify, alert, evaluate, and trigger mitigation responses to illegal or accidental dumping events within the wastewater collection system, thus protecting the downstream water reclamation facilities, receiving waters, and future potable users.

Characterization of organic matter and contaminants during DPR processes compared to surface water supplies

C. Hoppe-Jones, University of Arizona, Tucson, AZ, USA, S. Beitel, University of Arizona, Tucson, AZ, USA, K. Daniels, University of Arizona, Tucson, AZ, USA, I. Lopez, University of Arizona, Tucson, AZ, USA, M. Park, University of Arizona, Tucson, AZ, USA, S.A. Snyder, University of Arizona, Tucson, AZ, USA and Nanyang Technological University, Singapore

Abstract

With growing demands and stresses on drinking water sources especially in arid and semi-arid regions around the world, augmenting potable water supplies with reclaimed water is increasingly of interest. The goal for potable reuse facilities is to produce “safe water”, however, regulatory agencies mainly focus on bulk organic parameter to assess the water quality. Monitoring compounds of emerging concern (CECs) will give further insides into the removal efficiencies of the advanced treatment trains at water reuse facilities. However, due to the large number of chemicals present in wastewater effluents, it is not feasible to test for all of them. Non-targeted analysis (NTA) and bioassays are valuable tools to evaluate removal efficiencies of unknown/unidentified compounds in water reuse applications.

The goal of this research is to compare different methods to characterize organic matter, CECs, and other water quality parameters and to evaluate their suitability in water reuse applications. Samples from five water reuse facilities around the United States and the world were collected. At each site, samples from different treatment stages, as well as the drinking water source and supply were collected and compared to the effluent of the water reuse facilities. Different treatment trains, RO-based and non-RO-based, were evaluated. Samples were analysed for bulk organic parameters (DOC, UV, and Fluorescence), CECs, bioassays, and NTA using LC-qTOF.

Removal of bulk organic parameters was site specific. DOC removal was usually greater than 95%, 57%, 60% for RO-based, UVAOP-BAC, and BAC-Ozone treatment trains, respectively. Common CECs that occurred at high

frequencies and concentrations at most wastewater effluents were acesulfame, sucralose, iopamidol, iohexol, and carbamazepine. Most water reuse treatment trains removed more than 95% of the CECs detected in wastewater effluents. NTA analysis was used to compare samples after each treatment step. Correlation coefficients below 0.3 were calculated between the wastewater effluents and the effluent after advanced treatment, indicating weak to no linear relationships between the samples. Further information on the removal and formation of transformation products were also evaluated.

Is the water fit for use or reuse? How determination and characterization of organics data drives decisions for critical control of potable reuse treatment processes.

Amanda Scott, Suez Water Technologies & Solutions Analytical Instruments, Boulder, USA;

Summary Description: Total Organic Carbon (TOC) Analysis and Dissolved Organic Carbon (DOC) Speciation for Critical Control of Water Reuse Multiple Barrier Treatment from Wastewater Effluent to Advanced Treated Water

Topic: Monitoring and compliance

This paper looks at how several reuse projects use organics monitoring and organics characterization as key control tools throughout multiple barrier treatment to optimize the performance of each barrier, adjust treatment based on changes in source water, and ensure effective organics removal for quality effluent.

Organics monitoring and characterization empowers operators to make real-time, data driven decisions that optimize processes with action and shutdown limits. It also allows facilities to monitor the overall health of treatments systems and meet goals for effluent water quality. Growing needs for water reuse and emerging treatment technologies are driving framework development for DPR. This framework will depend on reliable, real-time monitoring, such as TOC analysis, and improve characterization, like SEC DOC speciation, to protect public health and ensure efficient operations.

The utilities in this study use TOC as a reliable, sensitive, consistent, and rapid test to understand and minimize organic contamination. On-site TOC analysis can track changes in source water organic loading and enable real time decisions to be made that optimize treatment such as chemical dosing, ozone dosing, membrane backwashes, and BAC or GAC regeneration. Proper pre-treatment for UF/MF helps prevent against organic and inorganic membrane fouling. Smarter ozone dosing helps account for changes and effects due to background TOC to ensure breakdown of trace organics. Tracking organics removal through the system helps optimize removal efficiencies and ensure final effluent quality. This study will also explore ways to validate RO permeate TOC for both log removal credit and low-level

accuracy.

However, as a bulk parameter, a TOC number is made up of a variety of organic compounds so sometimes it's advantageous to understand what specific organics contribute to a TOC number. Organics characterization using a DOC Detector as part of a size exclusion chromatography system can provide an analysis of a sample's organic footprint that includes all organics not just those with a chromophore or fluorophore as a function of molecular weight. The combined system provides better understanding of what organics are present and what organics might cause problems. These compounds range in size and complexity, so the organics footprint enables deeper understanding and insight for predicting and troubleshooting to ensure treatment targets, membrane health and water quality.

A steric pore-flow model for predicting rejection of *N*-nitrosamines by reverse osmosis membranes

Haruka Takeuchi, Kyoto University, Shiga, Japan
Takahiro Fujioka, Nagasaki University, Nagasaki, Japan
Long.D. Nghiem, University of Technology Sydney, Sydney, Australia
Hiroaki Tanaka, Kyoto University, Shiga, Japan

Introduction

Since water quality requirements for potable water reuse are very stringent, most water reclamation plants for potable water reuse have adopted reverse osmosis (RO) membrane technology as a key barrier to ensure adequate removal of trace organic chemicals. However, the rejection of *N*-nitrosamines, in particular *N*-nitrosodimethylamine (NDMA), by RO membranes can vary significantly. Due to the low and highly variable removal of *N*-nitrosamines by RO membranes, a subsequent treatment process such as UV process is often introduced to comply with their guideline or maximum permissible concentration in the final product water. Thus, it is envisaged that ability to predict and simulate the removal of *N*-nitrosamines by RO membranes can be particularly useful for process optimization. This study aimed to develop a predictive model for *N*-nitrosamines rejection by RO membranes to contribute to more reliable and energy efficient RO membrane treatment.

Materials and methods

This study based on the steric pore-flow model to predict the rejection of eight *N*-nitrosamines. In this approach, solute rejection is predicted by estimating the free-volume hole-size. The free-volume hole-radius was determined with pure water permeability of a membrane and a single reference compound (i.e. NDMA) by minimizing the variance between the experimentally obtained and calculated NDMA rejection values at the permeate flux of 20 L/m^{2}h. The model was also integrated with a membrane free-volume hole-radius previously obtained by positron annihilation lifetime spectroscopy (PALS) analysis and its accuracy was compared with the model developed with a reference solute during the model validation phase. The predicted rejection of eight *N*-nitrosamines in the model were validated by comparing with experimentally obtained values.

Results and discussion

The obtained free-volume hole-radius of ESPA2 RO membrane was 0.348 nm, which was larger than the value previously determined by positron annihilation lifetime spectroscopy (PALS) analysis (0.289 nm). The model incorporated with the estimated free-volume hole-radius could accurately predict the rejection of eight *N*-nitrosamines under a range of permeate flux (2.6–20 L/m^{2}h). The applicability of this approach was also evaluated using other three RO membranes － ESPA1, ESPA4, and ESPAB membranes －. As in the case of the ESPA2 membrane, the model could successfully predict the rejection of eight *N*-nitrosamines under a range of permeate flux (2.6–20 L/m^{2}h) by the three RO membranes. This approach can lead to a significant reduction in labor and its associated cost for the evaluation of trace organic chemical removal by RO membranes.

Conclusion

We proposed a new approach to apply the steric pore-flow model to predict the rejection of eight *N*-nitrosamines by RO membranes. Using our approach, solute rejection is predicted by estimating the free-volume hole-size with a single reference solute and membrane pure water permeability. The model incorporated with the estimated free-volume hole-radius could accurately predict the rejection of *N*-nitrosamines by four RO membranes under a range of permeate flux.

Deleterious role of silica and lead contaminated drinking water in the induction of Chronic Kidney Disease

Starlaine Mascarenhas, Srikanth Mutnuri *and* ***Anasuya Ganguly***

BITS-Pilani K K Birla Goa Campus,Zuarinagar,Goa,India;

ganguly@goa.bits-pilani.ac.in

Abstract:

This study is about a strange form of Chronic kidney disease reported in the Canacona taluka of south Goa(India), whose etiology is unlinked to typical reasons like diabetes & hypertension, hence it is named as Chronic Kidney Disease of Unknown etiology(CKDu). This disease is believed to be induced by environmental toxins, hence we aimed to elucidate the environmental factors of CKDu. We conducted detailed hydrochemical analysis of groundwater. It was found to be acidic (pH-5.6), which resulted in its contamination with two major nephrotoxins viz. borderline lead levels(9.98µg/L) & high silica levels(115.5 mg/L). Bioavailability of these toxins were amplified due to the acidic-pH & Ca-Mg cum essential metal deficiency of groundwater. Cellular nephrotoxicity mechanism of lead is well-described unlike silica. We analysed the nephrotoxic potential of silica via in-vitro cytotoxicity-assay(i.e.MTT assay) on human-kidney-cell-lines viz.HEK. Silica demonstrated dose & time dependent nephrotoxicity with severe toxicity (i.e. enhanced cell-death) on chronic exposure(i.e.100-120mg/L). Our study is the first report to highlight that borderline levels of lead and high silica levels can be potential nephrotoxins responsible for the development of CKDu in Canacona.

Keywords: CKDu; groundwater; trace-elements; nephrotoxins; silica; lead.

Introduction

CKDu has been reported since 1990s in various developing countries like India,Central America,Sri Lanka & Egypt. This disease targets financially poor rural communities that rely on groundwater for drinking. This nephropathy is believed to be environmentally induced on exposure to nephrotoxins like heavy metals and more recently the trace geogenic element viz. silica(Gifford et al., 2017). incidence of CKDu have been reported for the last 25 yrs from the Indian state of Goa specifically

Canacona taluka) but the etiology is unknown till date(DNA,2010). Hence this study is aimed to analyse environmental causes of CKDu. We have conducted a detailed hydrochemical analysis. From our results, lead & silica were found to be potential causals for CKDu.

Material and Methods

Study design

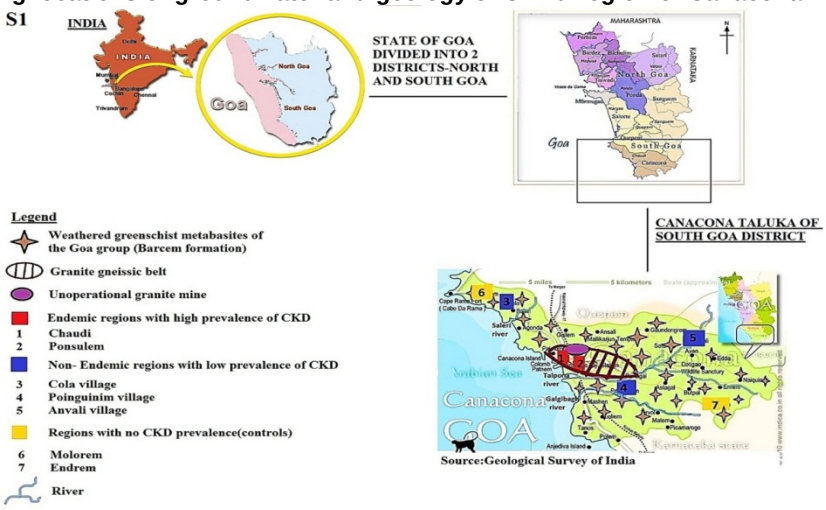
The study population for groundwater samples (infiltration wells) collected were divided into three groups. Group 1 comprised of 114 CKDu affected subjects of Canacona from endemic villages- Ponsulem & Chaudi. Group 2 comprised of 28 diabetes & hypertension induced CKD patients of Canacona from villages- Cola, Poinguinim & Anvali, and Group 3 comprised of 124 healthy & unaffected controls from villages- Molorem & Endrem.

Hydro-geochemical analysis of groundwater of Canacona

a. Sample collection

The groundwater(well-water)samples used for drinking by the study population were collected during 3 different seasons:-pre-monsoon(PRM)(May 2016),monsoon(MON)(July 2016)& post-monsoon(POM)(November 2015).Samples(500ml each)were collected in duplicates from each well in clean high-density polypropylene bottles, with one acidified with 10% conc. nitric-acid for trace-metal analysis. 114 samples were collected from CKDu endemic study-area1, 28 from CKD non-endemic region study-area2 & 124 from healthy region study-area3.The sampling regions, location of the abandoned granite-mine & geology of study-areas are shown in **Figure 1**.

Figure 1: Sampling locations of groundwater and geology of CKDu-region of Canacona.



Red squares denote CKDu endemic,blue squares-non-endemic and yellow squares-no CKD prevalence regions from where groundwater was collected.Number inside boxes corresponds to name of the village of the 3 regions.The geological formation of Canacona that is the granite gneissic belt & metabasite cover are shown.There is a non-operational granite mine located in Chaudi named village which is located in close proximity of the CKDu region.(Reprinted from Masacarenhas et al., 2017).

b. Physiochemical & Trace-metal analysis of groundwater of Canacona

pH & electrical-conductivity were analysed in-situ using multi-parameter portable meter (Thermo Scientific Eutech PCSTestr 35,Singapore). Physical parameters like Alkalinity,Total dissolved solids(TDS),Turbidity& Total-Hardness were analysed by A.P.H.A standard methods(Eaton et al.,2005a).The chemical characteristics like Na^{+},K^{+},Ca^{+2},Mg^{+2},NO_3^{-},PO_4^{-3},SO_4^{-2},Cl^{-1} & F^{-1} were measured by ion-chromatography (Dionex ICS-2000 Ion-chromatography system,CA,USA) as previously described (Thamban et al.,2010).Trace-metals except silica was measured by ICP-MS(Perkin Elmer ELAN 9000 ICP-MS,MA,USA) analysis as described earlier(Al-Badaii et al., 2016).Silica was measured by APHA–ammonium-molybdate spectrophotometric (Shimadzu UV-1800,Tokyo,Japan) method(4500-SiO_2.C)(Eaton et al.,2005b).

In-vitro cytotoxic effect of silica on human kidney cells

Cytotoxicity of silica was analysed on 2 human kidney cell-lines viz. kidney carcinoma cell-line(A498) & normal primary kidney cell-line-Human embryonic kidney cells(HEK) over a chronic exposure(for 7 days) to silica levels noted in the groundwater of CKDu affected regions viz.80-120 mg/L by measuring the reduction in cell viability by MTT-assay as previously described(Chen,2011).

Results and Discussion

Hydro-geochemical analysis of groundwater of Canacona

a. Physiochemical characteristics of the groundwater

Physiochemical profile of the groundwater during 3 different seasons–PRM,MON & POM of the 3 study-areas were carried out. The groundwater of CKDu affected-region was found to be highly acidic(pH-5.6) which is possibly attributed to acid-mine-drainage(AMD) occurring from unoperational granite-mine located in the vicinity of this region. AMD was supported by dominance of sulphate anion in the CKDu affected region’s groundwater(Table 1). Low levels of buffering agents-Ca & Mg(Table 1)contributed to higher groundwater acidity due to sodium-plagiogranitic bedrock of the aquifer(rich in Na & K,poor in Ca & Mg oxides) hence enriched in Na-

K rather than Ca-Mg due rock-water interactions.Neutral-pH of healthy regions is due to farness from granite-mine escaping AMD & water-interaction with metabasitic aquifer (rich in Ca,Fe,Mn,Mg due to substitution of Si & Al) resulting in Ca-Mg enrichment of water (Fernandes & Widdowson,2009).

b. Trace-metals profile of the groundwater

Trace-metals levels in the 3 study-regions' groundwater were studied. Toxic heavy-metals like Cr, Cd, Hg & As were below detectable levels in all 3 study-areas. Nephrotoxic heavy metal-lead was significantly higher(mean=9.98µgL^{-1})in the CKDu affected region(study area 1) as compared to other two study areas. These higher lead levels were possibly attributed to the acidic-groundwater interaction with lead deposits intruding the aquifer's granitic-bedrock(2.5% by wt)(Fernandes& Widdowson,2009)resulting in enhanced leaching of lead into groundwater. Negligible Pb levels in study areas 2 & 3 is due to groundwater's neutral-pH & low Pb-deposits in metabasitic-aquifer (Fernandes & Widdowson,2009). Studies have shown that chronic low-level Pb exposure(6-8µgL^{-1})causes Chronic tubulointerstitial nephritis (CKDu manifestation)due to its bio-accumulative potency & long half-life causing aggravation of renal injuries resulting in renal failure(Fadrowski et al.,2013).

Interestingly, trace geogenic-element-silica was significantly higher in the CKDu-region's groundwater(study area 1) as compared to other 2 areas. This could be accredited to the acidic groundwater causing enhanced silica leaching from the CKDu-region's granitic-aquifer(serving as rich silica source(>75% wt)as silica availability is noted to rise at acidic pH(Zuhl & Amjad,2013). Negligible levels in other two areas was attributed to the groundwater's neutral pH & aquifer's metabasitic bedrock(containing low silica-<30%)(Fernandes &Widdowson, 2009**)**

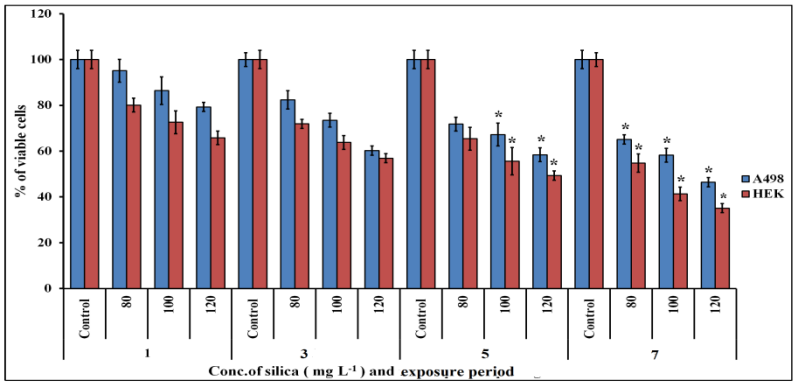
Epidemiological & animal studies have stated that chronic exposure to high silica(90 mg/L) causes renal histopathological alteration of tubular atrophy & fibrosis,typical of CTN(the CKDu patholoy),hence proved to be a potential causal of CKDu in Canacona(Khandare et al., 2015;Radovanovic et al.,1991).

Bioavailability of nephrotoxins viz.lead & silica was significantly higher in the CKDu region that resulted in higher exposure & associated nephrotoxicity that manifested in CKDu in this region(Amjad and Zuhl,2010).

In-vitro cytotoxicity of silica on human kidney cell lines

As shown in Figure 2 silica induced nephrotoxicity was noted to be a function of dose & time with significant decrease(> 50%)in HEK-cell-viability noted on chronic exposure(7th day)to high silica levels(100-120 mgL^{-1}) supporting the role of silica in CKDu causation in Canacona at the exposure levels prevalent in the region.

Figure 2. Silica induced Cytotoxicity of A498 & HEK cells over chronic exposure (1-7 days).



Data is presented as a percentage of viable cells relative to untreated control against different silica doses for 7 days exposure for both cell types. A rise in cytotoxicity with rising dose and exposure period was noted with 35.1% of HEK cells surviving as compared to 52.4% of A498 cells surviving after expsoure to highest dose (120 mg L^{-1}) for the longest period(i.e.7 days). Data are depicted as mean ± S.D from 3 independent experiments.*$p<0.05$ was significant. Error bars depict less than 5% SD.

Conclusions

This is the first study to highlight that CKDu development in Canacona taluka of Goa (India) could be an outcome of individual or synergistic effects of chronic exposure to high-levels of nephrotoxic trace geogenic element-silica & borderline levels of heavy metal-lead via regular intake of untreated groundwater.It delivers new-insights into cellular mechanism of silica nephrotoxicity in CKDu causation & nephrotoxicity incited by lead at low-levels.These results can be extrapolated to the CKDu crisis faced in groundwater relying developing-countries, thus could reduce the overall CKD burden.

References

- Amjad, Z., Zuhl, R.R. (2010).The role of water chemistry on preventing silica fouling in industrial water systems. In: CORROSION 2010 Conference and Expo. National Association of Corrosion Engineers International, Houston, paper no.10048, 1-14.
- Chen R.(2011).MTT assay of cell numbers after drug/toxin treatment. Available at:- http://www.bio-protocol.org/e51(Accessed March 3,2016).
- Daily News & analysis,2010. Urine Tests in Goa for Early Detection of Kidney Ailments.Availableat:-http://www.dnaindia.com/health/report-urine-tests-in-goa-for-early-detection-of-kidney-ailments (Accessed December 15, 2014).

- Eaton, A.D., Clesceri, L., Rice, E.W., Greenberg, A.E. Standard Methods for The Examination Of Water And Wastewater (2005a). 21st edn, American Public Health Association/Water Environment Federation,Washington DC, USA.
- Fadrowski, J.J., Abraham, A.G., Navas-Acien, A., Guallar, E., Weaver, V.M., Furth, S.L. (2013).Blood lead level and measured glomerular filtration rate in children with chronic kidney disease. Environmental Health Perspectives, 121(8), 965-970.
- Fernandes, O.A., Widdowson, M. (2009). Petrogenesis, geochronology and crustal evolution of the Canacona region of southern Goa, in:Mascarenhas, A. and Kalavampara, G. (Eds.), Natural Resources Of Goa:A Geological Perspective. Geological Society of Goa, Goa(India), 69–95.
- Gifford, F.J., Gifford, R.M., Eddleston, M. and Dhaun, N.(2016). Endemic nephropathy across the world. Kidney International Reports, 2(2), 282-292.
- Khandare, A.L., Reddy, Y.S., Balakrishna, N., Rao, G.S., Gangadhar, T. and Arlappa, N. (2015). Role of drinking water with high silica and strontium in chronic kidney disease: an exploratory community-based study in an Indian Village. Indian Journal of Community Health, 27(1), 95-102.
- Mascarenhas, S., Mutnuri, S. and Ganguly, A. (2017). Deleterious role of trace elements–Silica and lead in the development of chronic kidney disease. Chemosphere, 177, 239-249.
- Zuhl, R.W. and Amjad, Z. (2013). Solution Chemistry Impact on Silica Polymerization by Inhibitors. In: Mineral Scales in Biological and Industrial Systems. CRC Press, Boca Raton, 173-198.

Potable Reuse: US examples of changing the conversation to be about more than a "project"

Moderator: Justin Mattingly, The Water Research Foundation, Alexandria, VA, USA,

Panel: Melissa Meeker, Gwinnett Water Innovation Center, Georgia, USA, Patricia Sinicropi, WateReuse Association, Virginia, USA, Eva Steinle-Darling, Carollo Engineers, Texas, USA, Mark Poling, Clean Water Services, Oregon, USA,

Panel Summary:

This panel discussion will highlight multiple US potable reuse projects including project needs with a specific focus on the public engagement process. These projects are striving to change the conversation around water to create a sense of ownership and pride in water supply resiliency, which goes beyond any single potable reuse project. The panel will each present a few introductory slides but then have an open discussion, with audience participation, to share lessons learned and best practices, with the goal of identifying needed engagement tools that can be developed in the future.

The follow described a few program highlights:

Gwinnett County's Water Innovation Center is integrating applied research, technology innovation, workforce development and public engagement to advance water supply resiliency.

Hampton Roads Sanitation District's SWIFT program is a model for communities in coastal areas facing land subsidence and saltwater intrusion - fighting water with water and ensuring that the home to one of the world's largest natural harbors and backbone of America's naval strength remains resilient.

SF PUC Living Machine is a model for communities focused on distributed reuse systems through building-based on-site reuse -- enabling growth to continue in America's urban cores.

Tahoe-Reno Industrial Center is a model based on economic development and the distribution of recycled effluent to the desert to support new economy/tech businesses – enabling Tesla Motors, Google and Switch to create jobs in a region starved for water.

Big Spring, Texas was the United States' first potable reuse project and has virtually no outreach program but has been successful.

Wichita Falls, Texas implemented a direct potable reuse project in an emergency. When the emergency subsided and the utility discontinued the DPR, the complaints started rolling in.

El Paso, Texas has had an extensive public engagement campaign that has garnered public support for the United States' first direct-to-distribution project.

Clean Water Services, OR spearheaded the original Pure Water Brew effort that utilizes purified water for home brew competitions to address public concern over potable reuse. This effort has garnered massive US support (and duplication of the effort), as well as world-wide recognition and has led to similar efforts for wine, vodka and ice sculptures.

The growth of water reuse in Europe: 2006 to 2017

Boubekri, S., Jeffrey, P. and Le Corre, K.S.

Water Reuse Europe, Vincent building, Central Avenue, Cranfield, MK43 0AL, United Kingdom.

Abstract

Although water reuse is now widely recognised as a suitable strategic water management option (particularly under conditions of increasing water stress) at both national and European levels, there have been few attempts to characterise the growth and character of the sector. Such summaries offer important insights into not only the extent of reuse practices but also how different types of scheme are being preferenced by public bodies and investors. This paper uses data collected by Water Reuse Europe for their 2018 review to provide a comprehensive update on the current status of the European water reuse sector and how it has evolved since 2006, the date of the last in-depth review of the sector.

Keywords: Wastewater; Reuse; Europe; Sector growth.

Introduction

As any other region in the world, Europe is confronted by a number of water resources challenges. Water scarcity resulting from the combined effects of climate change and over abstraction of water resources are increasing the imbalance between water supply and demand across many countries and regions of the European Union. By 2007, 17% of the EU territory was affected by water scarcity issues (EEA, 2012). In 2014, thirteen river basins located in the Mediterranean region were affected by severe water stress issues, with the Segura river basin on the eastern coast of Spain being the most affected region with a reported water exploitation index above 40% (EEA, 2017). These challenges extend to northern European countries such as Belgium, the Netherlands, the United-Kingdom and Denmark as well where ever increasing pressures on water supply through the synergetic effects of urbanisation, industrialisation and climate change are causing concern. To illustrate, in 2007, the EC reported Denmark as being deeply affected by water scarcity issues with abstraction levels "*exceeding sustainable recharge by up to 300% around Copenhagen and other large towns"* (DG Environment, 2007). In 2018, for a second consecutive year, Belgium, and more specifically the western part

of Flanders, suffered from severe drought over spring and summer, with only 68% of the normal average rainfall of 213mm being recorded.

Consequently, recent years have seen an increase in the deployment of water reuse schemes as a strategic water management option to combat water scarcity across Europe. Support for such initiatives has been forthcoming from the European Commission who recently called for a transition towards a more circular economy, involving improved water management through wastewater reuse as a "*means of increasing water supply and alleviating pressure on resources*" (EC, 2017). However, until recently the status of the European water reuse sector remained unclear with few attempts to evaluate its growth and actual extent. Indeed, the last in-depth review of the sector was published in 2006 by Bixio *et al.*, with the intervening period characterised by significant climate change effects; the years 2008 to 2017 were described by the European Environment Agency as the warmest on record (EEA, 2018). In this context, Water Reuse Europe (WRE), the industry association for the water reuse sector in Europe, published a comprehensive review of the sector in 2018 in order to provide an update on its current status and illustrate how it has evolved since 2006. This article provides a summary of the key findings from the WRE review.

Methodology

The data presented in this study were collected from a range of sources (academic publications, commercial reports, websites etc.), including information on (*inter alia*) location, capacity, treatment technologies, drivers, reuse applications and commissioning date. These sources of information were searched by keywords using the general terms "water reuse" OR "water reclamation" in English, French and Spanish. Additional information on country specific reuse schemes were collected using the same keywords and adding the targeted location e.g. "water reuse schemes in Malta" or the end use e.g. "water reclamation in the textile industry". The searches were conducted for 28 European countries. Each document result was evaluated for reliability according to four criteria, ranked in the following order: (i) the credibility of the source of information (e.g. peer-reviewed journals, policy statements, government reports, industrial references); (ii) the possible identification of the publishing organisation or the author(s), (iii) the availability of a publication date and

(iv) the reliability and trackability of the sources cited in the publication. The results collected were compiled in a database, analysed and compared with the results from Bixio *et al.* (2006) to assess the evolution of water reuse practices in Europe from 2006 to 2017.

Results and Discussion

The survey identified 787 reuse schemes distributed across 16 European countries (Figure 1), an increase of 437 schemes (including 45 'pilot' scale schemes) since 2006, with Spain counting the highest number of schemes (361), followed by France (112) and Italy (99). Of these 787 schemes, 62% are located in water scarce areas with high population densities along coastlines where freshwater resources are limited and adversely affected by over-abstraction due to tourism and intense local agriculture. For instance, 47% of the listed schemes are located along the Mediterranean coast with over 200 schemes alone situated on the east coast of Spain spanning from Murcia to Barcelona. This is unsurprising in a region where tourism and agricultural activities impact significantly the demand for freshwater especially at times when water resources are already under great pressure (i.e. May to September, EEA 2009).

In terms of final use of the recovered effluent, the schemes cover a wide range of potable and non-potable applications for agricultural, industrial and urban activities. Overall, agricultural reuse remains the most common water reuse application in Europe (e.g. 39% of the schemes) especially in southern European countries followed by industrial reuse (15%) and recreational reuse (11%). Contrastingly, the proportion of water reuse schemes dedicated to agricultural reuse decreased from 49% in 2006 to 39% in 2017. Reductions were also recorded for urban schemes (down from 17% to 16%) and for environmental enhancement schemes (down from 18% to 11%). Unlike in other regions of the world, and more specifically the USA where the number of potable reuse projects is gaining momentum with 49 planned and constructed direct and indirect potable reuse schemes reported in 2017 (EPA, 2017), potable reuse applications remains scarce in Europe. Indeed, the Wulpen Toreele water reclamation scheme for groundwater recharge (Belgium) and the Langford scheme for surface water augmentation (UK) remain unique examples of

operational indirect potable reuse (IPR) schemes. However, new initiatives towards IPR are currently being reported in France and Spain. For instance, Vendée Eau, the French public utility in charge of the production and distribution of drinking water on the west coast of France, is exploring IPR as a solution to the ever increasing pressure on water resources in this water scarce area. This new project, currently under evaluation at pilot scale, will involve a tertiary treatment process and an artificial wetland prior to river discharge or reservoir storage. A project scheme involving soil aquifer treatment for indirect potable reuse was also commissioned in 2015 in El Port de la Selva (Spain). This scheme is still operational and the object of further monitoring although to date water quality already complies with the Spanish requirements for drinking water (WRE, 2018).

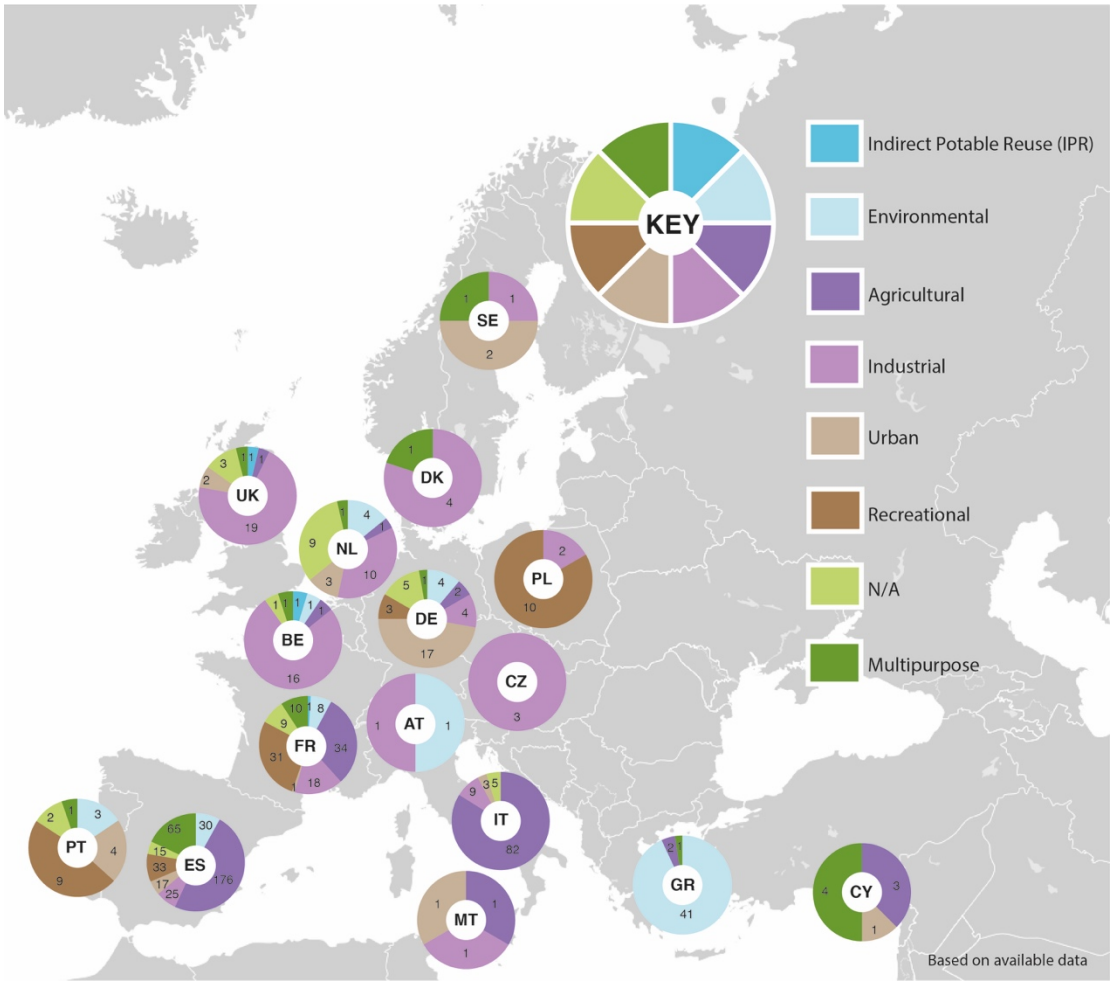


Figure 1 Distribution of reuse schemes in Europe - 2017

When compared with the 2006 figures, although the absolute number of schemes has increased across all end-use types (e.g. agricultural, industrial), the relative proportions indicate some interesting trends. For example, the proportion of

agricultural schemes has decreased from 49% to 39% whilst that for industrial applications increased from 8% to 15%. This is not surprising as industrial activities (including cooling for energy production) is one of the biggest abstractor of fresh water in Europe (55%) followed by agriculture (24%) (EEA, 2009). Water reuse is indeed particularly attractive for industries as it potentially offers them opportunities to reduce their environmental impact, their freshwater demand, whilst resulting in various economic benefits (e.g. reduced water bills, lower discharge costs etc.). The UK Bakkavor Cucina Sano scheme (UK) is a good example of the successful implementation of an industrial water reuse scheme. The scheme, operational since 2016, involves the use of low energy MBR technology and RO systems, followed by UV and chlorine dosing. The system treats all of the wastewater from a food processing factory and enables treated water to be blended with the incoming town's water supply, before being returned safely into the factory for use as potable water. With up to 85% of treated wastewater being reused by the factory and net savings of over 800k€/year after deduction of operating costs, the site is unique in Europe (WRE, 2018). Reductions are also evident for urban uses (e.g. street-washing, landscape irrigation); from 17.2% in 2006 to 15.8% in 2017 and environmental enhancement; from 17.7% in 2006 to 11.5% in 2017.

The causes of these trends can only be conjectured but the significant growth seen in the total number of schemes between 2006 and 2017 demonstrates both increasing need for water reuse in areas, such as the eastern coast of Spain, where the supply-demand balance becomes of concern and where other supply enhancement options are limited or not economically viable. As highlighted in the WRE review, raising wastewater treatment and water supply costs, tighter regulatory discharge standards and raised public awareness of industries' environmental and water footprints may also explain the particular needs for the industrial sector to promote onsite water reuse, hence the fast growth observed. The growth also suggests increasing confidence amongst water users, water management professionals, regulators, and politicians in the safe, cost-effective design and operation of reuse schemes.

Conclusions

This paper has provided a snapshot of the state of the European water reuse sector in 2017 and contrasted this with the situation in 2006. The intervening decade has seen significant growth, both in terms of the number of operational reuse projects and in terms of a rapidly developing regulatory system at both national and federal levels. Research, supported by both the European Commission and national funding, continues to inform practice and a growing community of skilled reuse professionals is emerging. Where previously there was promise and potential, there is now increasing experience and confidence; suggesting that we might expect the next ten years to deliver further advances and expansion in this important field.

References

Bixio, D., Thoeye, C., De Koning, J., Joksimovic, D., Savic, D., Wintgens, T., Melin, T., (2006) 'Wastewater reuse in Europe', Desalination, 187(1–3), pp. 89– 101.

DG Environment, European Commission, European Commission (2007). Water Scarcity & Droughts in-depth assessment. Second Interim Report – June 2007, 93pp. Accessed April 2019 at: http://ec.europa.eu/environment/water/quantity/pdf/comm_

droughts/2nd_int_report.pdf

EC (2017). Report from the commission to the European parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Ninth Report on the implementation status and the programmes for implementation (as required by Article 17) of Council Directive 91/271/EEC concerning urban waste water treatment.

EEA (2009) Water resources across Europe — confronting water scarcity and drought. Report No 2/2009, European Environment Agency, Copenhagen, 55p.

EEA (2012). Towards efficient use of water resources in Europe. EEA report No 1/2012. European Environment Agency, Copenhagen, DK. Accessed April 2019 https://www.eea.europa.eu/publications/towards-efficient-use-of-water

EEA (2017). Electronic report of the European Environment Agency on the Use of Freshwater resources available as a website at: https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-2/assessment-3

EPA (2017) Potable Reuse Compendium, USEPA; CDM Smith. Accessed April 2019 at: https://www.epa.gov/sites/production/files/201801/documents/potablereusecompendium_3.pdf

WRE (2018). Water Reuse Europe Review. 61pp. ISBN: 978-1-5272-2364-6.

Posters

Use of soil column to assess ion mobility present in treated effluent

R. D. Lucena[1], Agreste Academic Centre, Federal University of Pernambuco, Caruaru, BR; J. L. A. Biserra[2], Agreste Academic Centre, Federal University of Pernambuco, Caruaru, BR; E. Pastich[3], *Agreste Academic Centre, Federal University of Pernambuco, Caruaru, BR; K. K. Barros[4], Agreste Academic Centre, Federal University of Pernambuco, Caruaru, BR.*

Introduction

Irrigation of agricultural crops with treated effluents (E) has been presented as a way of reducing the using of mineral fertilizers in agriculture, this due to nutrients, needed to the plant growth, presents in the effluents. However, the excess of nutrients in the soil cause negative impacts; thus, it is necessary to stud the ion behaviour in the various soil layers, to avoid structural problems and toxicity to plants. Therefore, the use of soil columns can be a viable technique to monitor the mobility of ions in the soil profile. In front of that scenario, the present research had investigated the stratification of some ions present in treated effluent, in the soil layers more superficial.

Methods

The experiment was carried out in the Environmental Engineering Laboratory of Federal University of Pernambuco. The hydraulic equipment was compound by acrylic columns, with 7 cm of diameter a 30 cm of height, filled of a typical Planosol from dry region of Pernambuco state, Brazil. The irrigation of columns was carried out by drip, with average flow equal to 0.70 $mL.s^{-1}$.

The effluent was collected in the Sewage Treatment Station from Caruaru city, Pernambuco state. The experiment as planned in completely randomized design, with 5 treatments and 3 replicates: T1 (irrigation with supply water), T2 (irrigation with nutritive solution 2 of Hoaglan & Arnon (1950)), T3 (irrigation with E), T4 (irrigation with A+E 1:1, v/v), T5 (irrigation with A+E 1:3, v/v). The results were statically evaluated by Analysis of Variance (ANOVA), Test F and Tukey Test (at 1 and 5% of probabilities). The movement of the ions in the soil was studied in the layers of 0-20 cm and 20-40 cm, to investigate their stratification in the soil layers more superficial.

Results

The results showed that, to a depth of 20 cm, the P, Ca, Mg and K contents increased in 118%, 67%, 25% e 10%, respectively, after the irrigation with undiluted treated effluent. The soil studied in that experiment, by being a Planosol, presents good natural fertility and it is considered a reservoir of nutrients to the plants, especially P, Ca and Mg. Thus, with the addiction of those elements to the soil, via treated effluent, it was expected an increasing in the levels of those nutrients.

The knowledge about the dynamic of nutrients in the soil is important for the decision-making despite of fertilization. Concerning P, for being an element with low mobility, the P leachate content was not significate (6,3 $mg.dm^{-3}$, in the depth of 0-20 cm of soil submitted to T3), when compared to the P content adsorbed in the same layer (135 $mg.dm^{-3}$, in T3).

Regarding the forms of N present in soil, the NH4+ was adsorbed, because it is retained for it binds to the negatively charged soil cation exchange complex (CEC), to be assimilated by the plants. Before being submitted to the treatments, the soil had a concentration of 14.3 $mgNH_4^+.kg^{-1}$, after application of the nutrient solution (T2) and undiluted treated effluent (T3) to the soil, the levels of NH_4^+ increased at 47% (T2) and 31% (T3), in the most superficial layer (0-20 cm), which corroborates the hypothesis of CEC binding. The predominant nitrogen form in the leachate at all treatments was the organic nitrogen. The NH_4^+ was only found in the leachate collected from the soil column irrigated with the nutrient solution, at depth of 0-20 cm (2.56 $mg.L^{-1}$).

Conclusions

The application of treated effluent (diluted or not) increased the P, Ca, Mg, K and NH_4^+ contents in the soil, mainly in the soil layer more superficial (0-20 cm). The P was the element with the highest percentage of soil adsorption (118%), suggesting that phosphate fertilization can be disregarded since, depending on the type of soil, the addition of treated effluent already supplies the needs of plants.

References

HOAGLAND, D.R.; ARNON, D. I. **The water culture method for growing plants without soils**. Berkeley: California Agricultural Experimental Station, 347p., 1950.

Influence of effluent use on coriander germination

Nathália Felix Bomfim, Marcos Ribeiro, Wanderli Rogério Moreira Leite, Maria de Lourdes Florencio dos Santos, Mario Takayuki Kato, Environmental Sanitation Laboratory - Postgraduate Program in Civil Engineering - UFPE, Recife, Brazil

Introduction

The usage of sewage treatment plant byproducts for agricultural purposes represents an environmentally practice as well as an alternative to cut off costs and benefit the production in places with water scarcity such as semi-arid regions. Evaluating the effects of treated sewage on seed germination is an important step for the viability of these actions. Thus, the influence of treated sewage on the germination behavior of Coriandrum Sativum seeds was studied.

Methodology

The research was carried out in a protected greenhouse in Recife. The commercial coriander seeds were provided by the company Feltrin seeds, and presented the germination percentage and purity of 87 and 99.7%, respectively.

Three types of water treatment were used: distilled water (T1), treated well (T2) and treated sewage (T3). The treated sewage was collected in the discharge pipe at the Mangueira Sewage Treatment Plant, Recife, Brazil which consists of preliminary treatment, UASB reactor and stabilization pond. Chemical analyzes were performed according to APHA (2005). According to FAO (2003), T3 has an initial degree of irrigation restriction to in the range light to moderate (Table 1).

Table 1 - Data on chemical characteristics of treatments

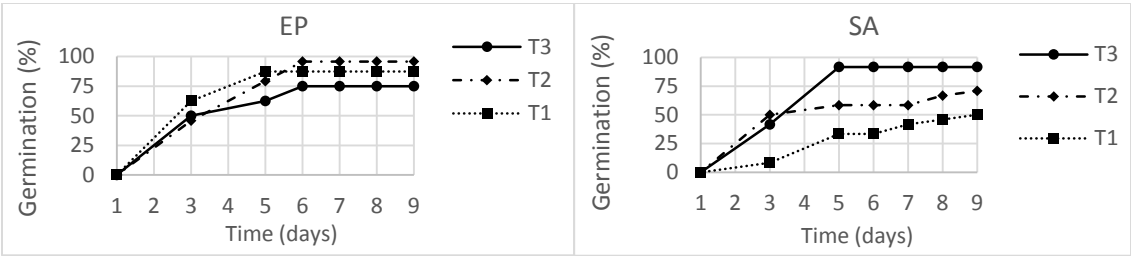
Treatment	Na (mg/L)	K (mg/L)	Ca (mg/L)	P (mg/L)	pH	Conductivity (µS/cm)
T1	0.0	0.0	0.0	0.00	6.9	3.4
T2	32.8	5.2	4.5	0.34	6.8	316.1
T3	82.7	13.8	15.9	2.82	7.5	749.9

The germination of the Coriandrum seeds occurred using three culture media: seeds on paper (EP), on cotton (AS) and on natural soil. The EP and AS tests followed recommendations of the Brazilian Ministry of Agriculture (MAPA, 2009), i.e., 24 seeds inoculated for each treatment. Besides, the irrigation blade of 70% of the pot capacity where 4 seeds per pot were placed. The soil chemical analyzes were performed in accordance to Teixeira et al. (2017).

Results and discussion

A stabilization tendency (1st measurement of 3 consecutive measurements of equivalent values) of the percentage of germinated seeds in the EP tests was observed on the 6th day, regardless the treatment used. In respect the stabilization time, the tests SA and EP with the treatment T3 presented a similar time (5 and 6 days respectively). This behavior was not evidenced in the other treatments (Figure 1).

Figure 1 - Percentage of seeds germinated by treatment in the support medium EP and SA



The plants emergence in pots was observed on day 7 for all treatments. The mean height on the 10th cultivation day was higher for the T3 (9.5±1.26 cm) than for T1 and T2 (9.0±0.79 and 5.0±1.39 cm, respectively). In this way the T3 benefited the germination of coriandrum in the experiment with pots. This evidence corroborates the effect of the accelerated germination that the use of T3 provided to the AS test (Fig 1).

Conclusion

T3 presented better performance in the pots and EP tests, while the T1 presented the worst results in SA and pot tests. The rate of stabilization in the percentage of germination in the tests for T3 was maintained (5 to 7 days), while the other treatments obtained larger rates. The mean height of the plants with T3 was higher in the measurements 10 and 20 days than in the other treatments and the average growth from 10 to 20 days was also higher for T3. With these results the treated sewage was considered suitable for seed germination of Coriandrum Sativum.

References

APHA (2005). Standard methods for the examination of water and waste water 21st edition. Washington, D.C.

FAO. 2003. User manual for irrigation with treated wastwater. Cairo : FAO Regional Office for the Near East, 2003.

MAPA. 2009. Regras para análise de sementes. Brasília : Ministério da Agricultura Pecuária e Meio Ambiente, 2009.

Teixeira, Paulo César, Donagemma, Guilherme Kangussu e Teixeira, Wenceslau Geraldes. 2017. Manual de métodos de Análise de solo. Brasília : EMBRAPA, 2017.

Chlorination for anti-clogging in drip irrigation emitters using reclaimed water: A case study in Suranaree University of Technology (Thailand)

Jareeya Yimrattanabovorn[1], Intira Sangboon[1], Pornvalai Nernploy[1], Ratchaporn Saeyan[1], Thitiporn Machikowa[2], School of Environmental Engineering[1], School of Crop Production Technology[2], Suranaree Univ. of Technology, Nakhon Ratchasima, 30000, Thailand

Introduction

A water shortage and water pollution are becoming increasingly serious all over the world, reclaimed water and polluted surface water are also reused for irrigation to solve the imbalance between and demand (Song et al, 2017). The use of drip irrigation is a priority when applying reclaimed water to agricultural land (Aiello et al, 2007). In practice, drip irrigation with reclaimed water is limited by emitter clogging. The emitter clogging issue has become one of barriers to application and promotion of drip irrigation using reclaimed water (Li et al, 2012; Zhou et al, 2017). Chlorination has been considered as the most effective method of controlling emitter bio-clogging (Song et al, 2017). Although, chlorination was generally helpful in reducing the emitter clogging in the drip irrigation systems, the effect of chlorination on plant was still unclear. Therefore, to determine a better and more appropriate mode of chemical chlorination for controlling clogging and less impact on plant were examined in a drip irrigation experiment using reclaimed water treated with the coagulation and flocculation process. The objective of this study was investigated using chlorination to anti clogging in drip irrigation using reclaimed water of SUT (Suranaree University of Technology) and effect on lettuce (*Lactuca Sativa Var.Crispa L.)* cultivation.

Material and Methods

The study was carried out to collect effluent from wastewater treatment system of SUT and analyzed for COD, color, turbidity, TDS and pH. The coagulation-flocculation batch studies were carried out using the jar test method to determine the optimum pH range, suitable volume of polyaluminium chloride ($Al_2(OH)_3Cl_3$ or PAC and polymer for reclamation of water. The results of optimum conditions was applied to reclaim water. And the reclaimed water was investigated the relation of chlorine dose and residual chlorine concentration. The drip irrigation experiment was

conducted in an open field of SUT farm to evaluate the emitter clogging and effect on lettuce. The effluent of SUT was reclaimed through the coagulation-flocculation process. The reclaimed water was applied to drip irrigation for lettuce cultivation. Four treatments of residual chlorine concentration (residual chlorine concentration in range of 0.5, 1, 1.5 and 2.0 mg/L namely R_1-R_4 sets respectively) were applied into reclaimed water. Meanwhile, two control treatments with tap-water (W) and reclaimed water without chlorination (R_0) were set up for comparison. The outflow of drip irrigation emitters were measured for clogging evaluation. And the growth rate and physical appearances were measured and noticed for impact on plant.

Results and Discussions

In the present work, the effects of residual chlorine concentration in anti-clogging of drip irrigation was studied by monitoring outflow of emitters. The results showed the R_4 sets with residual chlorine concentration 2 mg/L had retained continuous flow rate better than the other sets including of W and R_0 sets. The results indicated that chlorination could be used for anti-clogging in drip irrigation. These results are similar as finding in Song et al (2017) that chlorination could control the bio-clogging in drip irrigation. And the studies of impact on lettuce showed the R_4 sets had lowest growth rate and abnormal physical of plants. The R_2 set with residual chlorine concentration 1 mg/L was suitable chlorination for using in drip irrigation with similar clogging and impact on lettuce of control sets.

References

Aiello, R., Cirelli, G. L., Consoli, S. (2007). Effects of reclaimed wastewater irrigation on soil and tomato fruits: A case study in Sicity (Italy). Agricultural Water Management, 93, 65-72.

Li, GB., Li, YK., Xu, TW. (2012) Effects of average velocity on the growth and surface topography of biofilms attached on the reclaimed wastewater drip irrigation system laterals. Irrig Sci. 30(2), 103-113.

Song, P., Li, Y., Zhou, B., Zhou, C., Zhijing, Z., Li, J. (2017). Controlling mechanism of chlorination on emitter bio-clogging for drip irrigation using reclaimed water. Agricultural Water Management, 184, 36-45.

Zhou, B., Li, Y., Song, P., Zhou, Y., Yu, Y., Bralts, V. (2017). Anti-clogging evaluation for drip irrigation emitters using reclaimed water. Irrig. Sci, 35, 181-192.

Treated domestic effluent reuse in the germination process of Zea Mays 'BRS Gorutuba'

E. V. F. Gomes; E. J. Galindo*; J. V. M. Jordão*, N. R. Silva*, K. K. Barros*;*
**Environmental Engineering Laboratory (LEA), Agreste Academic Center - Federal University of Pernambuco (UFPE-CAA), Caruaru, Brazil.*

INTRODUCTION

Matters about water reuse are always present in the governmental and scientific institutions schedules. Northeast Brazil has edaphoclimatic characteristics that foment this discussion. In the world production scale of corn, Brazil ranks third. Zea Mays 'BRS Gorutuba' maize variety presents open pollination and super early cycle, and adapts well to the semi-arid climate, because its productive potential is not reduced under more limited water availability conditions (EMBRAPA, 2018). Essential nutrients for the development of the plant are often found in enough concentrations in treated domestic effluents, which exempts mineral fertilization and generates input savings. The objective of this work was to evaluate the effect of the exposure of corn seeds to different dilutions of treated effluent (TE).

METHODOLOGY

The experiment was realized in a Soil and Plant Preparation Room (SPPR), with solar radiation and air ventilation of LEA, UFPE-CAA, in Caruaru, Brazil. The experimental design was completely randomized, with 6 treatments and 2 replicates, namely: T1 - distilled water, T2 - supply water, T3 - TE diluted to 40% ($vol.vol^{-1}$), T4 - TE diluted to 70% ($vol.vol^{-1}$), T5 - undiluted TE, T6 - negative solution (ZnS solution, Zinc Sulphide, concentration 1%). The treated effluent used for irrigation was collected in a maturation pond (final stage of the treatment system in operation at the Sewage Treatment Station – Rendeiras – ETE Rendeiras). The drinking water used in that experiment was came from the distribution system of the Pernambuco Supply Company (COMPESA). The seeds of *Zea Mays* 'BRS Gorutuba' variety were provided by the Agronomic Research Institute of the state of Pernambuco, Brazil (IPA). In this experiment, 68 seeds were conditioned, with homogeneous spacing of 2.0 cm, in transparent plastic trays, with 30 cm in diameter. The substratum used in the plays were non-toxic paper towels (water retention capacity 5,91 $cm^3H_2O.g^{-1}$), which were kept saturated through daily replenishment according to MAPA

(1992). All samples were weighed, beforehand and at the end of the experiment, to measure productivity. The temperature of the room was recorded daily with a thermostat. After the first sign of root and aerial development, the root and shoot lengths of the seedlings were measured. The duration of the experiment was 14 days. We considered as germinated all seeds with root growth of about 2 mm (Hadas, 1976) The results were analyzed by means of summary and dispersion measurements, simple linear regression and growth rate.

RESULTS AND DISCUSSIONS

With the solutions mentioned above and at room temperature (minimum of 75.31 ºF ± 0.27 and maximum of 78.8 ºF ± 1.66), the seeds studied presented a germination range between 92 and 96%, even those exposed to the negative solution (1% ZnS). However, the development of the root system of the seeds submitted to the negative solution delayed 1 day in relation to the other samples. In addition, this solution also led to subsequent disruption of seedling development. The highest growth rate of the radicle was in T4 - ET diluted at 70% (vol.vol^{-1}), 1.40 cm.day^{-1}, and the highest seedling growth rate was recorded in undiluted T5 - ET, 1.64 cm.dia^{-1}, both with significant difference from the fourth day of experiment. At the end of the experiment, T5 - undiluted TE presented best biomass productivity (29,35 g.tray^{-1} ± 0,43), that is because after the germination phase, the plant need for essential micro and macronutrient begins to grow.

CONCLUSION

From the results obtained, it was noticed that the use of the treated domestic effluent for corn seeds germination and breeding of corn seedlings can be a promising alternative, since it improves plant growth rate and seedling productivity (t.ha^{-1}).

REFERENCES

BRASIL, Ministério da Agricultura e Reforma Agrária. Regras para análise de sementes. Brasília, DF: SNDA/ DNDV/CLAV, 1992. 365 p.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUARIA – EMBRAPA. Milho – BRS Gorutuba Brasília: 2015.

BRASIL, Ministério da Agricultura e Reforma Agrária. Regras para análise de sementes. Brasília, DF: SNDA/ DNDV/CLAV, 1992. 365 p.

HADAS, A. Water uptake and germination of leguminous seeds under changing external water potencial in osmotic solution. Journal Express Botany, 27: 480-9, 1976.

Enabling aquifer storage and recovery (ASR) by high flowrate filtration for improved water management

Societal challenge

- Manage (extreme) rainfall and prevent pluvial flooding
- Water banking for use during later droughts

Engineered solution

- Aquifer storage and recovery of harvested stormwater

Benefits of the solution

- Local discharge, long-term water conservation
- Large capacity, limited spatial footprint, quality conservation

Technical challenge

- Design of a stand-alone, high capacity rainwater treatment of low spatial footprint which cost-effective decreases infiltration well clogging rate
- Optimal design and operation to prevent overflows and oversizing

Methodology

- Evaluation of pre-treatment systems available
- Extensive field test of rapid and compact filtration system and disinfection fed by rainwater with a high clogging potential

SuWaNu-Europe: Network for effective knowledge transfer on safe and economic wastewater reuse in agriculture in Europe

Rafael Casielles Restoy, BIOAZUL S.L., Málaga Spain

Water scarcity is a global problem which is not only limited to traditional dry areas. Indeed, 17% of European territory suffers from water scarcity and 46% of the European population lives in places which are water-stressed. The problem is especially acute in Southern Europe where a growing water demand mainly for the agriculture and tourism sectors.

SuWaNu Europe, with contract number 818088, is a Thematic Networks focused on the reuse of treated wastewater in agriculture. The reason behind is that wastewater treated according to appropriate standards and methods has a strong potential to complement conventional water resources used in agricultural irrigation. The aim of the project is to promote the effective exchange of knowledge, experience and skills between practitioners and relevant actors of water reuse in agriculture, so that direct applicable technological and organizational solutions are widely and balanced disseminated all around Europe resulting in a more resilient agricultural sector to cope with water scarcity and climate change effects.

SuWaNu Europe is based on a previous EU project called *SuWaNu: Sustainable Water treatment and Nutrient reuse options*, which consisted in developing strategies based on water reuse to solve problems such as the scarcity or the availability of nutrients. However, SuWaNu Europe has been conceived not only as an extension of former SuWaNu project activities but also as the creation of a new instrument based on an existing network to accelerate the uptake of research results in the field of water reuse in agriculture.

For that reason, the project will create Regional Working Groups between consortium members and relevant actors in 8 target regions that will work to spread the project findings. The objective is to establish permanent links - beyond the project timeframe - with relevant local actors, encouraging flow of information among researchers, private innovators, civil organizations and public administration.

Recommended Limits of Reclaimed Water for Industrial Use

Hsin-Hsu Huang, Sinotech Engineering Consultants, Inc., Taipei City, Taiwan; Yu-De Huang, Sinotech Engineering Consultants, Inc., Taipei City, Taiwan; Ching-Ping Chu, Sinotech Engineering Consultants, Inc., Taipei City, Taiwan; Yu-Jen Chung, Sinotech Engineering Consultants, Inc., Taipei City, Taiwan

Water Scarcity and Industrial Water Demand in Taiwan

Due to overly concentrated rainfall and the topography, only 20% of rainfall is available use in Taiwan. The impact of water shortage has become a serious issue in Taiwan. The annual industrial water consumption is about 1.5 to 1.7 billion tons and the trend is gradually increasing. The low water availability and increasing water demand cause a threat to industrial development. In response to the challenge of sustainable water use, Taiwan has set a policy target to evaluate the usage of reclaimed water as 10% of the public water supply. About 50% of the annual industrial water consumption is contributed to manufacture of chemical materials and manufacture of electronic parts and components. The industries have low tolerance for water outage, and the stability of water supply for industrial users can be improved by using reclaimed water.

Identities of Industrial Water Use

According to the water consumption, water for industrial use can be divided as 3 categories, including domestic water, industrial water and miscellaneous water. Domestic water is supply for the staff activities such as drinking, sanitation and washing which related to the production. Industrial water is used for manufacture processes, including fabricating, processing, washing, heating, cooling, or incorporating water into a product etc. Miscellaneous water is used for floor cleaning and landscape watering etc. The ratio of water usage for different purposes are relied on the industrial manufacture properties. For chemical materials industry, around 40% to 50% intake water is used for cooling. Furthermore, for some electronics production, the ratio of process water may higher than 60%. Accordingly, the cooling water and process water can be the target water supplied from reclaimed water.

Proper Reclamation Treatment Process for Wastewater Water Treatment Plant

Reclamation of the effluent from the municipal wastewater treatment plant (WWTP) has been considered as most efficient reclaimed water resource as the effluent quality is usually stable and acceptable. Furthermore the quick growth of public sewer construction and connection in urban area provides an appropriate environment to develop reclaimed water resource. In Taiwan, several large WWTP effluent reclamation projects have gradually been commenced in the near future. The user will be those electronic, metal and chemical material industries. The planned effluent reclamation processes including sand filtration + disinfection or ultrafiltration filtration + reverse osmosis + disinfection depends on the requirement of users.

Recommended Limits of Reclaimed Water for Industrial Use

In order to promote the WWTP effluent reclamation projects, it is necessary to set up the recommended limits of reclaimed water for industrial use. Take the general water quality of WWTP effluent and the performance of reclamation technology into consideration, two limits are suggested. For process water purpose, the concern items including total organic carbon and total dissolved salt. Therefore, the recommend reclamation process is ultrafiltration filtration + reverse osmosis + disinfection. For cooling water, the effluent was suggested treated by sand filtration + ultrafiltration. Furthermore, the fouling cause substances such as total hardness, silica etc. shall lower than the recommend limits to keep the heat transfer efficiency of cooling tower.

Reuse of treated wastewater in industrial symbiosis

Kerstin Hoyer, VA SYD, Malmö, Sweden

Reuse of wastewater has long been discussed in the world. Lately, also in Sweden, a country with generally good water supply, reoccurring dry summers and local challenges of water supply have put the topic on the agenda.

Techniques to treat wastewater for reuse in different applications have been studied in general. In order to implement reuse of treated wastewater in industry and agriculture (for irrigation purposes), besides technical surveys and studies, business concepts based on the local conditions at different wastewater treatment plants are needed. In this project, eight municipal water and wastewater organizations in Sweden corporate to study which applications for wastewater reuse are interesting for industry and agriculture in connection to the participating wastewater treatment plants. This approach gives a better understanding of the potential for treated wastewater for different applications, mostly in symbioses between water and wastewater organizations and industry or agriculture. Interesting applications for industrial reuse of wastewater are identified and studied further. The focus on industrial symbiosis between the wastewater treatment plants and industry and agriculture leads to results which can be implemented in connection to wastewater treatment plants within the near future.

The project covers a compilation of the potential for reuse of treated wastewater in industry and agriculture, identification of treatment processes needed for the identified applications focusing on the integration in the wastewater treatment plants as well as an economic analysis. The results will be presented at the conference.

Long-term effect of oxygen concentration on BAC performance in a water reclamation plant

Laura Palli[1], *Stefano Fiaschi*[1], *Michele Allocca*[2], *Vittorio Viviani*[2], *Claudio Lubello*[1], *Riccardo Gori*[1], *Roberto Camisa*[2], *Donatella Fibbi*[2]

[1]*Department of Civil and Environmental Engineering, University of Florence, Italy*
[2]*G.I.D.A. SpA, Prato Italy*

Prato (Tuscany, Italy) is an important textile district which is one the more water-consuming industrial sector [1]. In the past, the main water supply source of the city was the local groundwater, leading to a progressive depletion of this resource. For this reason, wastewater reclamation has played a key role for the industrial district since 1990s [2,3], through a refining plant managed by GIDA SpA. The plant is composed of the following sections: chemical decoloration, sand filtration, biological activated carbon (BAC) filtration and then disinfection with sodium hypochlorite and hydrogen peroxide. The most expensive section in term of operational cost is the BAC, due to the energy demand (required for the oxygen transfer) and the oxygen supply cost. Among the 5 BACs of the plant, two of them worked in parallel from 2012 until 2018, treating more than $3 \cdot 10^6$ m^3 of water each, but one (filter A) having a doubled oxygen dosage than the other (filter B). In the present work, a study on the effect of different dosage on the performances of the plant has been carried out. Moreover, the concentration of the biomass and the amount of biomass removed with backwashing has been evaluated. A comparison between the filters A and B in terms of color, $N\_NH_4^+$ and COD removal, shows typical different behaviors (Figure 1). A linear decrease of performance over the time can be seen for color, which is removed mainly by adsorption. On the contrary, ammonium removal, by means of biological processes, doesn't show any tendency with a typical high variability due to influent concentration. COD removal shows an intermediate behavior, even if a clear fall is present after 1 million cubic meters. Comparing the average removal rates of these three parameters, the increase in oxygen dosage leads to an increase of 40% of ammonium removal, 10% of COD removal and 6% of color removal with respect to the low-oxygen filters. On the other hand, considering the costs for energy requirements and oxygen supply, costs for the two different dosages have been estimated to 0.033 €/m^3 for filter A and 0.009€/m^3 for filter B.

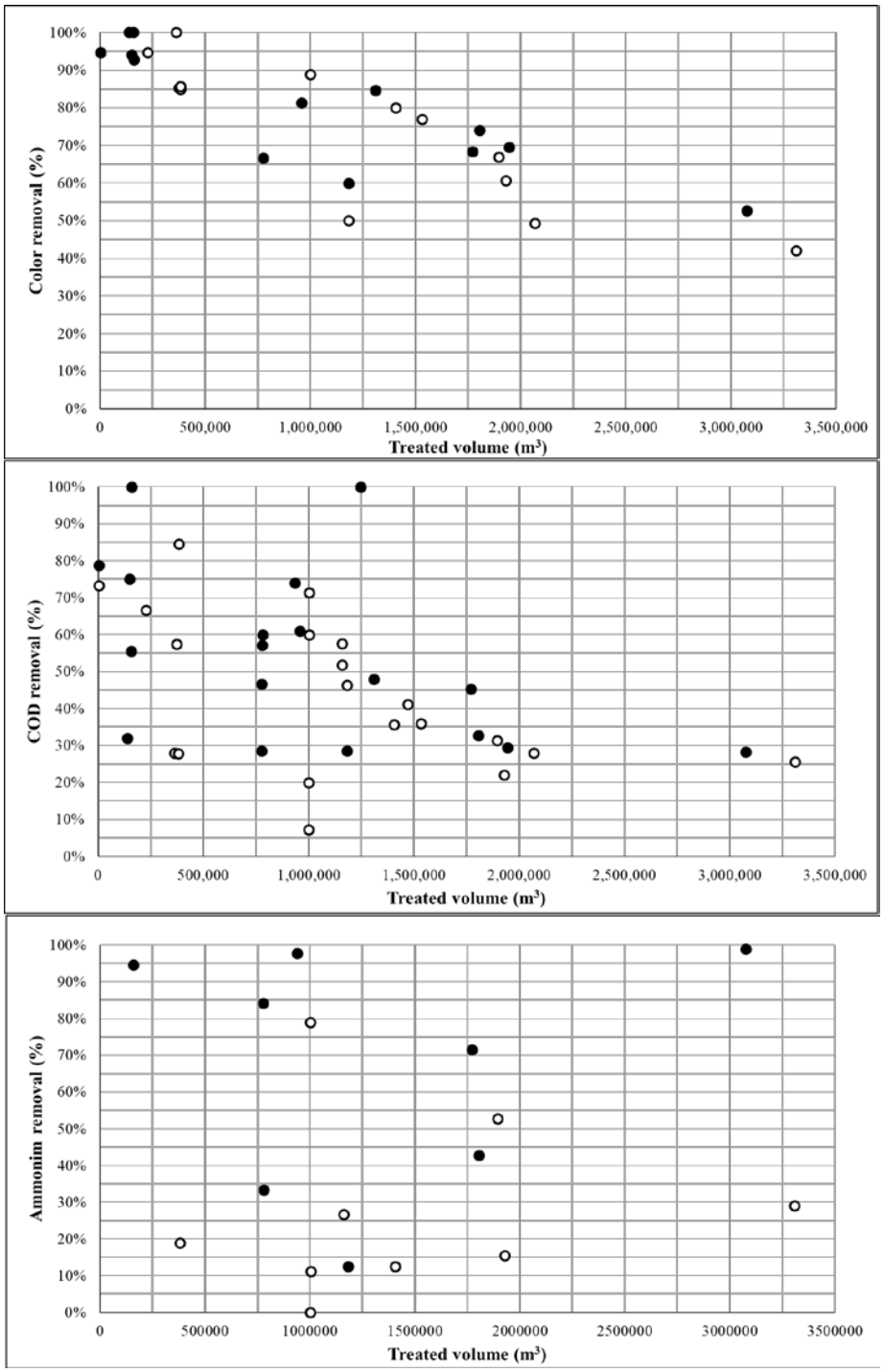


Figure 1. Removal efficiencies of the studied BACs for color, COD and N_NH$_4^+$
Legend: ●High-oxygen filter (A); ○ Low-oxygen filter (B).

References

[1] Vajnhandl, Volmajer Valh, The status of water reuse in European textile sector, J. Environ. Manage. 141 (2014) 29–35.

[2] Caretti, Coppini, Fatarella, Lubello, Membrane filtration and sonication for industrial wastewater reuse, Water Sci. Technol. 64 (2011) 2500–2507.

[3] Gori, Lubello, Ferrini, Nicese, Coppini, Reuse of industrial wastewater for the irrigation of ornamental plants, Water Sci. Technol. 57 (2008) 883–889.

Impact of organic fouling layers on micropollutants rejection by FO membrane for water reclamation

Duksoo Jang, KAIST, Daejeon, Republic of Korea; Seungju Choi, KAIST, Daejeon, Republic of Korea; Seoktae Kang, KAIST, Daejeon, Republic of Korea

Summary

In this study, the impact of organic fouling layer on the transport of micropollutant (MPs) in the forward osmosis (FO) process was examined with three model foulants (humic acid, alginate, and bovine serum albumin). As a result, the rejection of neutral MPs with higher K_{OW} was severely decreased in the presence of organic fouling layers. The results suggested that the high affinity between hydrophobic MPs and hydrophobic structure of foulants resulted in the elevated concentration of MPs in fouling layers, thus, accelerated the diffusional transport of the solute across the active layer of the fouled FO membranes.

Introduction

One of the promising technologies for water and wastewater reclamation is the application of FO process such as hybrid FO-RO process. Although this approach offer a multi-barrier for contaminant rejection, there remain several challenges associated with the reuse of impaired water for potable use, especially concern over the occurrence of MPs in wastewater. Several recent studies have investigated the rejection of MPs by FO membranes. However, a complete understanding of the rejection mechanism of MPs by clean and fouled FO membranes is still a challenging issue. The aim of this study is to evaluate the impact of organic fouling layer on the transport of MPs in the FO process were examined.

Materials and methods

Five MPs that have been frequently detected in secondary treated effluent were selected in this investigation. A bench-scale flat-sheet cross-flow FO system described in our previous publication [1]. The HA, BSA, and SA were selected as a model organic foulants. Mass concentrations of organic foulant and each MPs in the feed solution (10 mM NaCl and 1 mM NaHCO3) were 100 mg/L and 10 μg/L, respectively. MPs were analyzed by LC-MS with solid-phase extraction.

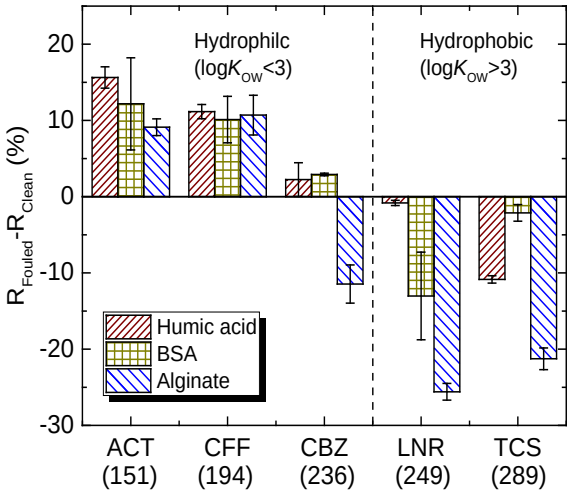


Fig. 1. Comparison of MPs rejection by different organic-fouled FO membranes

Results and discussion

As can be seen in Fig. 1, the rejection of hydrophilic MPs was increased above 95 % in the organic-fouled FO membrane. A possible explanation for this might be that the fouling layer hindered neutral MPs transport through the FO membrane and enhanced steric hindrance. However, the separation behaviors of LNR and TCS, which has high log K_{OW}, by clean and fouled membranes differ from hydrophilic compounds. The rejection for the fouled FO membrane decreases 25.6 and 21.3 % compared to virgin FO membrane, respectively. This result can be explained by cake-enhanced concentration polarization. The fouled layer may allow a higher amount of MPs to partition through the FO membrane (data not shown), and eventually, decrease the rejection.

Conclusion

Hydrophilic neutral compounds were rejected more effectively when the FO membrane was fouled due to the steric hindrance. However, the rejection of MPs with higher K_{OW} was severely decreased in the presence of organic fouling layers. The insufficient MPs rejection in FO was mainly attributed to the locally increased MPs concentration in the fouling layer at FO membrane surfaces.

Reference

[1] Jang, D., et al., *Relating solute properties of contaminants of emerging concern and their rejection by forward osmosis membrane.* Science of The Total Environment, 2018. **639**: p. 673-678.

Novel Smart Assemblies for Industrial Waste Water Remediation

P.Ambre[1], J.Paneysar[1],N.Ahmed[2], S.Barton[2], E.Coutinho[1]

[1]Bombay College of Pharmacy, Mumbai, India

[2]Kingston University, London, United Kingdom

Abstract

The planet earth would be facing about 40% shortfall in water supply by 2030, unless we dramatically improve the management of this precious resource. Discharged water from industry is significantly contaminated and may be dangerous to the health of mankind. It is a herculean task to prevent organic pollutants and toxic heavy metals from contaminated water, nonetheless sincere efforts are being made to recover the impure water and bring about zero discharge. The present study highlights the application of science and technology being developed to improve the purification process of contaminated water and its reuse in industries. Water soluble synthetic polymers have been widely explored to extract organic contaminants[1], while biodegradable polymers are being used for extraction of toxic metals from water[2]. A composite polymer that is able to extract both these types of contaminants simultaneously by the principle of adsorption has been exemplified in this work. Composite polymers have been made by grafting temperature responsive smart polymers on to the natural polymer pullulan. A series of novel water soluble temperature responsive graft smart materials have been synthesized using a ceric ammonium nitrate redox initiator method and characterized by FT-IR, DSC, TGA, GPC and ^{1}H-NMR. The propensity of these polymers was analysed by various analytical methods for removal of organic impurities such as phenols, anhydrides, textile dyes, pesticides, herbicides, antibiotics and inorganic heavy metals. The smart materials have individually shown an elimination of more than 90% for respective contaminants. Further, since the elimination of wide array of contaminants from wastewater revolves around the principal of surface area, particle size and adsorption efficiency of the designed material. The developed microspheres and nanofibres from these polymers have successfully exhibited ascendancy in terms of removal (97% and above), reusability and recycling ability for exclusion of dyes, organic and inorganic impurities from water. Moreover, the extensive reduction in levels of Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD)

for water pooled from various industries suggests the inclusion of such systems as a benefaction to the current methods used for purification of wastewater by the industries. Therefore, branding them as promising materials for industrial water remediation due to high reproducibility in synthesis, properties and elimination spectrum.

References:

1. T. Saitoh and M. Hirade, Environmental science and technology conference proceedings*,* **2007**, 1269-1276.
2. A. Bhatnagar and M. Silanpaa, Advances in Colloid and Interface Science, **2009**, 152, 26–38.

[POSTER]

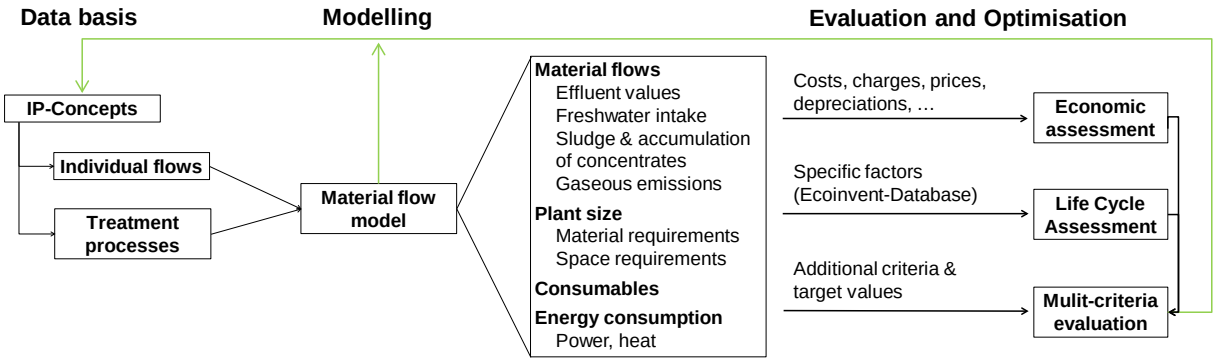
Multi-Criteria Assessment of Water Reuse in Industrial Parks

Dagmar Pohl, Leibniz University Hannover, Institute of Sanitary Engineering and Waste Management (ISAH), Hannover, Germany;
Maike Beier, Leibniz University Hannover, Institute of Sanitary Engineering and Waste Management (ISAH), Hannover, Germany;
Jorge Cristobal, TU Darmstadt, Institut IWAR, Darmstadt, Germany;
Jens Hilbig, IEEM gGmbH, Institute of Environmental Engineering and Management at Witten/Herdecke University, Witten, Germany;
Anna Dell, Technische Universität Darmstadt, Institut für Geodäsie, Darmstadt, Germany;

The authors are going to present a multi-criteria planning and decision support tool to assess water reuse potential and opportunities in industrial parks. Combining a multi-criteria set of environmental criteria based on life cycle assessment, economic aspects and the technical performance of different wastewater treatment technologies, the authors develop a model-based approach for planning and evaluating water reuse concepts in industrial parks.

Model-based planning and evaluation

A set of various user and process modules has been developed. User modules characterise water sources and sinks in terms of supplied or required water quality and quantity. Process modules contain information on treatment performance and plant dimensions. Based on these modules and several input factors, material flows are modelled and evaluated. Using different assessment approaches like economic cost-benefit analysis (CBA) and environmental life cycle assessment (LCA), a framework for the evaluation and optimisation of water reuse in industrial parks is outlined and tested. The developed methodology is used to compare decentralised and centralised water reuse concepts for a mixed-industry park within the research project WaReIp – Water ReUse in Industrial Parks.



Input data is collected from several sources like surveys among operators of industrial parks, literature reviews, databases (e.g. ecoinvent) and site visits in Germany, China and Vietnam. Using a multi-disciplinary approach, the authors strive to establish a useful and practical tool for evaluation and optimisation of water reuse in industrial parks.

This work has been conducted under the framework of the research project WaReIP – Water ReUse in Industrial Parks – under the WavE research programme – Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination – funded by the German Federal Ministry of Education and Research (BMBF, grant no. 02WAV1409).

The authors would like to express their gratitude to the BMBF for the financial funding of the WaReIP project (grant no. 02WAV1409), as well as the experts and partners in Germany, Vietnam and China for their cooperation and contribution.

Cost-Benefit Analysis of Water Reuse in Industrial Parks

Jens Hilbig, IEEM gGmbH, Institute of Environmental Engineering and Management at Witten/Herdecke University, Witten, Germany;
Karl-Ulrich Rudolph, IEEM gGmbH, Institute of Environmental Engineering and Management at Witten/Herdecke University & Faculty of Management and Economics, Witten/Herdecke University, Witten, Germany;
Birte Boysen, IEEM gGmbH, Institute of Environmental Engineering and Management at Witten/Herdecke University, Witten, Germany;
Jonas Beckmann, IEEM gGmbH, Institute of Environmental Engineering and Management at Witten/Herdecke University, Witten, Germany;

The authors are presenting an economic evaluation of water reuse opportunities in industrial parks as part of a multi-criteria planning and decision support tool to assess water reuse potential and opportunities. Based on an assessment of internal economic criteria (e.g. capital expenditure (CAPEX) and operational expenditure (OPEX) for provision of water input and wastewater treatment processes in industrial parks) as well as externalities and socio-economic cost and benefits of different water utilisation strategies, the authors develop economic criteria to analyse the costs and benefits of water reuse in industrial parks.

Cost-benefit analysis (CBA)

The work is part of a model-based planning and evaluation tool developed under the framework of the research project WaReIP – Water ReUse in Industrial Parks funded by the German Federal Ministry of Education and Research (BMBF, grant no. 02WAV1409C).

For a set of various user modules (which characterise different water sources, required water input as well as (wastewater-)output qualities and quantities) and different process modules (characterised by treatment performance and plant dimensions etc.) economic data (e.g. cost-functions, energy consumption, commodity prices) is collected and evaluated. A comparison of this data with several water reuse options gives a first overview of feasible reuse opportunities inside the industrial park from an economic perspective. Taking into account further external costs and

benefits, the research project strives to identify sustainable and cost-efficient applications of water reuse.

Financing models

Based on the cost-benefit analysis, different financing models for water reuse are analysed. This includes on the one hand internal cost-recovery inside the industrial parks and on the other hand further financing options e.g. subsidies or transfers. Depending on externalities or political decisions (for example environmental or employment policy), different financing models to incentivise water reuse are presented.

Input data is collected from several sources like surveys among operators of industrial parks, literature reviews, databases and site visits in Germany, China and Vietnam. The CBA is part of a multi-disciplinary approach to establish a useful and practical tool for evaluation and optimisation of water reuse in industrial parks.

The authors would like to express their gratitude to the BMBF for the financial funding of the WaReIP project (grant no. 02WAV1409), as well as the experts and partners in Germany, Vietnam and China for their cooperation and contribution.

Establishing water reuse networks in mixed-industry parks using a model-based approach

Dagmar Pohl, Maike Beier, Stephan Köster

Institute of Sanitary Engineering and Waste Management (ISAH), Leibniz University Hannover, Germany

Research background

Industrial water reuse has already been implemented in many contexts. New concepts and approaches are required to further reduce fresh water demand. A decisive next development step will be water reuse networks at the industrial park level. Although the need for such networks has long been recognized and discussed, they have rarely been implemented so far. Especially larger mixed-industry parks show highly diverse wastewater qualities and freshwater demands. Consequently, this type of industrial parks has great potential for implementing water reuse networks.

In the conceptual design phase, there is a great variety of options, and accordingly great potential to maximize the value of the project's outcome. However, typically only limited and highly uncertain data is available concerning the performance of treatment processes, flow rates and contaminant loads as well as the future development of requirements and boundary conditions.

The model-based approach

Within the project "Water Reuse in Industrial Parks" (WaReIp) a model-based decision support methodology for selecting water reuse concepts for industrial parks is developed. It is used to compare centralized and decentralized reuse concepts for a mixed-industry park. The technical, economic and ecological performance of the water reuse networks is assessed based on simulations. For this, a flowsheet simulation model has been developed and implemented in SIMBA#2. Main features are

- extendable model library containing pre-configured modules for typical industrial water treatment processes and water users,
- water quality characterization through commonly used quality parameters,
- calculation of data for cost-benefit analysis and life cycle assessment,
- adapting case-specific data and simulation of different scenarios.

Water users (sources and/or sinks) and treatment processes are represented by modules which can be connected to form flowsheets of water reuse networks (see Figure 1). User modules specify both the amount and quality of produced wastewater flows and the required freshwater. They can be parametrized, e.g. by the yearly production capacity, and adapted to local conditions. The treatment process modules contain a simplified static model of the selected process. Performance parameters and specific demands can be case-specifically adapted. The modular structure allows replacing single modules in a flowsheet, e. g. using a more sophisticated model for a certain treatment process once additional information is available. The model library can be extended by user-defined modules for treatment processes or water users.

The required input data for the model broadly matches the data that is typically available or can be easily determined early on. Special care was taken to allow for the flexible handling of missing data. The quality parameters that characterize all streams are measurable and relevant to the process design.

For all treatment processes, effluent data, energy and auxiliaries demand and generated waste streams for steady-state conditions as well as plant dimensions based on the influent characteristics are computed. Prerequisites and limits for the application of the processes are checked in the simulations to ensure the feasibility of the designed treatment trains. The model output contains all required data to check if quality standards are met, to estimate capital and operating expenses and to perform an ecological assessment.

Conclusions and Outlook

The pursued model-based approach addresses the requirements of the early conceptual phase, supports the overall planning and decision-making process and pushes innovative solutions. As the model is computationally inexpensive, large numbers of model runs can be performed. Beyond simulating different scenarios, this facilitates the application of optimization algorithms and global sensitivity analysis methods, which will be the subject of future research.

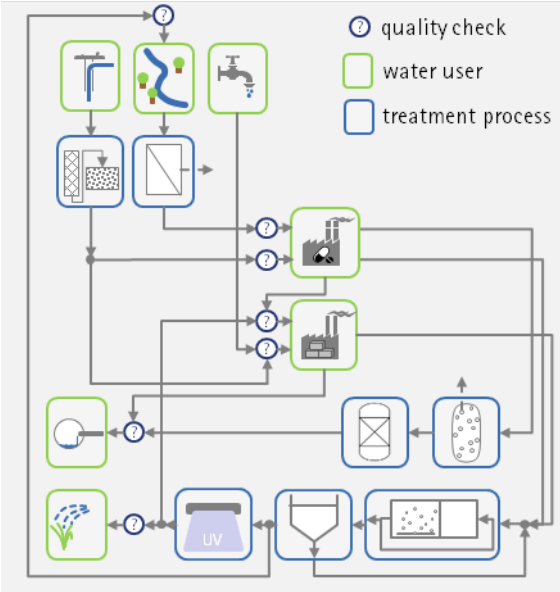


Figure 1 Flowsheet of a small water reuse network with different water users and treatment technologies

Ceramic-based Microflotation-Microfiltration Process for the Reuse of Challenging Industrial Effluents Through the Removal of Suspended Solids, Fats, Oils and Greases

Deepak Srinivasan, akvola Technologies GmbH, Berlin, Germany; Dr.-Ing. Matan Beery, akvola Technologies GmbH, Berlin, Germany

This paper studies the performance and economical value of industrial water reuse using chemical dosing and a ceramic flotation filtration process in the manufacturing, metalworking and oil industries.

INTRODUCTION

Due to decreasing natural resources, manufacturing companies worldwide are forced to improve their water management. Especially in dry regions where fresh water is scarce and expensive, water reuse has a huge additional value as it saves cost and relieves the local water stress. The reuse applications continue to evolve and are recognized as viable options as water stress continue to drive the industries to focus on sustainability with regards to the water resources. In order to reduce the cost of disposal and to comply with the local legislation standards of water disposal, the metalworking industry is looking to increase the reuse of water. Greater water reuse can offset the need for intake of process water from water resources and thereby have a positive impact on the environment.

Also, offshore and onshore oil wells have several special requirements and challenges concerning the implementation of wastewater management. They have to monitor the water production and discharge carefully. Consequently, the Oil and Gas industries are required to review their effluent treatment processes or waste disposal options to meet the targets. Both dissolved air flotation (DAF) and froth flotation (using sodium dodecyl sulfate as frother and stainless-steel rings as packing media in the flotation column) were shown in the past to be an effective method of treating metal cutting fluids [1,2]. Microfiltration was also shown to be successful treating such waters. Schoeman and Novhe investigated the treatment of spent cutting oil from a glass industry after passing it through a bag filter to remove all metal particles. Treating the solution with a MF membrane and backflushes of 1 s every 3 min could

reach a sustainable flux and manageable membrane fouling reaching COD removal of 75 to 90% and FOG removal of 97 to 99,7% [3]. Hilal et al. have investigated the effect of concentration polarization during UF and NF treatment of metalworking fluids. They advised using an integrated membrane approach of decreasing membrane pore size in subsequent membrane filtration steps in order to avoid increasing the feed cross flow velocity and improve the permeate quality [4]. The applicability of microfiltration technology on metalworking fluids was also investigated using tubular ceramic membranes. John Wentz et al. showed that steady state fluxes of 200 - 300 LMH were achieved with the membrane backpulsed every 2 minutes for 1 second. The ability of the membrane to remove extraneous oils was also demonstrated while maintaining the steady state flux [5].

Weschenfelder S.E et al. [6] have also studied the use of microfiltration for produced water treatment. The process described demonstrated that a sustainable permeate flux could be maintained with backwashes interval of 30 minutes along with backpulsing interval of 5 minutes. The process was also effective in generating high quality effluent with more than 95 percent removal of TSS and oil concentration. The use of tubular ceramic microfiltration (ZrO2) membranes for produced water treatment was examined by Zhong et al. [7]. The produced water was mixed with flocculants as a pretreatment step and then passed through a microfiltration membrane at a constant applied pressure of 1,1 bar. At a permeate flux of 173,5 LMH, the filtered permeate showed high removal rates of oil namely 95,6 percent and the treated water was in accordance with the Chinese national discharge limits. The use of flocculation as a pretreatment was known to cause less fouling of the membrane and also improved the oil removal rates from 83 percent (no flocculation) to 95,6 percent. Ceramic membranes in produced water treatment were first reported by Pedenaud et al. [8]. The authors concluded, that they can be economically competitive in many oil and gas fields using high fluxes of 200-300 lmh. However, cross flow membrane systems have a rather high energy consumption compared to submerged membranes as Ripperger [9] described, because of high crossflow velocities.

MATERIALS AND METHODS

The technology described in this paper is a hybrid ceramic flotation filtration process with low energy consumption and high separation efficiency (figure 1). The microbubbles (50-100 micron) required for flotation are generated by MicroGas, a fine bubble generation device based on rotating ceramic diffusers fed with pressurized air at 1-2 bar. The bubbles agglomerate with particles and droplets in the waste water, carrying suspended matter, such as oil and metal particles to the surface. These agglomerates form a float layer on the water surface that is skimmed off the tank. Below the float layer, submerged ceramic flat sheet microfiltration membranes made of SiC are located. With a pump water is filtered through the membranes, applying a vacuum pressure of around 0,2-0,4 bar. The membrane's pore size according to the manufacturer is 0,1 µm. Depending on the feed water, pretreatment chemicals such as emulsion breakers and coagulants can be dosed to the feed in order to enhance the removal of organic compounds.

The technology can be applied in different industrial verticals, where oils and suspended solids are present. Typically, these are produced water treatment, refineries and metalworking fluids. Pilot tests were carried out with different pilot plants in the range of 0,2-2 m³/h capacity. Besides the transmembrane pressure (TMP), which is an indicator for the membrane fouling, other operating conditions such as flux and backwash/cleaning strategy are evaluated in a pilot project.

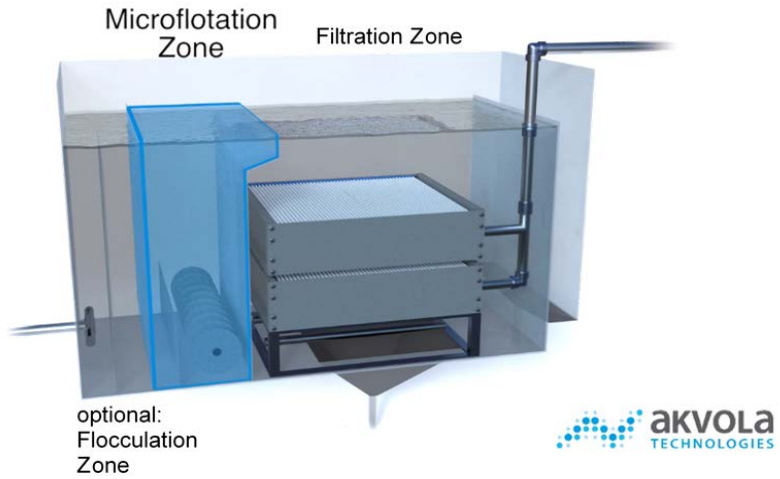


Figure 1: Scheme of the flotation-filtration technology

RESULTS AND DISCUSSION

A pilot plant was deployed at a wastewater disposal company in Austria and tests were conducted for several months. The majority of the water originates from

different metalworking sites. The goal of the pilot was to produce high quality treated water which can be fed into the company's own biological treatment plant. High removal of oil and substantial decrease of COD was desired. As a pretreatment chemical, a cationic polyelectrolyte as well as an organic polymer were used to destabilize the emulsion.

The test runs were carried out at a flux of 75 LMH with backwashes of 30 seconds duration every 15 minutes. The flotation-filtration process was very robust in continuously producing treated water with very low oil content (0,1 mg/l). The COD content of the wastewater was reduced by 94 percent. Both values comply with the treatment goal. The residual COD can be attributed to dissolved organics and surfactants in the wastewaters. Operational differences between the different demulsifiers were not visible in the study, although cationic polyelectrolytes are typically not recommended for membrane processes as they tend to cause fouling themselves.

Table 1 shows the qualities of the water in terms of oil and COD levels and figure 2 shows what the influent and effluent actually look like in this case.

Parameter	**Influent**	**Desired Effluent Limit**	**Treated Water Effluent**
Oil (mg/l)	400	< 1	0,1
COD (mg/l)	90.000	< 20.000	5.000

Table 1: Water quality analysis of wastewater for a wastewater disposal company

Figure 2: Samples of the influent (left) and treated effluent water (right)

CONCLUSIONS

The technology clearly has a promising potential for industrial water reuse especially under extreme conditions that make treatment with more conventional technologies (DAF, polymeric membrane filtration) and unreliable and inefficient.

REFERENCES

1. Bensadok, K., M. Belkacem, and G. Nezzal. "Treatment of cutting oil/water emulsion by coupling coagulation and dissolved air flotation." Desalination 206.1 (2007): 440-448.
2. Bunturngpratoomrat, Apichaya, et al. "Cutting oil removal by continuous froth flotation with packing media under low interfacial tension conditions." Separation and Purification Technology 107 (2013): 118-128.
3. Schoeman, Jakob Johannes, and O. Novhe. "Evaluation of microfiltration for the treatment of spent cutting-oil." Water SA 33.2 (2007).
4. Hilal, Nidal, et al. "The use of ultrafiltration and nanofiltration membranes in the treatment of metal-working fluids." Desalination 167 (2004): 227-238.
5. Pedenaud, P., Wayne, E., Samuel, H., Didier, B. “Ceramic Membrane and Core Pilot Results for Produced Water Management.” Offshore Technology Conference Brazil (2011)
6. Ripperger, S. “Energetische Betrachtungen zur Querstromfiltration mit Membranmodulen.” F&S Filtrieren und Separieren, volume 1/17 (2017).
7. Wentz John, E., Kapoor Shiv, G., DeVor Richard, E., Rajagopalan Nandakishore. ”Applicability of Microfiltration for recycling Semi-Synthetic Metalworking Fluids.” Illinois Waste Management and Research Center (2007): RR-111.
8. Weschenfelder S.E., Borges C.P., Campos J.C. ”Oilfield produced water treatment by ceramic membranes:Bench and pilot scale evaluation.” Journal of Membrane Science 495 (2015): 242-251.
9. Zhong J., Sun X.,Wang C. “Treatment of oily wastewater produced from refinery processes using flocculation and ceramic membrane filtration.” Sep.Purif.Technol.32 (2003): 93-98.

Minimal Liquid Discharge (MLD): A water source and discharge solution

Tina Arrowood, Dow Water Solutions, Edina, MN USA

The realization that water is a finite resource for domestic and economic growth has now taken root on a global basis. Industrial water users generally are the first to feel the pressures of water scarcity. This burden is compounded when strict discharge regulations are also in place. To meet both water availability and discharge challenges, membrane based minimal liquid discharge (MLD) treatment to maximize water recycle is becoming recognized as a cost effective solution for sustainable water management. Not only does MLD allow an industrial plant options to recycle and reuse its own wastewater, but the technology is also suitable to convert municipal wastewater into reuseable water providing access to unconventional water sources. MLD operations, however, must be designed for the challenges of higher contamination levels common in wastewaters. Dow Water Solutions has high performing products geared for this challenge including, ultra-filtration membranes for colloid and suspended solids removal, high capacity softening ion-exchange resin for scale control, fouling resistant reverse osmosis membranes for pure water recovery and salt concentration, and nano-filtration membranes for ion separation, brine recovery and waste reduction. Depending on the specific treatment challenge, a suitable combination of separation technologies can be assembled. In total, more than 100 industrial MLD, water reuse processes are using Dow products. Examples of three industrial water reuse processes enabled by advanced reverse osmosis and nanofiltration membranes will be reviewed in this presentation including representation from the food and beverage, textile, and chemical industries.

Phosphate uptake from wastewater using iron oxide doped halloysite nanotubes

Dema Almasri, Qatar Environment and Energy Research Institute, Hamad Bin Khalifa University, Doha, Qatar; Muataz Ali Atieh, Qatar Environment and Energy Research Institute, Hamad Bin Khalifa University, Doha, Qatar; Said Ahzi, Qatar Environment and Energy Research Institute, Hamad Bin Khalifa University, Doha, Qatar

Abstract

The development of low-cost, environmentally friendly, and efficient treatment processes has been the subject of global importance at the rise of the century, specifically from industries, governments, and researchers alike. This was mandated to address the issues of water scarcity and water security, which coexist in many parts of the world and towards developing sustainable solutions. In regions where seawater desalination prevails for the generation of drinking water and other water applications, the use of alternative water sources is essential in maintaining water sustainable approaches. While groundwater is generally one of the preferred water sources in arid regions due to its convenient availability, its over-extraction and anthropogenic contamination make it limited for use. The reuse of treated wastewater in industrial applications is deemed to be a reliable water source. However, high residual nutrients such as phosphate could make it unsuitable for its disposal in natural waters or reuse in certain industrial applications such as in cooling towers.

Resorting to membrane processes could be a good step towards developing a more sustainable environment; however, membranes are prone to scaling and fouling due to total dissolved solids (TDS) (e.g. calcium, magnesium, nitrates, and phosphates), hydrocarbons, and microorganisms available in the source water and require a pre-treatment step. Adsorption is considered to be one of the most

attractive options for water pre-treatment due to its high efficiency, simplicity, and cost effectiveness.

Clay minerals and their modified counterparts lie within a group of adsorbents used for the adsorption of many chemical contaminants from an aqueous solution. Halloysite nanotubular (HNT) clay is a naturally occurring mineral with a nanotubular structure. Its chemical structure and properties denote it as a novel alternative material for adsorption.

The modification of HNT with an environmentally benign modifier such as iron oxide provides a ‘green’ class of adsorbents that is selective towards the removal of phosphate from water. In this study iron oxide doped HNT (Fe-HNT) was prepared using a facile modification procedure. A detailed characterization of the raw and modified HNTs is conducted by X-ray diffraction (XRD), X-ray fluorescence (XRF), Fourier transform infrared spectroscopy (FTIR), thermal gravimetric analysis (TGA), zeta potential analysis, BET surface area analysis, scanning electron microscopy (SEM), and transmission electron microscopy (TEM). Upto 90% removal of phosphate was removed from the reused treated wastewater within 2 hrs. The influence of contact time, pH, initial phosphate concentration, and coexisting ions on the adsorption capacity were also studied. Results demonstrated that Fe-HNT was highly selective towards phosphate removal of water.

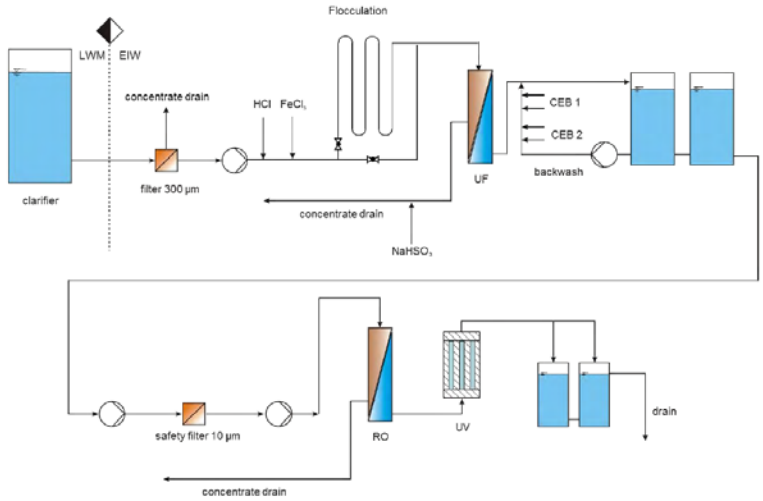
Wastewater reuse in a potato factory: from pilot studies to full scale reuse plant

Eva Koper, Evides Industriewater, Rotterdam, Netherland; Dr. Sven Lübbecke, Evides Industriewater, Stade, Germany; Dr. David Moed, Evides Industriewater, Rotterdam, Netherland

Wastewater reuse pilot studies potato factory

The potato factory (PF) is one of the world's leader in potatoes manufacturing and has a plant in the Netherlands. PF was looking for technical solutions to reduce its water footprint by 50% till year 2020. To meet that target water reuse is the most promising solution. At the PF site an effluent stream of about 72 m³/h from the existing wastewater treatment plant (WWTP) should be made reusable as process water.

Evides Industriewater, with its years of experience in industrial water applications, serves PF with around 1,45 Mio m³/a of process water made from surface water. Both companies came to the agreement to verify in a pilot trial if the effluent from the PF WWTP is usable for recycling. The pilot plant consisted of ultrafiltration (UF) in combination with reverse osmosis (RO) to produce water of high quality that can be used as process water in the production process.



In the pilot studies it was shown that the chosen technologies, UF in combination with RO desalination, are proven to be a reliable process for reuse of effluent from the existing WWTP at the PF site.

With a maximum achievable UF flux of 85 l/m²h the results are better than the guidelines from the membrane supplier recommend for such an application. For a robust design with some process safety 75 l/m²h were chosen for the full scale

design. Iron dosage of 3 mg/l is essential to stabilize the UF permeability, contact time of about 1 minute improves the process.

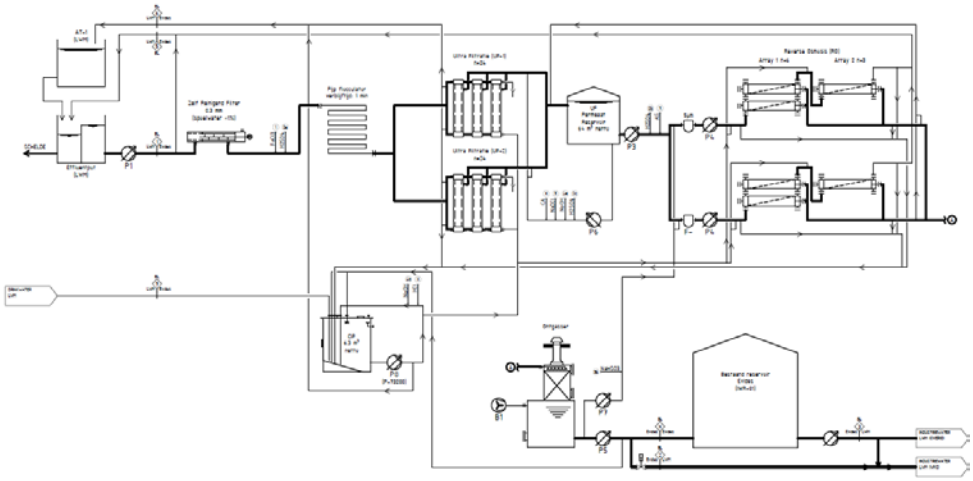
Recovery of 90% for the UF could be achieved at maximum. This recovery is also taken into the full scale design calculation. Pre-treatment of UF with a self-cleaning filter of 300µm is sufficient for UF membrane protection. Timer controlled backflush was not successful, Δp-based backflush stabilized filter performance and gives more flexibility in case of variations in feedwater quality.

The permeate quality of the RO was within guidelines for most of the parameters and a recovery of 87% is achievable. To meet all specifications a degasser should be added. Phosphate removal upstream of the RO in the WWTP can reduce OPEX significantly. With lower phosphate concentration the acid dosing can be reduced by approximately 34%.

Full scale reuse plant potato factory

The full scale reuse plant has been designed with the expertise already existing within Evides Industriewater on re-use of effluent to produce RO permeate as well as the pilot results. Since the pilot studies indicated the use of a degasser and a reduction of o-phosphate in the RO feed, these two process steps were added in the design. Moreover, the pilot studies showed, which process settings can be used and which quality the final product will have.

The overall recovery of the reuse plant is 78 % with a production of 56,3 m^3/h (493.000 m^3/y) process water.



The full scale reuse plant is under construction and should go into operation in the end of 2019. UF and RO will be build containerized. PF has assigned the reuse plant to Evides Industriewater through a DBFO contract (Design, Build, Finance, Operate) with a term of 15 years.

Stabilized-hypobromite as a novel agent for biofouling control in the polyamide RO membrane systems

Hiro Yoshikawa, ORGANO Corporation, Kanagawa, JPN; Yuki Nakamura, ORGANO Corporation, Kanagawa, JPN; Taro Oe, ORGANO Corporation, Kanagawa, JPN

Summary:

We investigated the potential of stabilized-hypobromite (SHB) as a biofouling control agent for polyamide (PA) RO membrane. No adverse effect in membrane performance based on permeate flux and salt rejection was confirmed after 1000 hours use of SHB with 0.2 mg/L as chlorine at pilot test. And the differential pressure of the test unit with SHB was kept stable during the test time. These results suggest that SHB is suitable for biofouling control in PA membrane systems.

Introduction

The most critical issue to be overcome in RO membrane technology is the fouling problem, especially biofouling. Biocide is one of the effective measures to prevent biofouling in RO systems (Khan. 2015). However, sodium hypochlorite cannot be applied to RO membranes continuously, as it deteriorates the thin polyamide layer of the RO membranes. SHB has lower oxidizing potential than hypochlorite and is expected to have lower influence on membrane performance. In this study, basic characteristic and pilot test study of SHB are discussed.

Material & Methods

ORPERSION E2661 (ORGANO corp.) was used as SHB solution. Hypochlorite was provided as 12 wt% sodium hypochlorite solution (Tosoh corp.). Chlorosulfamate was prepared as water solution containing 50 wt% of 12%NaClO, 16 wt% of sulfamic acid and 8 wt% of sodium hydroxide. Each chemical solution was diluted by filtered groundwater to 10mg/L as total-chlorine and was adjusted to pH 7.3, and then ORP of each solution was measured using RM-20P (DKK-TOA corp.). Operational condition of the RO pilot test is shown in **Table 1**. The differential pressure and the rejection of electrical conductivity (EC) were evaluated in RO pilot test.

Results and Conclusions

Figure 1 shows ORP of each chemical. The ORP of SHB was just in the middle of that of chlorosulfamate or hypochlorite. This result shows that SHB is a weaker oxidant than hypochlorite which is harmful to PA membrane. **Figure 2** and **Figure 3** show the trend of differential pressure and salt rejection of RO membrane in pilot test. Differential pressure with SHB did not increase during the testing term. And the EC rejection of the RO unit with SHB was kept stable, while EC rejection of the RO unit without SHB dropped significantly because of biofouling on the membrane surface. These results indicate that SHB can prevent biofouling effectively, while not adversely affecting PA membrane. The results of this study suggest that SHB is suitable for biofouling control in PA membrane systems.

Table 1 Operational condition of the RO pilot test

Feed water	Groundwater+acetic acid
Feed conductivity	250 μs/cm
Feed TOC	5 mg/L
Feed rate	760 L/hr
Feed pressure	0.65 MPa
RO membrane	PA, 4-inch element
SHB	0.2 mgCl/L

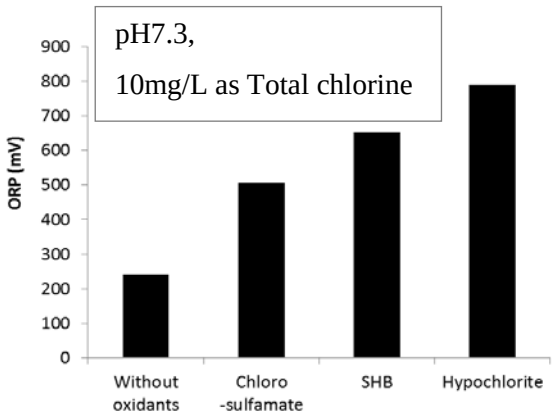


Figure 1 ORP of SHB and other oxidants

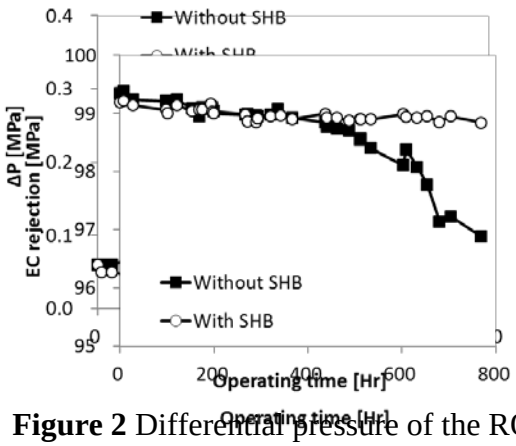


Figure 2 Differential pressure of the RO
Figure 3 EC rejection of the RO

References

Muhammad Tariq Khan, Pei-Ying Hong, Nabil Nada, Jean Philippe Croue, “Does chlorination of seawater reverse osmosis membranes control biofouling?” Water Research, 78 (2015) 84-97

Flushing toilets with Seawater a step in creating sustainable cities

B. Godskesen[1]; M. Vester[2]; H. Hoffmann[2]; H. J. Albrechtsen[1]; M. Rygaard[1]

[1]Technical University of Denmark (DTU), DK-2800 Lyngby, Denmark; [2]HOFOR (Greater Copenhagen Utility), Ørestad Boulevard 35, DK-2300 København S)

The lack of sufficient water resources for water supply has recently been on the global agenda, lately in the UN SDGs, goal N_o 6. The resources are threatened by drought, pollution and poor water safety. In Denmark, groundwater is used for drinking water supply. The implementation of the EU Water Framework Directive and recent detections of catchments polluted with pesticides have pointed out that the resource is not as abundant and pristine as previously considered.

To reduce the consumption of groundwater for water supply this project demonstrate a way of substituting approximately 30% of coastal households' water consumption by flushing toilets with non-potable water - in this case Seawater. The aim of the project is to bring us a step further in demonstrating the potential and evaluating the sustainability of use of Seawater for flushing toilets in coastal areas.

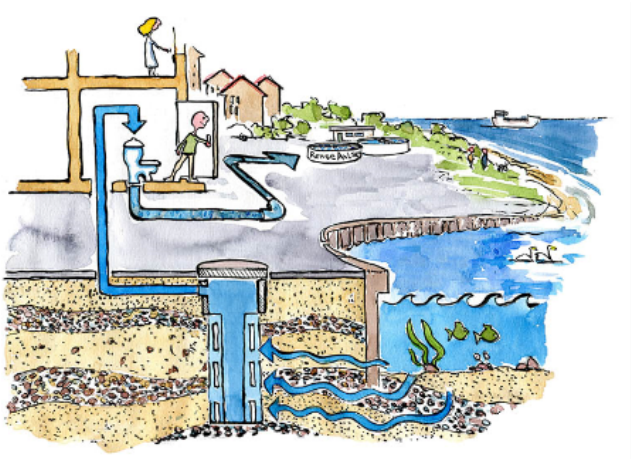


Figure 1. a sketch of the use of Seawater for flushing toilets in Copenhagen, Denmark.

Use of Seawater for flushing toilets is being used in other places (Liu et al., 2016) but in Denmark it is new way of constructing the water supply system. In our system a coastal well is abstracting groundwater with such a high salinity that it is characterized as Seawater (Fig. 1). The salt is not removed making the salinity too high for drinking water quality. However, the water is appropriate for non-potable purposes such as flushing toilets. Toilet flushing constitutes a substantial part of the

households' water consumption and was in the first 10 months of the project metered to 30%. By substituting drinking water used for flushing toilets with Seawater it is possible to obtain a 30% reduction of the groundwater demand in the City.

At the conference, we would like to present how this project has 1) demonstrated the successful construction of the first non-potable water facility owned and operated by a utility in Denmark, 2) evaluated the facility upon selected sustainability criteria (Table 1, first column).

Table 1. Evaluation of flushing toilets with Seawater compared to groundwater based drinking water supply. The criteria area evaluated upon a scale from -2 to 2: -2 means that Seawater is evaluated unfavourable in comparison to drinking water and 2 is advantageous. 0 means the systems are equivalent.

Criteria contributing to creation of sustainable cities	Seawater in comparison to groundwater based drinking water	
	Specific change	Criteria evaluation
Customer satisfaction	Extensive support	+2
Costs for the end user	+6.5 Euro/person/year	-1
Environmental impacts: climate change, particulate matter, acidification, eutrophication, resource consumption	-1 to 33%	-1
Freshwater withdrawal impacts	-29%	+2
Health related evaluation	No increased disease risk	0
Microbial risk assessment		
Water safety	Local inexhaustible resource	+2
Affecting wastewater system with salty sewage water	Unchanged	0

The results are positive when it comes to criteria of customer satisfaction, freshwater withdrawal impacts and water safety. Criteria having a slightly negative impact are costs and environmental impacts and criteria with a neutral impact are health related evaluation, microbial risk assessment and affecting wastewater treatment processes. From this evaluation, we conclude that flushing toilets with Seawater is one possible step towards creating sustainable cities.

References

Liu, X., Dai, J., Wu, D., Jiang, F., Chen, G., Chui, H.K., van Loosdrecht, M.C.M., 2016. Sustainable Application of a Novel Water Cycle Using Seawater for Toilet Flushing. Engineering 2, 460–469. https://doi.org/10.1016/J.ENG.2016.04.013

Fouling characteristics of reverse osmosis membrane along feed channel of a full-scale plant for municipal wastewater reclamation

Xin Tong[a], Yun-hong Wang[a], Yuan Bai[a], Xue-hao Zhao[a], Tong Yu[a], Nozomu Ikuno[b], Yin-hu Wu[a], Hong-ying Hu[a,c]

[a] *Environmental Simulation and Pollution Control State Key Joint Laboratory, School of Environment, Tsinghua University, Beijing 100084, China*

[b] *Kurita Water Industries Ltd., Nakano-ku, Tokyo 164-0001, Japan*

[c] *Shenzhen Environmental Science and New Energy Technology Engineering Laboratory, Tsinghua-Berkeley Shenzhen Institute, Shenzhen 518055, China*

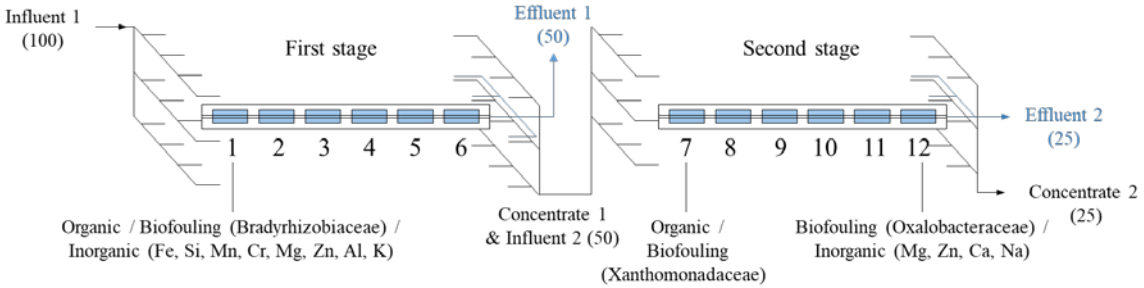


Figure.1 Samples and fouling characteristics of a fouled RO system

Introduction

Reverse osmosis (RO) plays an important role in the reclamation process with the ability of high desalination performance. However, membrane fouling has a significant adverse impact on the operating of RO system. Current studies concerning about fouled RO membrane autopsy usually focused on a certain element. Till date, scarce research investigated the fouling properties and different kinds of foulants distribution among several elements of on-site RO membrane systems. This study aims to analyze physiochemical and biological characteristics of the foulants along feed channel of an on-site RO system and to find out the distribution property of different kinds of fouling.

Methods and Materials

In this study, a fouled RO system in a full-scale municipal wastewater reclamation plant were autopsied and analyzed. It is a two-stage system with six elements in each stage. Each element was sampled and numbered in the sequence of location from the lead-element to tail-element as shown in Figure.1.

This study used RO modules from Kurita Water Industries Ltd., Japan to evaluate permeate flux and rejection efficiency of the fouled membrane. Excitation

emission matrix (EEM) was utilized to analyze different fractions of organic matters. Inductively Coupled Plasma (ICP) was applied to determine the metal ions on foulants layer. ATP content and heterotrophic plate count (HPC) were used to measure the amount of bacteria and 16srRNA was used to ascertain microbial community structure.

Results and Discussion

Filtration experiment showed that permeate flux of membrane samples firstly ascended and then descended, peaking at the No.7 and No.8 sample. Rejection performance of samples showed the same trend as flux. The results showed that fouling at the lead-element and tail-element were severest. Roughest surfaces appeared at No.1 and No.2 sample. Hydrophobic fraction was the highest part of organic compounds on all membranes as a result of the hydrophobicity of membrane surface.

Most dissolved organic compounds (DOC) precipitated on the lead-element of each stage (70% and 50% respectively). DOC concentration of the foulants declined from the lead to tail element of each stage respectively. Except No.1 sample, the DOC of the samples from the second stage were higher than that of the first stage, as a result of higher concentration of chemicals. EEM showed that the majority of DOC was amino acid, protein, polysaccharide and fulvic acid.

Metal ions, such as calcium, sodium, magnesium and aluminum, tended to precipitate on the two poles of the two stages, especially No.1 sample (>600 mg/m^2, over 70%). Iron took a large part of metal ions on No.1 sample, leading to a huge discrepancy of total amount between No.1 sample and others. It could be speculated that metal ions easy to precipitate would deposit on the lead-element, and those hard to precipitate would gradually accumulate and deposit on the tail-element.

According to microbial analysis, HPC value of the lead and tail element were highest, which indicated most serious biofouling. Proteobacteria and Bacteroidetes were most abundant among all samples, and the rising Shannon index in each stage showed richer bacterium species along the elements within the same stage.

Conclusion

Different types of fouling mainly happened at different locations the of RO system as shown in Figure.1. In summary, No.1 sample suffered severest fouling and its microbial community structure was remarkably different from others. No.12 sample

suffered the second severest fouling because its feed was the concentrate of the prior membranes, followed by No.7~No.11 samples where the feed was actually the concentrate of the first stage. Fouling of No.2~No.6 samples was the least serious.

Season effect on the efficiency of domestic grey water treatment by Green wall and Advanced Oxidation Processes for irrigation reuse: GrowGreen project

Abel Lara, LEITAT Technological Center, Terrassa, Spain; Rubén Rodríguez-Alegre, LEITAT Technological Center, Terrassa, Spain; Adrián Marí, LEITAT Technological Center, Terrassa, Spain; Edxon Licon, LEITAT Technological Center, Terrassa, Spain

Project framework

Increase in wastewater production due to the urban areas population growth aggravate water scarcity. Solely in Barcelona, the production of wastewater per person in 2017 was 450 L day^{-1} according to INE[1] and AMB[2], 10-20% of which correspond to grey water. A wide range of studies have been done to treat urban wastewater in order to improve the final effluent quality for reuse[3]. Nature-Based Solutions (NBS) are imposed as sustainable methods for treating wastewater effluents coming from different sources before pouring them into natural channels or to reuse as irrigation of crop field[4]. Notwithstanding, the implementation of these kind of technologies remains a challenge. In the present study, the viability of the green wall will be examined in order to treat domestic grey water (GW), minimizing the concentration of some contaminants along a period of time between autumn-spring. In the aforementioned period, the results showed the reduction of all the parameters studied.

Material & methods

A green wall seeded with *graminaceous*, *laminaceous*, *rosaceae* and *aliaceous* composes the NBS; GW is supplied to the system at the top of the wall, circulating across it, cleaning the water in each step. To purify the GW, each pot was filled with a specific substrate composed by argyle, textile and biocarbon, obtaining a hydroponic system as a result. A tank with 100 L of GW is located near the green wall to feed the NBS with a flux of 3 L h^{-1} in a single pass. Disinfection process was

[1] Instituto Nacional de Estadística (https://www.ine.es)
[2] Àrea Metropolitana de Barcelona (http://www.amb.cat)
[3] Masi, F., Bresciani, R., Rizzo, A., Edathoot, A., Patwardhan, N., Panse, D., & Langergraber, G. (2016). Green walls for greywater treatment and recycling in dense urban areas: a case-study in Pune. *Journal of Water, Sanitation and Hygiene for Development*, *6*(2), 342-347.
[4] Masi, F., Rizzo, A., & Bresciani, R. (2015). Green architecture and water reuse: examples from different countries. *Sustainable Sanitation Practice*, *23*, 4-10.

carried out through UV/H_2O_2 using different doses of H_2O_2 (20 and 50 mg L^{-1}.) The disinfection was performed using a 200-400 nm wavelength UV lamp of 0.5 L of volume connected to a 2 L feed tank. A peristaltic pump drove the solution through the circuit.

Results and discussion

Some physicochemical parameters were analyzed, such as Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Organic Carbon (TOC), Total Suspended Solids (TSS), turbidity, pH and Electrical Conductivity (EC), to determine the performance of the processes.

In a period of three months, the organic content (COD, BOD, TOC) in the final effluent was always lower than in the influent, reducing from 365 to 150 mg L^{-1}, from 128 to 15 mg L^{-1} and from 60 to 24 mg L^{-1}, respectively. Comparing to Stefanakis *et al.*[5], COD remotion was similar while BOD removal was slightly higher than previous works.

Regarding the turbidity (9 NTU) and TSS (8 mg L^{-1}), the results obtained were below the limit established by the Spanish legislation to reuse treated wastewater for irrigation of crop fields (10 NTU and 20 mg L^{-1} respectively). pH and EC was maintained constant and below the limit as well. The removal efficiency was equivalent to those observed in similar studies[6].

Disinfection process was carried out during 30 min and showed a complete removal of the microbial content in both cases; reducing the initial concentration from 10^5 to 10 CFU/100 mL of *E. coli*, according to results expected from Formisano *et al.*[7], who achieved a 99.77% reduction.

Conclusions

The green wall is working satisfactorily as a biofiltration process, reducing the amount of COD and TOC around a 60-70% and the BOD over a 90% on average. The effluent turbidity and TSS were reduced around a 67% and a 74% respectively, accomplishing the legislation requirements. Disinfection step showed a 99.99%

[5] Stefanakis, A. I., & Tsihrintzis, V. A. (2012). Effects of loading, resting period, temperature, porous media, vegetation and aeration on performance of pilot-scale vertical flow constructed wetlands. *Chemical engineering journal*, *181*, 416-430.
[6] Fowdar, H. S., Hatt, B. E., Breen, P., Cook, P. L., & Deletic, A. (2017). Designing living walls for greywater treatment. *Water research*, *110*, 218-232.
[7] Formisano, F., Fiorentino, A., Rizzo, L., Carotenuto, M., Pucci, L., Giugni, M., & Lofrano, G. (2016). Inactivation of Escherichia coli and Enterococci in urban wastewater by sunlight/PAA and sunlight/H2O2 processes. *Process Safety and Environmental Protection*, *104*, 178-184.

reduction of *E. Coli* when establishing an optimal H_2O_2 dose. With an overall cost of 0.32 €/m^3, this technology fulfils requirements for a new frameworks of circular economy in urban areas where the Water-Energy-Food nexus is more sustainable.

Ultrafiltration allows water reuse to mitigate water scarcity in northeast Brazil

V. Kohlgrüber, A. Abels, J. Wolters, J. Pinnekamp

Institute of Environmental Engineering (ISA) of RWTH Aachen University, Germany

Water scarcity in northeast Brazil poses a major obstacle for sustainable development of the region, affecting local economy and living conditions. Moreover, the increasing water demand is exacerbating the situation. The research project BRAMAR aimed to mitigate water scarcity in northeast Brazil and was funded by the German and the Brazilian ministries of research. [1]

To mitigate water-related problems, treated waste water can be reused instead of using fresh water. Therefore, the project partners identified how waste water could be reused and developed and tested a suitable technology, considering local circumstances like existing waste water treatment and legislation. They then evaluated how applicable the system could be under the specific conditions of this case.

When waste water is adequately treated, an alternative source of water can be provided. At the moment, the main treatment technology in northeast Brazil is the stabilization pond [2]. However, the effluents of such ponds contain pathogens and have high solids concentrations. Only after further treatment can those effluents be claimed for non-potable urban reuse.

For different types of non-potable urban reuse, water quality requirements are given in the Brazilian Association for Technical Standard's norm NBR 13696 [3]. These requirements include different values for several parameters like pH, turbidity, dissolved solids and fecal coliforms. A high probability of human exposure elevates the hygienic standard. This standard can usually be reached by using ultrafiltration.

Therefore, ultrafiltration was used to post-treat the effluent of a stabilization pond in João Pessoa. The ultrafiltration pilot plant consisted of two parallel, identical trains comprising several treatment steps: rapid sand filtration, surface filtration (150 µm), pH adjustment, flocculant dosage and filtration through capillary membranes (0.02 µm) that could be backwashed (see Figure 1).

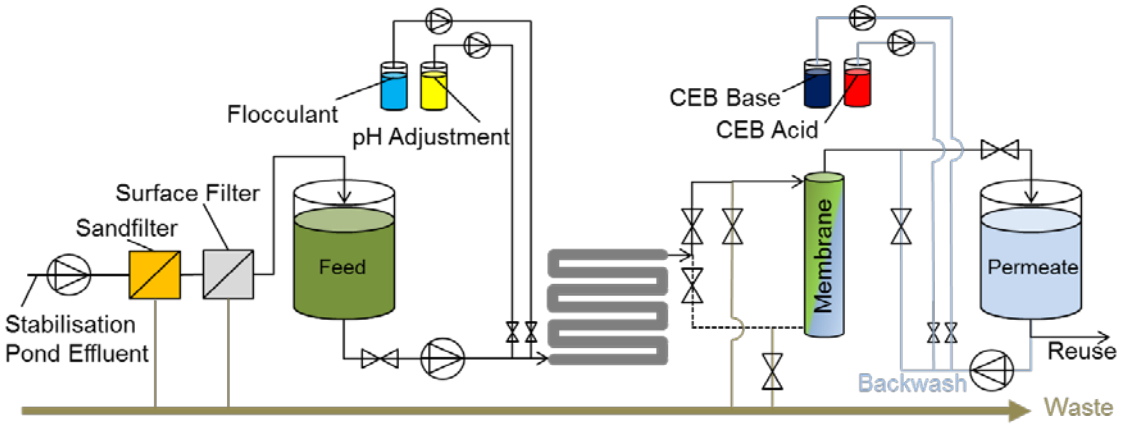


Figure 1: Schematic view of one train of the ultrafiltration plant [1]

This ultrafiltration process was optimized and evaluated in terms of treatment efficiency and operational stability. Stable operation was possible with a low and stable transmembrane pressure of < 0.3 bar, while showing little membrane fouling. Moreover, the high hygienic level of the permeate met the above mentioned legal requirements. The effluents treated in this way could be reused, for example, to wash floors, irrigate gardens, or flush toilets. However, no applications with direct human contact were possible due to high total solids concentration.

In conclusion, ultrafiltration of stabilization pond effluents was technically feasible when used in combination with in-line flocculation. From a technological point of view, such effluents are ideal for water reuse and could mitigate water scarcity, but there are still open questions on how to implement it properly. For example, long-term operation and a more extensive pre-treatment have to be tested. Moreover, the process is very complex and needs a high skill-level, another drawback. Hence, treatment with low-technology processes seems to be more adequate at the moment.

References

[1] ABELS, A. et al. (2018): Water Scarcity Mitigation in Northeast Brazil, ISBN: 978-3-00-059926-2.

[2] von SPERLING, M. (2002): Lagos de Estabilização. 2ª Edição – Belo Horizonte. Departamento de Engenharia Sanitária e Ambiental. Universidade Federal de Minas Gerais.

[3] ABNT (1997): NBR 13969. Tanques sépticos – Unidades de tratamiento complementar e disposicao final dos efluentes líquidios – Projeto, construcao e operacao.

Characterization of Microbial Community Structure on Biofilm in Forward Osmosis Membrane

*Sung Ju IM, Sanghyun JEONG and Am JANG**

Graduate School of Water Resources, Sungkyunkwan University, 2066 Seobu-ro, Jangan-gu, Suwon, Gyeonggi-do, 440-746, Republic of Korea

Abstract

The forward osmosis and reverse osmosis (FO-RO) hybrid system is well known technology due to low energy consumption, low fouling tendency and high production rate. This hybrid process using two target solution called as feed solution and draw solution. Therefore, FO-RO hybrid system can treat two water resources and produce high quality permeate. These advantages can leaded by FO process due to it principle. However, membrane fouling phenomenon in FO process is needs key/revolutionary solution to mitigate and control the problem, mainly due to decrease process efficiency and operation and maintenance cost. By employing the wastewater and seawater as feed and draw solution, organic fouling and biofouling is significantly influence to membrane performance and surface properties. A lots of previous studies have been carried out to develop cleaning agents and membrane surface modification to control membrane fouling (organic and biofouling). However, the basic research to control fouling is very poor. Micro-organism by product substances form biofouling layer matrix that govern physical and/or chemical properties and structural of biofilm. Understanding of physical/chemical properties and structure of biofilm in essential to control and mitigation of biofouling. Therefore, in this study, we characterization of microbial communities on fouled FO membrane when applied wastewater as feed solution by using the next generation sequencing (NGS) analysis. This study can provide useful deep knowledge on biofouling mechanism of FO process and possible insight for basic control strategies of micro-organism sight.

Acknowledgement

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT, & Future Planning (2017R1A2B3009675).

Modelling the behaviour of trace organic compounds during an aquifer recharge pilot-scale experiment: the SMART*plus* tank

Moser, Birte, Carl von Ossietzky University of Oldenburg, Institute for Biology and Environmental Sciences, Working Group Hydrogeology and Landscape Hydrology, D-26111 Oldenburg, Germany

Sanz-Prat, Alicia, Carl von Ossietzky University of Oldenburg, Institute for Biology and Environmental Sciences, Working Group Hydrogeology and Landscape Hydrology, D-26111 Oldenburg, Germany

Greskowiak, Janek, Carl von Ossietzky University of Oldenburg, Institute for Biology and Environmental Sciences, Working Group Hydrogeology and Landscape Hydrology, D-26111 Oldenburg, Germany

Karakurt, Sema, Chair of Urban Water Systems Engineering, Technical University of Munich, Am Coulombwall 3, 85748 Garching, Germany

Hübner, Uwe, Chair of Urban Water Systems Engineering, Technical University of Munich, Am Coulombwall 3, 85748 Garching, Germany

Drewes, Jörg E, Chair of Urban Water Systems Engineering, Technical University of Munich, Am Coulombwall 3, 85748 Garching, Germany

Massmann, Gudrun, Carl von Ossietzky University of Oldenburg, Institute for Biology and Environmental Sciences, Working Group Hydrogeology and Landscape Hydrology, D-26111 Oldenburg, Germany

key words: management aquifer recharge, trace organic compounds, tracer test, biodegradation, reaction rate constants, reactive transport model

Abstract

The sequential managed aquifer recharge technology (SMART) is proposed as a promising method based on setting an artificial sequence of oxic-anoxic zonation to improve the efficiency of biodegradation processes along the soil passage [1,2]. This technology is tested in an intensive monitoring and highly controlled-engineering pilot-scale experiment, the SMART*plus* tank. The objective of this study is the numerical characterization of the hydraulic conditions and the baseline removal efficiency of 23 trace organic compounds (TOrC's) inside the tank before the activation of the re-aeration system. Corresponding two-dimensional and three-dimensional models of flow and conservative transport dynamics were compared with real data in order to probe whether three-dimensional effects could be neglected, and consequently computational time reduced. A tracer test experiment with Primidone as conservative compound resulted in a mean residence time of circa 10 hours in the

whole tank for both models. The good fitting between local breakthrough curves of observed and simulated (2-D and 3-D) concentrations of Primidone supported the dimensional simplification of the reactive transport model. Furthermore, temporal averaged degradation constants of the TrOC's were determined by accounting for concentration changes at the inlet and at the outlet of the tank during 17 weeks of continuous performance of the SMART*plus* tank. Thus, half-lives of less than 10 hours were detected for Citalopram, Gabapentin, Sulfamethoxazole, Triethoprim, Antipyrine, 4-Formylaminoantipyrine (FAA) and Benzotriazole; half-lives of 10-30 hours could be estimated for Erythromicin, Caffeine, Diclofenac, Tramadol, Atenolol, Climbazole und TCEP; Due to the finite residence time of 10 hour calculated half-lives between 30-100 hours for Sotalol, Metoprolol, Tramadol und Venlafaxine are only rough estimates. By comparing simulated half-live values with those from literature [2, 3], it turned out that significant degradation was achieved for Benzotriazole, TCEP, Sotalol, Sulfamethoxazole, FAA and Antipyrine; whilst Trimethoprim, Iopromide, Diclofenac, Metoprolol, Gabapentin and Atenolol still reached comparatively high degradation constants. The degradation behavior of some TrOC's was described as persistent (Carbamazepine, Phenytoin, Primidone and 3-OH-Carbamazepine). In summary, the efficiency of the SMART*plus* tank for the degradation of the most compounds could be considered significantly good. Further research will quantify the enhance of the removal percentage of certain TOrC's by means of the SMART technology.

References:

[1] Regnery, J., Wing, A.D., Kautz, J., Drewes, J.E. (2016): Introducing sequential managed aquifer recharge technology (SMART) – From laboratory to full-scale application - Chemosphere, 154, 8 -16.

[2] Hellauer, K., Karakurt, S., Sperlich, A., Burke, V., Massmann, G., Hübner, U., Drewes, J.E., 2017. Establishing sequential managed aquifer recharge technology (SMART) for enhanced removal of trace organic chemicals: Experiences from field studies in Berlin, Germany. Journal of Hydrology.

[3] Greskowiak, J., Hamann, E., Burke, V., Massmann, G., 2017. The uncertainty of biodegradation rate constants of emerging organic compounds in soil and groundwater - A compilation of literature values for 82 substances. Water Research 126, 122–133.

Carbon Fiber-based Flow-Through Electrode System (FES) for Point-of-Use Reclaimed Water Disinfection

Hai Liu[†], *and Hong-Ying Hu*[*,†, ‡]

†Environmental Simulation and Pollution Control State Key Joint Laboratory, State Environmental Protection Key Laboratory of Microorganism Application and Risk Control (SMARC), School of Environment, Tsinghua University, Beijing 100084, PR China.

‡Shenzhen Environmental Science and New Energy Technology Engineering Laboratory, Tsinghua-Berkeley Shenzhen Institute, Shenzhen 518055, PR China.

The microbiologically safe water is crucial to humans by supporting the basic and healthy livelihoods. Conventional pathogen inactivation methods, including mainly chlorination and ozonation have been used widely for potable, industrial, and agricultural waters. However, formation of potentially toxic products, such as chlorinated and brominated organics from these methods has encouraged the development of alternative disinfection technologies. To address this issue, carbon fiber felt (CFF) with micron-sized fiber, high void content, and netlike fiber structure was utilized to construct flow-through electrode system (FES), and further to scale up the electrochemical devices with stacked FES units.

FES with post-anode via direct oxidation mechanism for water disinfection

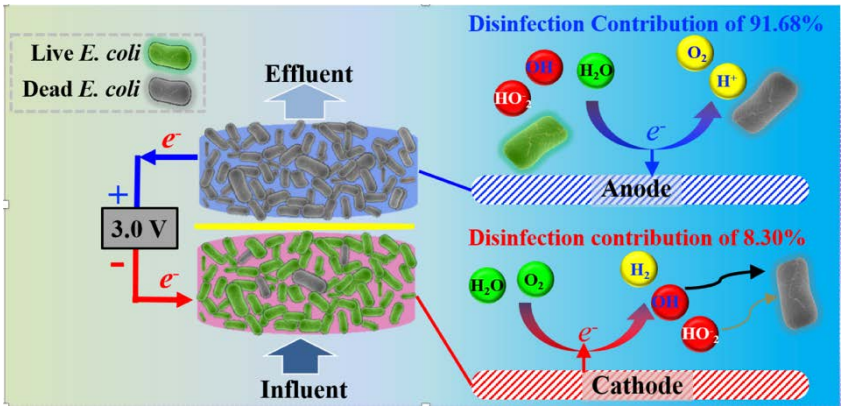


Figure 1. Depiction of electrochemical inactivation of *E. coli* cells for FES system with post-anode via OH^- and HO_2^--induced indirect inactivation on pre-cathode and direct oxidation on post-anode (10^{6-7} CFU mL^{-1}, electrolyte of 10 mM NaCl, solution pH of 6.15, applied voltage of 3.0 V, flow rate 75 mL min^{-1}).

For flow-through configuration, it is essential to ascertain the disinfection performance of FESs with pre-anode or post-anode. In-situ sampling experiments and electrochemical analyses supported a dominant mechanism of direct anode

oxidation, and revealed that the disinfection performance of post-electrodes was dramatically promoted by pre-electrodes. The FES with post-anode exhibited much better disinfection performance and energy efficiency, resulting from its easily accessible surface and favorable alkaline condition for direct anode oxidation created by pretreatment of pre-cathode (shown in Figure 1). The results in this study suggest the operation at 3.0 V not only avoided high energy requirements and formation of undesirable disinfection byproducts.

Scaling up of CFF-based FES with stack units for point-of-use reclaimed water disinfection

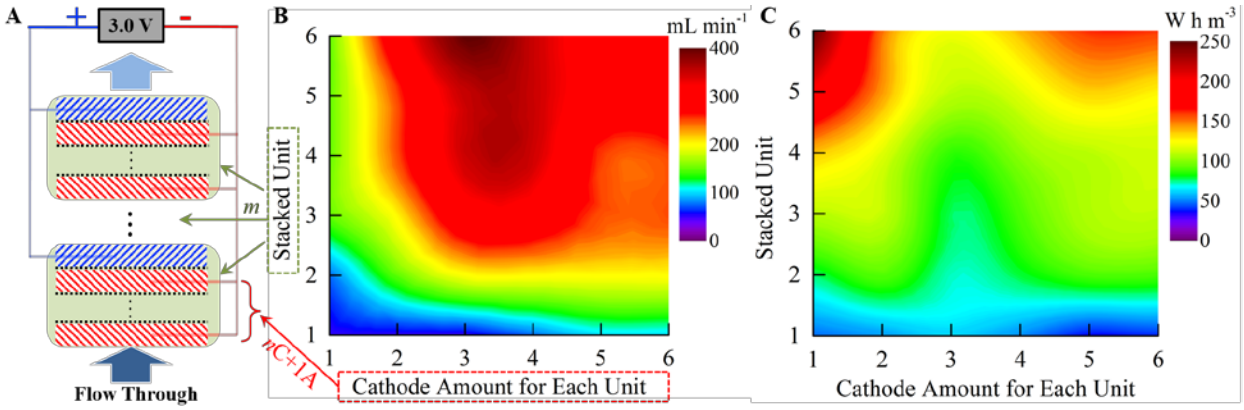


Figure 2. Depiction of multi-cathode unit (*n*C+1A) and stacked FES units (*m*(*n*C+1A) (A). Water treatment amount without live E. coli in effluent (B) and the corresponding energy consumption (C) of (*m*(*n*C+1A)) systems (applied voltage of 3.0 V, 10^{6-7} CFU mL^{-1}, electrolyte of 10 mM NaCl, solution pH of 6.15).

A multi-cathode FES unit, equipped with multiple cathodes and a counter anode (*n*C+1A), was particularly developed to enhance the disinfection ability of the anode in each unit. The FES (*m*(*n*C+1A)) with an increased number of stacked units (1 to 6) were further developed to investigate the effect of stacked units for FES scale-up on water disinfection (see Figure 2A). Indeed, as compared with the one cathode and one anode unit (1C+1A), the multi-cathode units exhibited significant improvement of disinfection performance and reduction of energy consumption (Figure 2B and 2C). Among the stacked (*n*C+1A) units, the FES with *m*(3C+1A) arrangement showed the highest water treatment amounts and energy efficiency. After 4-units stack, its water treatment amounts with no live E. coli in effluent reached up to 350 mL min^{-1} with energy consumption of around 75 W h m^{-3}. The findings of this study indicated the highly potential application of CFF based FES for point-of-use water disinfection.

The influence of an extra aeration pipe in a sand filter performance as anaerobic post-treatment system

D. A. C. Bueno 1; B. G. L. A. Gomes 1; R. L. Coasaca 1; L. P. Leonel 1; A. L., Tonetti 1

1School of Civil Engineering, Architecture and Urban Design, Sanitation and Environment Department - University of Campinas, Campinas, Brazil.

Background

The association between intermittent sand filter (ISF) and anaerobic filters (AF) has been considerate a good option for sanitary effluent treatment to small and remote communities. This system is a low-cost effluent polishing technology with a great potential to produce a high quality treated wastewater. The ISF are an aerobic treatment unit and are extremely dependent on the effluent oxygenation capacity. So, this study evaluated the influence of an additional ventilation pipe on the sand filter performance in the organic matter removal and in the nitrification process.

Methods

The experiment was carried out on a pilot scale system. Two systems were evaluated: 1) AF + ISF1 (with additional subsurface ventilation pipe) and 2) AF +ISF2 (the regular one). The Table 1 shows the analytical periods. The samples were collected from the inflow and outflow of each ISF and were analyzed for COD, DO, $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ according to *Standard Methods for the Examination of Water and Wastewater* (APHA *et al*., 2012).

Table 1. Characteristics of each stage of the research.

Analytical period	*HRT on AF *(hours)*	**SAR on ISF *($L.m^{-2}.day^{-1}$)*	Duration *(Days)*	Number of Samples	Samples per Week
1st	24	200	103	14	1
2nd	12	400	80	12	1
3rd	8	600	39	10	2
4th	4	1,200	13	8	3

*****HRT: Hydraulic retention time; **SAR: Surface application rate

RESULTS AND CONCLUSIONS

It is possible to conclude that the installation of a subsurface extra tube increased the oxygenation of the sand bed in low SAR, but had no effect no higher SAR (Table 2).

There was no improvement in COD removal due to the installation of an extra aeration pipe (Figure 1), probably because both ISF are very effectively with COD loadings. In the other hand, there was great improving on nitrification processes on the 1st and 2nd AP (low SAR) (Table 3).

Table 2 Statistical analysis of DO concentration in ISF.

Stage	Operation	Mean values of DO		Means differ from each other on:		
AP	SAR ($L.m^{-2}.day^{-1}$)	ISF1 ($mg\ O_2.L^{-1}$)	ISF2 ($mg\ O_2.L^{-1}$)	Vertical[1] Between AP ISF1	ISF2	Horizontal[2] Between Units ISF1 vs. ISF2
1st	200	6.8 ± 0.8	6.5 ± 0.8	A	A	ab
2nd	400	6.1 ± 0.9	5.8 ± 0.8	B	A	aa
3rd	600	5.0 ± 1.4	4.8 ± 1.4	B	A	aa
4th	1,200	2.3 ± 2.0	2.3 ± 1.9	C	B	aa

1: Vertically equal letters represent averages that do not differ from each other by the Kruskal-Wallis Test (5%); 2: Horizontally equal letters reflect averages that do not differ from each other through the Wilcoxon Test (5%).

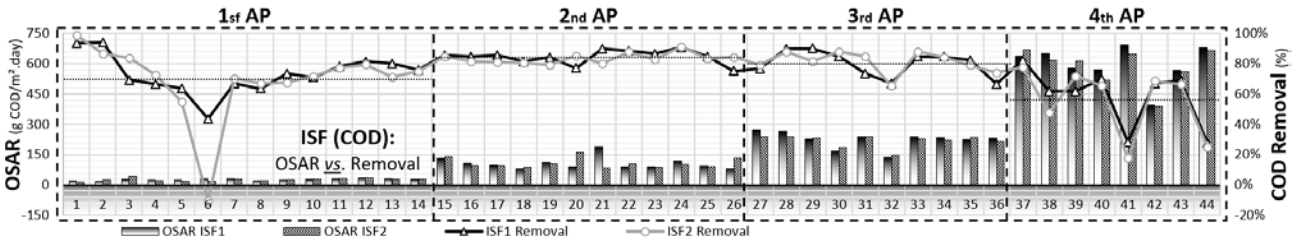


Figure 1. Historical series of COD removal compared to the OSAR (Organic Surface Application Rate).

Table 3 Statistical analysis of nitrogen compounds concentrations in ISF.

Stage	Operation	Mean values				Means differ from each other on:					
						Vertical[1] Between AP				Horizontal[2] Between Units	
		ISF1		ISF2		$N\text{-}NH_4^+$ Analysis		$N\text{-}NO_3^-$ Analysis		ISF1 vs. ISF2	
AP	SAR ($L/m^2.day$)	$N\text{-}NH_4^+$ ($mg\ N/L$)	$N\text{-}NO_3^-$ ($mg\ N/L$)	$N\text{-}NH_4^+$ ($mg\ N/L$)	$N\text{-}NO_3^-$ ($mg\ N/L$)	ISF1	ISF2	ISF1	ISF2	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$
1st	200	2.3 ± 3.6	74.8 ± 12.7	2.2 ± 3.3	73.1 ± 13.3	A	A	A	A	aa	aa
2nd	400	7.0 ± 11.5	74.2 ± 17.5	8.5 ± 13.6	69.5 ± 14.8	A	A	A	A	aa	ab
3rd	600	40.6 ± 11.5	41.2 ± 19.3	41.2 ± 10.7	41.6 ± 19.0	B	B	B	B	aa	aa
4th	1,200	67.1 ± 5.6	10.7 ± 7.0	68.4 ± 6.3	10.7 ± 6.6	C	C	C	C	aa	aa

1: Vertically equal letters represent averages that do not differ from each other by the Kruskal-Wallis Test (5%); 2: Horizontally equal letters reflect averages that do not differ from each other through the Wilcoxon Test (5%).

Therefore, we can concluded that the installation of an extra aeration pipe led to a greater natural aeration and even to a better nitrification in the low SAR (200 $L.m^{-2}.day^{-1}$ and 400 $L.m^{-2}.day^{-1}$). At higher SAR (600 $L.m^{-2}.day^{-1}$ and 1,200 $L.m^{-2}.day^{-1}$), there were no difference between ISF.

ACKNOWLEDGEMENTS

The authors are grateful to FAPESP (São Paulo Research Foundation, process 2017/07490-4 and 2017/12157-2) for financing this study.

REFERENCES

American Public Health Association. 2012. Standard Methods for the Examination of Water & Wastewater (American Public Health Association, American Water Works Association, and Water Pollution Control Federation, eds.), Washington D. C.

UV-LED as alternative to anaerobic systems effluents disinfection

N. B., Silva 1, L. P. Leonel 1; A. L., Tonetti 1

1 School of Civil Engineering, Architecture and Urban Design, Sanitation and Environment Department - University of Campinas, Campinas, Brazil.

Background

Major challenge of sanitary effluents disinfection is the search for reliable disinfectant agents that do not generate harmful by-products to the environment. Sodium hypochlorite is the most suitable product for disinfection in small systems, due to the easy of application and the low cost. However, the toxicological aspect of possible residual compounds or by-products formed using chlorinated compounds, present genotoxic, mutagenic and carcinogenic potential. One promising technology is ultraviolet (UV) radiation, which reacts with the oxygen dissolved in water, producing free radical and hydrogen peroxide. These reactive molecules interfere in pathogens cellular structures, inactivating those. The LED (Light Emitting Diode) is a viable alternative to the traditional mercury lamps, as UV radiation source, it is compact, resistant, consume less energy and have high durability (100,000 hours). The conjugation of different UV-LED wavelengths is an aspect still little explored in the literature. Therefore, the aim of this work is to determine the better combination of wavelength, exposure time and distance between the sample and the UV-LED source to inactivate a bacteria culture.

Methods

Was tested 4 wavelengths (255nm, 280nm, 365 nm and 405nm) individual and combined, totalizing 15 different programs: P1-255nm, P2-280nm, P3-365nm, P4-405nm, P5-255/280, P6-255/365, P7-255/405, P8-280/365, P9-280/405, P10-365/405, P11-255/280/365, P12-255/280/405, P13-255/365/405, P14-280/365/405 e P15-255/280/365/405 nm. In addition, each program was evaluated in both distances (between the *petri* dish and the LED): 3,76cm e 6,24cm, and with these exposure times: 2, 4, 8 and 16 minutes. A 20 mL aliquot of a solution contain 10^4 UFC/mL of unidentified bacteria culture, kept homogenized by magnetic stirrer and at room temperature, was exposed to UV radiation. The bacteria's inhibitions was evaluated by the Pour Plate technique.

Results and Conclusions

As show by the Figure 1, the programs, which presented the best performance in bacteria inhibition was P-5, P-11, P-12 and P-15, based on the calculations of the bacteria surviving ratio and bacteria reduction ratio.

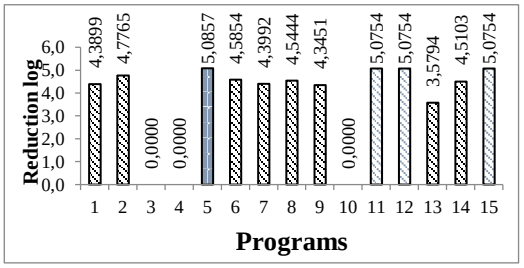


Figure 1. All programs performance

The program P-5 (255/280nm), with the height of 6.26cm, promoted total bacteria reduction, after 16 minutes of exposure. In addition, the programs P-12 (255/280/405 nm) and P-15 (255/280/365/405 nm) promoted total inhibition after 8 minutes of exposure with the height of 3.76 cm. While the program 11 (255/280/365 nm) shows the same reduction efficiency for both heights, even after 16 minutes of exposure.

The Figure 2 presented the performance of the four better programs.

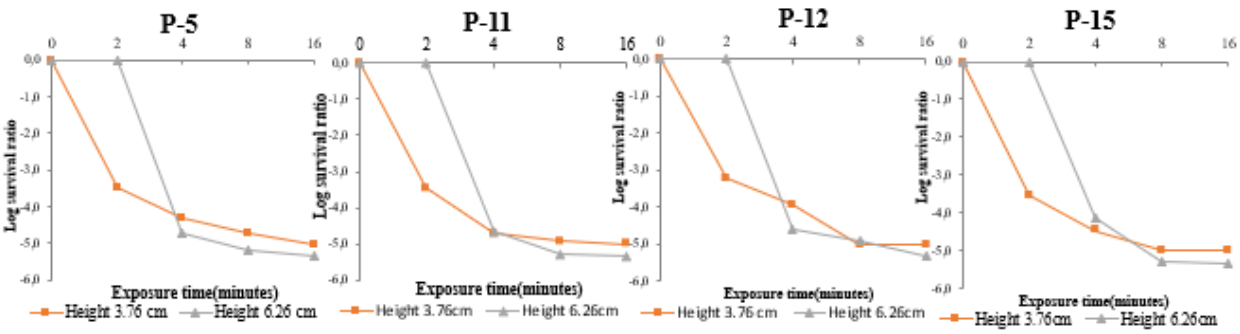


Figure 2. Programs performance in different exposure times

All the four better programs show similar performance in the bacteria reduction, but taking into accounting the number of LED lamps, and consequently the cost-benefit ratio, the program P-5 (255/280nm) with the height of 6.26 cm and the 16 minutes of exposure time could be consider the better configuration to inactivate a bacteria culture.

The UV-LED shown to be efficient for the bacteria culture inactivation, so this technology can be a good option to the anaerobic systems effluents disinfection, as an alternative to chlorine.

ACKNOWLEDGEMENTS

The authors are grateful to FAPESP (São Paulo Research Foundation, process 2017/07490-4 and 2017/12157-2) for financing this study.

Wastewater reuse in agriculture: an alarming presence of pathogens

L. P. Leonel1; A. L., Tonetti1

1 School of Civil Engineering, Architecture and Urban Design, Sanitation and Environment Department - University of Campinas, Campinas, Brazil.

Background

The lack of wastewater treatment is an environmental and public health problem. Among the pathogenic agents that cause waterborne diseases, protozoa and helminths are more prominent. These parasites have great resistance to adverse environmental conditions and the ingestion of small numbers of cysts and eggs is enough to cause infection. These characteristics enable them to be responsible for most of the parasitic diseases that affect humans and animals worldwide, especially in rural areas. So, the choice for a treatment system able to remove this organism is an important step to guarantee the quality of the effluent to be used in agriculture. Therefore, this study was aimed at evaluating simplified system efficiency, consisting of anaerobic filter filled with bamboo rings associated with sand filter, in order to remove Giardia spp. cysts and helminth eggs.

Methods

The experiment was carried out on a pilot scale system: an anaerobic filter (AF) filled with bamboo rings, associated with an intermittent sand filter (SF). We collected the samples in three points: Raw wastewater (RW), anaerobic filter effluent (AFE) and intermittent sand filter effluent (AFE). A total of 12 samples were analyzed.

For the Giardia spp. cysts detection it was used the concentration by centrifugation protocol (Robertson et al., 2000) and the membrane filtration method (Franco et al. 2001). For counting *Giardia* spp. cyst we used the immunofluorescence assay (IFA) test (Merifluor® Kit). To detect helminth eggs it was followed the methodology regulated by the Environmental Protection Agency of the United States (USEPA, 2003).

Results and Conclusions

Giardia spp. cysts were detected in 91.6% of raw wastewater samples, 91.6% of anaerobic filter effluent samples and in 83.3% of the sand filter effluent. While the helminth eggs were found in 58.3% of raw wastewater samples. Just in three

samples of AFE we detected helminth eggs. Table 1 shows the average of concentration of cysts and eggs in the samples.

Table 1: Giardia cyst and helminth egg concentration before and after the treatment.

Pathogen	RW	AFE	SFE
Giardia cyst (cyst L^{-1}	$5.7 \times 10^4 \pm 3.5 \times 10^4$	$1.5 \times 10^2 \pm 1.3 \times 10^2$	93 ± 92
Helminth eggs (eggs L^{-1})	24.0 ± 20.7	1.5 ± 1.2	Not detected

The concentration of helminth eggs in raw wastewater, as well as giardia cysts, relies on factors ranging from provision of sanitation to health conditions of the population and varies greatly according to specificities of each region. The most removal of the both pathogens occurred in the AF. Helminth eggs and giardia cyst are just particles in wastewater, the mechanism for this material removal is the same as the one used for suspended solids removal: sedimentation, filtration and coagulation/floculation. Thus, a large portion of cysts in the raw wastewater is only transferred from the effluent to the sludge, hence the importance of evaluating and treating sludge before its application in agriculture.

Besides the system has removed 99.7% of *Giardia* spp. cysts and 100% of helminth eggs in the raw wastewater, we also identified 93 ± 92 cysts L−1 of Giardia spp. in the final effluent. This demonstrates that there is a necessity to studies about disinfection process for decentralized systems, in order to prevent the spread of infectious forms of these parasites, when the effluent would be used for agriculture. Our research group has been evaluated some alternatives for disinfection of effluents, until the conference data we will have the results of this studies.

Acknowledgements

The authors are grateful to FAPESP (São Paulo Research Foundation, process 2017/07490-4 and 2017/12157-2) for financing this study.

References

Franco, R. M. B.; Rocha-Eberhardt, R.; Cantusio Neto, R. Occurrence of *Cryptosporidium* oocysts and *Giardia* cysts in raw water from the Atibaia river, Campinas, Brazil. **Revista do Instituto de Medicina Tropical**, v. 43, n. 2, p. 109-111, 2001.

Robertson, L. J.; Paton, C.A; Campbell, A.T; Smith, P.G; Jackson, M.H; Gilmour, R.A; Black, S.E; Stevenson, D.A; Smith, H.V. *Giardia* cysts and *Cryptosporidium* oocysts at sewage treatment works in Scotland, UK**. Water Research**, v. 34, p. 2310-2322, 2000.

USEPA—United States Environmental Protection Agency, 2003. EnvironmentalRegulations and Technology: Control of Pathogens and Vector Attraction inSewage Sludge. Appendix I: analytical method for viable helminth ova. USA.

Operating world's first UV Hypo AOP System for Reuse – An Operators Story

S. Tag Oh[1], S. Hammond[2], J. Scheideler[3], R. Aflaki[1], L. Thibodeaux[1], K. Robinson[4]

[1] City of Los Angeles LASAN, USA
[2]Parsons Corp. USA
[3]Xylem Services GmbH Germany
[4]Trussell Technologies USA

Abstract

As the Los Angeles Sanitation (LASAN) continues to leverage reuse at the newly expanded Terminal Island Water Reclamation Plant (TIWRP) to supply water resources to meet the demands of the greater Los Angeles area, this paper provides guidance on how a new AOP process has been implemented starting from initial bench-and pilot-scale testing to the full-scale design, commissioning, and operation at a 12 MGD indirect potable reuse plant. The combination of ultraviolet light and sodium hypochlorite has become a viable Advanced Oxidation Process (AOP) alternative for potable reuse because of its economic benefits when compared to the traditional UV-based AOP with hydrogen peroxide. The technology selection and sizing data were gained from a 12 month pilot study at TIWRP leading to the first Greenfield UV/hypochlorite AOP design in the world. Critical control points such as pH, scavenging potential, UV dose, and free chlorine concentration are presented along with how they were considered for the full-scale design to comply with California's groundwater recharge regulations. Results of the full-scale start-up, commissioning, and acceptance of the 12 MGD AOP system will be provided and compared to design assumptions. The paper will provide further insights in the first year of operation and how the system is further optimized with regards to chemical dosing and energy savings.

The Project, funded by Proposition 84, recipient of the ENR California Best Project Award 2017 in Water/Environment, Southern California, constructed by Walsh Construction Company Inc is being submitted for the ultimate sustainability award at I-4: Envision® Platinum.

Key-words: Advanced oxidation processes (AOP); Hypochlorite; Potable Reuse, UV.

Summary:

The UV AOP system at the Terminal Island Water Reclamation Facility is the first Greenfield AOP system that utilizes the combination of UV light and sodium hypochlorite for potable reuse. This presentation describes the experiences and lessons learned from the first year of operation from the chief operator's perspective.

Degradation Emerging Contaminant and Elimination of Toxic By-products from Reclaimed Water by Catalytic Ozonation

Yuting Zhang, Beijing Key Lab for Source Control Technology of Water Pollution, College of Environmental Science and Engineering, Beijing Forestry University, Beijing, PR China; Yechen An, Key Laboratory of Urban Stormwater System and Water Environment, Ministry of Education, Beijing University of Civil Engineering and Architecture, Beijing, PR China; Donghai Yuan, Key Laboratory of Urban Stormwater System and Water Environment, Ministry of Education, Beijing University of Civil Engineering and Architecture, Beijing, PR China; Yanning Li, Beijing Key Lab for Source Control Technology of Water Pollution, College of Environmental Science and Engineering, Beijing Forestry University, Beijing, PR China; Weidong Meng, Beijing Key Lab for Source Control Technology of Water Pollution, College of Environmental Science and Engineering, Beijing Forestry University, Beijing, PR China; Fei Qi, Beijing Key Lab for Source Control Technology of Water Pollution, College of Environmental Science and Engineering, Beijing Forestry University, Beijing, PR China*

Abstract

This study evaluated the performance of $LaCoO_3$ (LCO) catalytic ozonation on emerging pollutants degradation and toxic by-products elimination in effluent organic matter (EfOM) matrix solution, as well as the EfOM reactive activity in (catalytic) ozonation. The results showed that LCO catalytic ozonation improved the removal efficiency of benzotriazole (BZA) as an important emerging contaminant, UV_{254} and SUVA *via* enhanced HO· formation. Interestingly, LCO catalytic ozonation showed the ability on the elimination of keto-aldehydes and toxic halogenated organic by-products. And it was also surprising to find only chlorinated organic by-products, especially trichlormethane (TCM), but no bromodichloromethane (BDCM) or dibromochloromethane (DBCM). Moreover, the formed [TCM],

[bromochloroacetonitrile (BCAN)] and [dichloroacetamide (DCAcAm)] decreased significantly when the O_3 concentration was 2.0 mg/L in catalytic ozonation. Catalytic ozonation was also able to remove disinfection by-products (DBPs) precursor, such as TCM, bromodichloromethane (BDCM), trichloroacetonitrile (TCAN) and trichloronitromethane (TCNM). Degradation of DBPs precursor involved the transformation of EfOM in catalytic ozonation, which was confirmed by multi-spectrum methods, two-dimensional correlation spectroscopy (2D-COS) and hetero-spectral 2D-COS. In summary, LCO was shown to be an effective catalyst to improve the performance of the sole ozonation for removal of emerging containments and DBPs precursor degradation, as well as toxic by-products elimination.

Acknowledgement

This work was carried out with the support of National Natural Science Foundation of China (No. 51878047 and 51578520), Beijing Natural Science Foundation (No. L160006) and Open Project of State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology (No. HCK201709).

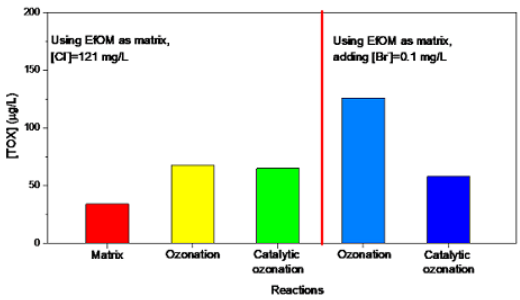


Fig. 1 Profile of formed [TOX] in (catalytic) ozonation.

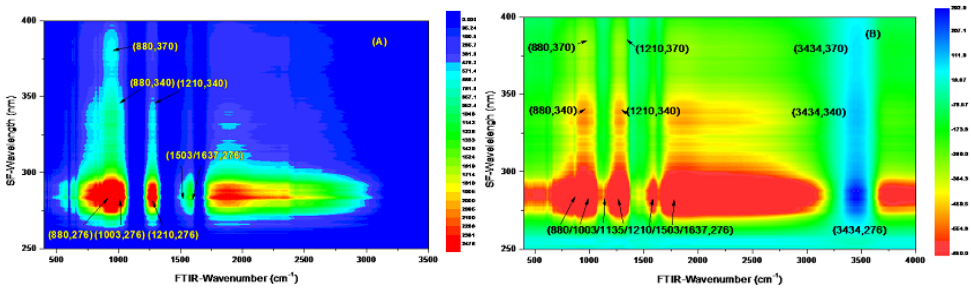


Fig.2 Hetero-spectral 2D-COS of SF and FT-IR spectroscopy with synchronous map (A) and asynchronous map (B).

A new insight into ozonation coupled with tubular ceramic membrane in wastewater treatment: performance, membrane fouling formation and the mitigation mechanism

Zilong Song, Beijing Key Lab for Source Control Technology of Water Pollution, College of Environmental Science and Engineering, Beijing Forestry University, Beijing 100083, P.R. China; Yanning Li, Beijing Key Lab for Source Control Technology of Water Pollution, College of Environmental Science and Engineering, Beijing Forestry University, Beijing 100083, P.R. China; Yuting Zhang, Beijing Key Lab for Source Control Technology of Water Pollution, College of Environmental Science and Engineering, Beijing Forestry University, Beijing 100083, P.R. China; Chao Liu, Beijing Key Lab for Source Control Technology of Water Pollution, College of Environmental Science and Engineering, Beijing Forestry University, Beijing 100083, P.R. China; Bingbing Xu, State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, P.R. China; Fei Qi [1], Beijing Key Lab for Source Control Technology of Water Pollution, College of Environmental Science and Engineering, Beijing Forestry University, Beijing 100083, P.R. China.*

Corresponding Author, Prof. Fei Qi

Tel.: +86 10 62336615; Fax: +86 10 62336596; Email: qifei@bjfu.edu.cn

Abstract: To guide the actively utilized of ozone coupled with ceramic membrane water treatment processes, the mechanism of mitigation membrane fouling with pre-ozonation and *in-situ* ozonation were systematically investigated. The comparative performance of pre-ozonation and *in-situ* ozonation on the filtration and effluent from WWTPs purification were evaluated. Pre-ozonation achieved better enhancement effect of flux at low ozone dosage and *in-situ* ozonation showed better effect at high ozone dosage. Both pre-ozonation-filtration and *in-situ* ozonation-filtration achieved significant performance on effluent purification. The introduction of ozonation obviously improved the cleaning efficiency of TCMs, especially for *in-situ* ozonation. Inorganic, organic and biofouling membrane fouling were identified to explain the

mechanism of mitigation membrane fouling with different ozonation mode. SEM-EDX was employed to detected the formation of inorganic membrane fouling, the elements Ca, Mg, Si, Al, and Fe were the main inorganic components. Regarding organic membrane fouling, the mitigation mechanism of pre-ozonation was reducing the load of organics in effluent. But *in-situ* ozonation changed the composition of membrane fouling layer. Total cells, proteins, *α*- and *β*-D-glucopyranose polysaccharides were the major components in the fouling layer and identified by multiple fluorescence labeling and confocal laser scanning microscopy. *In-situ* ozonation was more effective than pre-ozonation in biofouling membrane fouling control.

Keywords: Fouling mitigation; Filtration; *in-situ* Ozonation; Pre-Ozonation; Tubular ceramic membrane.

Acknowledgement: This work was carried out with the support of National Natural Science Foundation of China (No. 51878047) and Beijing Natural Science Foundation (No. L160006).

Total Organic Carbon as a Surrogate for the Removal of Pharmaceutical and Personal Care Products in the Coagulation-Flocculation Process

Kyle Pierce, University of Nevada, Reno, USA; Begum Jahan, University of Nevada, Reno, USA; Krishna Pagilla, PhD, PE, BCEE, University of Nevada, Reno, USA

Jar testing is widely used for removal of organics in drinking water treatment. With reuse as the final goal for the treated wastewater, removing as many organics and inorganics from the water is key. There are detectable concentrations of pharmaceuticals and personal care products (PPCPs) being observed in the Truckee River in Reno, NV and from the effluent from the local wastewater treatment facility. The goal is trying to find a cheaper alternative for the removal of PPCPs so that the advanced treated water can be reused.

Methodology

The goal of the jar testing was for DOC removal, turbidity removal, pathogen removal and other inorganics removal. Figure 1 is displaying the DOC and final turbidity for all four coagulants. The highest removal of both turbidity and DOC was achieved with the EC-309 coagulant with a removal of 1.4 mg/L of DOC and a final turbidity of 0.167 NTU. The alum provided the least amount of DOC removal with only removing 0.64 mg/L of DOC but had the second highest turbidity removal with a final turbidity of 0.255 NTU. When looking at the ability of the formed flocs to settle, the PAX-XL8 formed large heavy flocs. The majority of the flocs were settled after 5 min and all flocs were fully settled at about 10 minutes into the settling period. The EC-309 formed smaller flocs but was still fully settled after about 15 minutes. Out of all four coagulants, the EC-309 had the highest amount of sludge production while alum had the lowest amount of sludge produced. The arsenic removal for all four can be seen in Table 1. The alum had the highest percent of arsenic removal at 75% of the arsenic removed. The ferric chloride had the lowest percentage of arsenic removed at 49% removed. All coagulants had significant DOC, turbidity and inorganics removal.

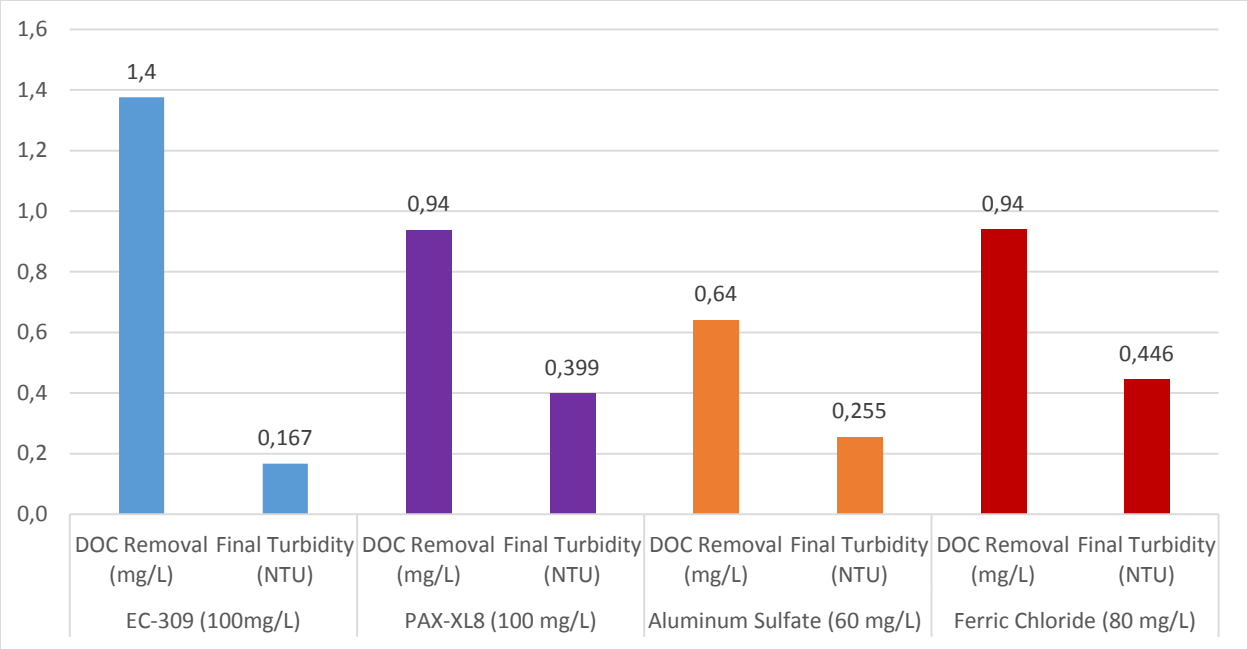


Figure 1: Jar testing results for DOC removal and final turbidity for four coagulants (The results are based on multiple jar tests for each (n>5))

Table 1: Jar testing results for total arsenic removal for four coagulants

Coagulant	Coagulant Dose (mg/L)	Total Arsenic (ppb)[a]	Total Arsenic (ppb)[b]	% Removed
EC-309	100	150	60	60
PAX-XL8	100	150	60	60
Aluminum Sulfate	40	200	50	75
Ferric Chloride	40	100	51	49

[a] Original water from secondary effluent

[b] Treated water from jar testing

Expectations

Since PPCPs are organic in nature, there is a high possibility of being able to removal multiple types of PPCPs with the coagulation and flocculation process due to adsorption on the flocs with same mechanistic processes as DOC removal. The next big questions to answer is does it actually remove PPCPs and at what percentage? Will the removal be high enough to make this a viable treatment option for PPCPs removal? These are being investigated currently.

Potable Reuse in the City of Cape Town to Improve Water Supply Resiliency

Geoff du Toit, Aurecon South Africa, Cape Town, South Africa

Introduction

The Day Zero campaign in the City of Cape Town generated international attention about the water supply crisis experienced by the City due to an unprecedented drought. The new Cape Town Water strategy has as its central objective to make Cape Town a water resilient City. One of the key mechanisms to achieve this is the provision of direct and indirect water reuse schemes to augment the City's water supply to the City. The implementation of these schemes has several challenges and this Poster provides an overview of these challenges from the context of a developing nation.

Challenges identified to implementing potable reuse in Cape Town

Lack of a National Water Reuse Standard. South Africa does not have a water reuse standard, and the existing potable water standard is wholly inadequate for reuse applications. The lack of a common internationally accepted water quality standard resulted in a bespoke standard being developed for the City of Cape Town based on various international standards (WHO, Australia, Texas and California). This is purposefully conservative and was developed in collaboration with international experts.

Characterization of local wastewaters. The characterization of the source water was limited by the ability of local laboratories to test the water. The implementation of a demonstration facility by the City has incentivized the establishment of private laboratories equipped to test CEC's to the required detection levels. To date most testing has been done in USA. The City has further set up a toxicity lab.

Localised CEC's. The source water has, amongst others, elevated concentrations of anti-retroviral (ARV) drugs due to the proportionally high number of people suffering from HIV. Further there is a prevalent use of Methamphetamine, colloquially known as *tik*, as a recreational drug which is also present in the source water. There is

limited research on the destruction of these compounds, the exposure limits or facilities to measure these compounds available.

Performance of WWTWs. The performance of a reuse scheme is dependent on the quality of the effluent wastewater it receives. Thus, there has been a drive to improve the institutional collaboration between various departments (wastewater and bulk water) within the City to enhance governance, and also to ensure the proposed advanced treatment scheme and the existing wastewater and water treatment facilities all function together as an integrated system. As the WWTW's providing the source water are still to be upgraded, which is being done as part of a broader project, the WQ parameters measured are measured at worse values than we expect would be the case in the future. Thus, there is some level of over-conservative design.

Feasibility. Cape Town has a small tax base to support a large population and thus infrastructure spending is very constrained. Early feasibility studies indicated that direct potable reuse was very competitive in comparison to the other alternatives to augment the water supply. This is especially so if reverse osmosis (RO) is excluded as a process step. RO was deemed unnecessary as salinity is low in the source effluent waters and the CEC's can be adequately removed through other processes.

Public Perception. Although Southern Africa has long been associated direct potable reuse due to the Windhoek Scheme in neighboring Namibia celebrating 50-years of operation in 2018, there remains work to be done to educate the broader population of the City of Cape Town about water reuse and assure them that it can be done safely by this authority The City is presently developing an inclusive public participation process regarding the scheme.

Smart Biodegradable Composite Materials for Waste Water Management

J.Paneysar[1], P.Ambre[1],A.Vasilaki[2], S.Barton[2], , E.Coutinho[1]

[1]Bombay College of Pharmacy, Mumbai, India

[2]Kingston University, London, United Kingdom

Abstract

One of the most challenging areas that private and public sectors face is the efficient use, conservation and protection of water. Good quality potable water is one of the basic necessities for sustenance of life. It is therefore important to make it available in plentiful volumes for the society. However, access to good quality water is becoming increasingly difficult as mother earth and environment is being polluted every day due to large scale pollution by industrial, agricultural and domestic activities. These activities also pollute rivers and other water bodies with toxic heavy metals and organic chemicals in varying quantities. To the best of our knowledge, no reusable and recyclable biodegradable waste water management systems for elimination of such impurities have been customised so far. The current project proposes to devise smart biodegradable composite materials, which are suitable for converting the waste water to potable water and helps to recycle, reuse the waste water by eliminating the organic, inorganic and toxic agrochemical pollutants. It is known that cationic natural polymers in native state are highly efficient in removing toxic metals from aqueous solutions. On the other hand, synthetic smart polymers have a unique feature of eliminating organic impurities from aqueous solutions due to adsorption triggered by heat. Thus a combination of both the natural and smart polymer would yield smart biodegradable composites with an adsorption spectrum that covers removal of organic as well as inorganic impurities[1]. All the attributes of smart biodegradable composites have been characterized by various chemical, spectroscopic and chromatographic techniques like conventional FT-IR, ^{1}H-NMR, GPC, and DSC/TGA. Viscosity measurements for rheology of the polymers, surface area and porosity measurements (adsorption) are assessed by BET and BJH isotherm plots. The composites have been screened for their abilities to extract impurities such as organic, herbicides, pesticides, textile dyes & metal ions using sophisticated analytical techniques. The polymers have shown more than 85% removal for contaminants at concentrations as low as 300mg/L. Further, since the

wide spectrum of adsorption is mainly dependent on surface area, particle size & adsorption efficiency of the polymer, the obvious procedure followed is size reduction of polymers in the form of microspheres and nanofibres. These modifications resulted in almost 97% elimination of all the impurities at a further reduced concentration of 100mg/L. The composites have been assessed as per the guidelines prescribed by the Central Pollution Control Board (CPCB). They have also shown astute efficiency in reduction of Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) for water obtained from a Central Effluent Treatment Plant (CETP). Therefore delivering a system that is economical, environment friendly (biodegradable), meets industrial standards, user friendly and a good substitute for processes currently being used for water treatment and purification. In our opinion the biggest beneficiary of such a technology would be not only the industries but the regular households as well.

References

1. Paneysar, J. S.; Barton, S.; Chandra, S.; Ambre, P.; Coutinho, E., Novel thermoresponsive assemblies of co-grafted natural and synthetic polymers for water purification. *Water Science and Technology* **2017,** *75* (5), 1084-1097.

Integrated water management for industrial parks in Vietnam – a case study for textile industry

M. Sabelfeld, S.-U. Geißen, Technische Universität Berlin, Berlin/Germany

Introduction

Since the 1980s, the textile and dyeing industry in Vietnam has grown rapidly (6% of GDP in 2016) and is now responsible for large portion of the industrial pollution load [1]. The textile industry discharges about 24-30 million of m^3 wastewater per year, whereupon only 10% are treated. The textile wastewater contains solids and organic pollution in high concentration.

In view of the increasing water shortage and highly polluted water resources, the industrial sector in Vietnam, which is predicted to grow at an annual rate of 7% [1], will face a major challenge. A prioritization of cost-effective interventions to address water stress and water pollution issues, like wastewater treatment and reuse measures for industrial sector, are highly recommended.

Material and Methods

Within the scope of the ERWIN project (BMUB funding label 16EXI2281A), the optimization of water management was carried out on the example of the Vietnam's textile industry. For this purpose, published data in [2] on the typical production steps of cotton fabric, including water consumption and the characterization of the wastewater streams are used.

The simulation system SIMBA# was applied for the modelling of water flows including treatment processes and substrate concentration. The options for direct water recycling were selected on the basis of literature research on the state of the art [3, 4].

Results and discussion

In the investigated textile company 65% of overall water consumption is generated in washing and rinsing steps; the cooling systems consume around 10% of the total water. Accordingly, the highest water saving with total of 37% is achieved by changing the washing processes from overflow to drop-fill wash and reusing water from the 2nd and subsequent washing steps (Fig. 1). The total specific water consumption of the investigated company (241 L/kg product) lies in the middle range

of the reported data for the Vietnamese textile industry (150 – 400 m³/t product [2]), but is significantly higher than the values of 50 to 100 L/kg achievable according to BREF [4]. A specific water consumption of 108 L/kg (55% reduction) can only be achieved when all the measures presented are applied (Fig. 1).

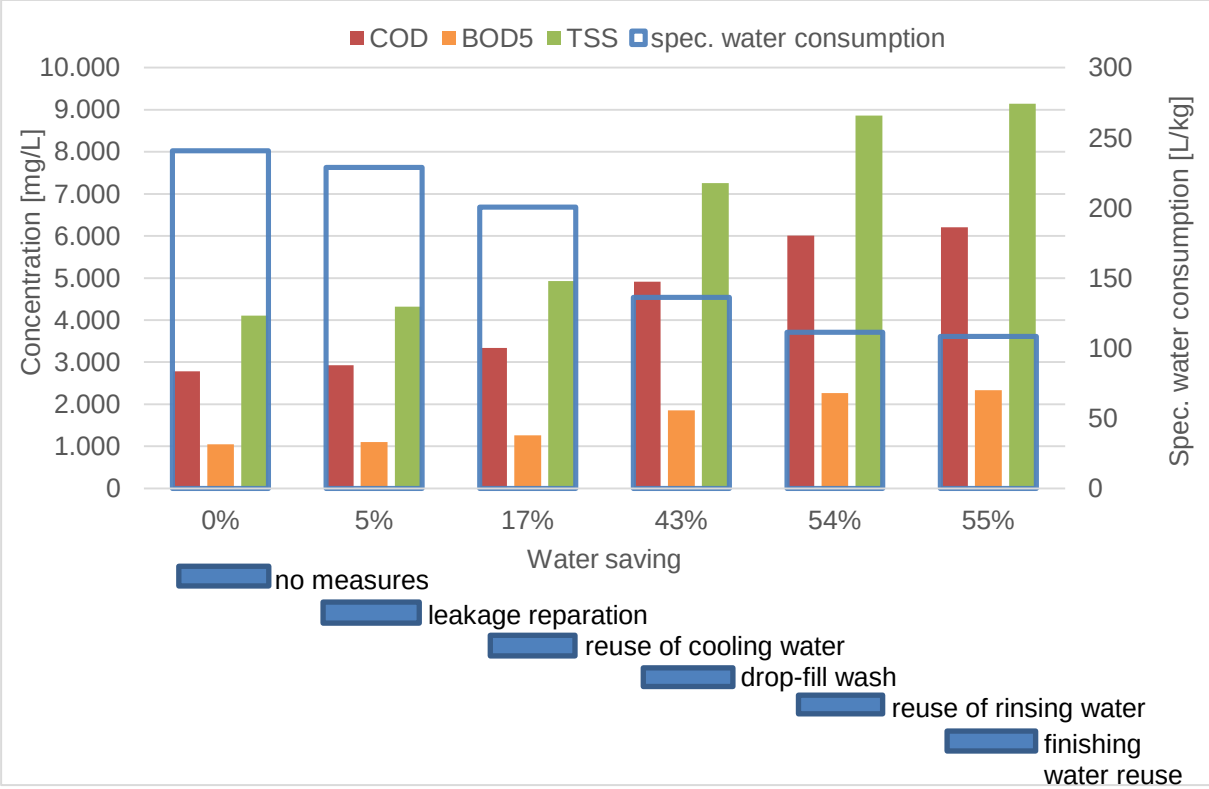


Figure 1: Water saving and wastewater composition depending on water management measures

Based on the payback periods of water interventions for textile factories [7], a reduction of water use by up to 20% (leak reparation and cooling water reuse) can be achieved at relatively small cost and is therefore a strong case for investment.

References

[1] Sagrist, T., Tahir, S., Möller-Gulland, J., Quang, N.V., Abbott, J., Yang, L. (2017). Vietnam: Hydro-economic framework for assessing water sector challenges.

[2] Phuong, L. N. T. (2011). Greening textile industry in Vietnam.

[3] European Commission (2003). Reference Document on Best Available Techniques for the Textiles Industry (BREF).

[4] Greer, L., Keane, S.E., Lin, Z. (2010). NRDC's Ten Best Practices for Textile Mills to save money and reduce pollution. Energy, 1, 1-8.

[5] Sagris, T., Abbott, J. (2015). An analysis of industrial water use in Bangladesh with a focus on the leather and textile industries. Washington DC, USA.

Single household greywater recycling using Constructed wetland in developing countries

Swapnil Punyapwar and Srikanth Mutnuri

Applied and Environmental Biotechnology Laboratory, Department of Biological Sciences, Birla Institute of Technology and Science –Pilani, K. K .Birla Goa campus, Goa, India

Tel: 0091 832 2580125, Fax: 0091 832 2557033, Email: srikanth.mutnuri@gmail.com, srikanth@goa.bits-pilani.ac.in

Sustainability drives every household to save water consumption. Sewage water recycling efforts are stymied by socio-cultural bottlenecks. Greywater here stands best chance to succeed. There are rare proven sustainable technologies available for greywater reuse. At household level, small treatment systems for greywater reuse can suffice non-potable demands like gardening, irrigation and toilet flushing.

With goal of developing sustainable engineered water treatment system that are friendly, compatible with environment and humans, the application of wetlands is more significant. Constructed wetlands (CW) could be robust, cost efficient and simple treatment system for water recycling. They are prominently used to treat sewage water in many European countries at community scale, whereas, developing countries like India have just started adopting the technology which is limited to sewage water treatment. Tropical Indian climate favours application of wetland to be more effective than temperate zones.

In current report, Vertical flow (French two stage) constructed wetland for greywater recycling was assessed over 9 months at single household (5-6 PE). Greywater from bathroom, washing and kitchen sink was recycled by wetland which was utilised for gardening. The main purpose of this study was to investigate the greywater loading characteristics, provide convenient on-site mini wetland recycling system. *Canna indica* plants were used in the system, substantially exhibited growth in the conditions of CW. Pollutant removal efficiency of CW in terms of COD, BOD and phosphorus removal was 96%, 95% and 84% respectively. pH and coliform content were well within WHO standards for treated water. However Nitrogen (Nitrate 37%, Nitrite 91%, NH_4-N 71%, and TN 60%) removal efficiency was relatively less. Results confirm that the CW system was effective to remove pollutant from

household greywater and can be used as treatment system for greywater recycling at household level. In view of future applications, system is still operational and further efforts are required to increase the nitrogen removal efficiency and disinfection.

Wastewater disinfection for agricultural reuse using solar radiation in a developing county: field observations

Tamires Lima da Silva1, Department of Rural Engineering, Agronomic Science Faculty- São Paulo State University, Botucatu-SP, Brazil, Rodrigo Máximo Sánchez Román, Department of Rural Engineering, Agronomic Science Faculty- São Paulo State University, Botucatu-SP, Brazil; João Gabriel Thomaz Queluz, Institute of Geosciences and Exact Sciences- São Paulo State University, Rio Claro-SP, Brazil

Wastewater treatment for agricultural purposes can contribute to decrease discharge of pollutants into water bodies, reduce water uptake from the surface water and groundwater, and recycle nutrients. However, there are environmental risks associated to irrigation with wastewater, mainly due to presence of pathogenic microorganisms. Solar disinfection is a low-cost disinfection method suitable for developing country that can allow safe use of recycled wastewater for irrigation. A pilot study was performed in Botucatu, São Paulo, Brazil, to determine the feasibility of using solar radiation to disinfect reclaimed urban wastewater for agricultural reuse. The effluent from Botucatu City Wastewater Treatment Plant (WWTP) was used as supply; this wastewater passed through biological filters bed (BFB's) before being directed to solar disinfection. The solar disinfection system (SODIS) used in the experiment has a concrete base and shape of an inverted truncated cone with the following measures: 1.00 meter for larger radius, 0.25 meters for smaller radius and 0.30 meters height. This structural form was adopted to ensure that the walls of the reactor do not produce shadows on the effluent surface for the longest time possible. The experiment was conducted at Faculty of Agronomic Sciences-UNESP, Botucatu-SP, Brazil (22º 51' 12" S and 48º 25' 45" W). Fixed depths of wastewater (0.10; 0.15 e 0.20 m) were tested considering different time of exposure to solar radiation from May to July 2018. After passing through the BFB's, the wastewater presents mean values for chemical oxygen demand (COD), total suspended solids (TSS), turbidity and fecal coliform (*Escherichia Coli*) of 27.8 mg L^{-1}, 8.6 mg L^{-1}, 1.5 NTU, 2.0 x 10^4 MPN 100 mL^{-1}, respectively. The three fixed wastewater depths were exposed to solar radiation for a period of 10 hours (from 08:00 a.m. to 6:00 p.m.). The collection of wastewater samples for fecal coliform (*E-Coli*) analysis was performed every two hours. Results of inactivation assays showed that SODIS can bring down *E-coli*

concentrations of 10^4 MPN 100 mL^{-1} in urban wastewater to < 3 MPN 100 ml^{-1}. *E-coli* was more effectively disinfected by SODIS with 0.10 m wastewater depth, exhibiting logarithms reduction values ranging between 2 $\log_{10}$ (99%) to 4.3 $\log_{10}$ (99.99%) than by the depths of wastewater of 0.15 m (1.2 $\log_{10}$ to 3.8 $\log_{10}$) and 0.20 m (1.0 $\log_{10}$ to 3.9 $\log_{10}$). Although statistical analysis did not show a significant difference ($p \leq 0.05$) between the wastewater depths tested. A model was developed to estimate the remaining population of fecal coliforms in wastewater after being exposed to SODIS knowing its initial population, depth of water being treated and solar energy received. SODIS was effective in reducing mean concentration of *E. coli* in the three wastewater depths tested at the standard recommendation for agricultural reuse proposed by World Health Organization -WHO (≤ 1000 MPN 100 mL^{-1}) after six hours exposures to direct sunlight. Thus, SODIS treated wastewater can successfully be used by rural communities in developing countries.

Keywords: Solar disinfection, wastewater reuse, developing country, *E-coli*.

Reclaimed Water Development and Opportunity in Taiwan

KUANG-CHIH CHANG[a], QIN-HAN ZHENG[a], Te-Yuan CHEN[a], David Da-Wei Tsai[b,], Ya-Fen WANG[b], Sheng-Jie YOU[b]*

[a] *Water Resources Agency, MOEA*

[b] *Chung Yuan Christian University*

**Corresponding Author*

Due to the climate change impacts, it definitely raises the stress of water supply in the urban region with the high density of population and industrial activities. Facing these challenges, the Taiwan Water Resource Agency has proposed a series of strategies to manage the water resource to strengthen the infrastructure of Taiwan and ensure the implementation for the corresponding sustainable development goals (SDGs). For this propose, the water diversity is an emphasis issue recently. The alternative water resources, like reclaimed water and seawater desalination are applied to supplement the insufficiency of traditional water resources. Since 2017, a master plan for improving the water environment was executed to create more water resources from the reclaimed water. A huge market is then emerged from these infrastructure investments to construct the 7 wastewater treatment plants whose the effluent will be reclaimed. The first one would be Fengshanxi plant, which will start serving on August 2018. The following construction bidding includes Linhai, Anping, Yongkang, Shuinan, Futian and Fengyuan Plant will be constructed. The wastewater treatment plant requires a further improvement to reclaim the effluent to reach the regulated quality for a general use, including the treatment units, control and operation skills. On the other hand, the users should improve their own pipeline works to utilize the reclaimed water. These all are emerging market for investment in Taiwan. Furthermore, the produced reclaimed water then increase the water supply to the industrial sector and decrease the stress of city water supply. The target of reclaimed water usage is set up to 1.32 million cubic meter per day in year 2031, roughly 10% of the city water supply. According to the Reclaimed Water Act, there are two types of reclaimed water: from the sewer system (60% in the aforementioned policy target) and from the individual factories or household community (40% in the aforementioned policy target). According to a rough estimation, there will be $ 5 billion investment occurring in this field, including the construction, equipment, facility

renewal and the operation/maintenance. This will largely provoke the development of the water industry in Taiwan and enhance the resilience capacity in the cities. Furthermore, the new ICT technologies also bring a new chance to enhance the performance, create a new business model and more jobs in the future water industry.

Mine water reuse as option for urban areas close to mining

Katrin Brömme, Ruhr University Bochum, Bochum, Germany; Harro Stolpe, Ruhr University Bochum, Bochum, Germany; Trinh Quoc Viet, Ruhr University Bochum, Bochum, Germany

The R&D project WaterMiner focuses on a spatial-temporal coordinated regional recirculation and reutilization of mining impacted waters from the hard coal mining industry as well as the need-based and efficient reuse of this wastewater for mining purposes as well as for other purposes outside the mining area. The R&D project WaterMiner is funded by the Federal German Ministry of Education and Research (BMBF).

WaterMiner project is located in northern Vietnam in the eastern part of Ha Long City on Hon Gai peninsula, Quang Ninh province. The mines in this area are managed by the state-owned mining company Vietnam National Coal - Mineral Industries Holding Corporation Limited (VINACOMIN).

The R&D project WaterMiner consists of the following work packages:

- Project coordination (eE+E environmental Engineering and Ecology, RUB)
- Basic data survey, system analysis, system description (eE+E environmental Engineering and Ecology, RUB)
- GIS water infrastructure management (Disy Informationssysteme Ltd, Karlsruhe)
- Monitoring information system (ribeka Ltd, Bornheim)
- Spatial and temporal material flow analysis (eE+E environmental Engineering and Ecology, RUB)
- Technical concepts for water treatment, water distribution, regional integrated control of water flows and coal dust reclamation (DGFZ e.V - Dresden Groundwater Research Center)
- Economic concept, acceptance (Environmental Economics, University Koblenz-Landau)

- Exemplary implementation: monitoring, pilot facility for waste water treatment (DGFZ e.V - Dresden Groundwater Research Center; LUG Engineering Ltd., Cottbus; VINACOMIN)

Hard coal mining in Quang Ninh province is taking place for many decades. Most of the open pits are scheduled to be closed over the next 10 years or are shifted to underground mining. As a result, the amount of mining impacted water changes according to location, quality and quantity.

The mine water flows via equalization basins to the mine water treatment plants and is treated there. In the rainy season and especially during heavy rainfall events, wastewater is only partially treated or discharged into the surface waters without treatment.

The treated mine water is partially reused inside the mines (coal washing, truck washing, dust control, etc.). Additionally, there is a large water demand in the surrounding urban area of Ha Long City for irrigation purpose (park, golf course, agriculture), road cleaning and drinking water, especially during dry season.

The R&D project WaterMiner investigates under different considerations (material flow management, surface water and sediment management as well as economy) how and to what extent the existing water demand in the mining area and parts of the water demand in the urban area can be covered by treated mine water.

Integrated water management and water reuse solutions for prosperous regions tackling water scarcity

M. Krauss[1], S. Wasielewski[1], S. Stauder[2], P. Richter[1], P. Maurer[1], M. Hügler[2], Y. Zahumensky[3], H. Kosow[3], C. León[3], R. Minke[1]

[1]Institute for Sanitary Engineering, Water Quality and Solid Waste Management (ISWA), University of Stuttgart, Stuttgart, Germany

[2]TZW: DVGW-Technologiezentrum Wasser - Water Technology Center, Karlsruhe, Germany

[3]Center for Interdisciplinary Risk and Innovation Studies (ZIRIUS), University of Stuttgart, Stuttgart, Germany

Introduction

Surface water e.g. rivers, lakes and reservoirs is one of the main sources for drinking water. Sufficient protection of these waters is inevitable to keep their ecological equilibrium and to minimize health risks when exploiting them as drinking water resources. Population and economic growth in combination with competing water demand often leads to overuse, i.e. higher abstraction than natural regeneration, thus major water scarcity challenges. These challenges can be tackled by planning integrated and modular water supply and wastewater disposal concepts, which take seasonal changes in the availability of water resources into consideration and are adapted to changing social and economic conditions in the watershed. This approach requires the integration of innovative water technologies and stakeholder involvement at different stages of the process of developing and evaluating solutions. Using the water catchment area of the river Lurín in the area of Lima/Peru as an example, concepts are being developed that can be transferred to other water scarcity areas.

Methodology

Based on the analysis of the natural and anthropogenic water cycle at water catchment level, small-scale water balances are determined for spatial clusters typical of the area. Potentials for closing the water cycle are determined with the aid of PINCH-technology and, taking into account local boundary conditions such as settlement density, income or irrigation requirements, concepts for locally adapted water management are developed in cooperation with stakeholders which promise a more efficient, culturally accepted and sustainable use of water as a resource. Some of the concepts are tested for technical feasibility using pilot plants. The concepts developed are examined in a three-stage evaluation process, which consider the fulfilment of UN's Sustainable Development Goal 6 as well as national policy

principles reflected in laws and guidelines. The participatory assessment by local stakeholders using multiple criteria is the third stage.

Results

A water balance for the Lurín catchment was generated using statistical data, data from grey literature like governmental and non-governmental reports, monitoring campaigns, model results and data gathered directly from stakeholders using interviews or transect-walks. Potentials for water reuse, in particular treated municipal wastewater for irrigation purposes in agriculture and for groundwater recharge, based on the results of the water balances for the catchment area were identified. In particular, the intensive use of groundwater in the lower catchment area leads to seawater intrusion. By means of systematic groundwater recharge, seawater intrusion can be mitigated. Nevertheless, the current effluent quality of the main waste water treatment plant (WWTP) in the catchment is not sufficient for groundwater recharge or safe water reuse in agriculture. Therefore, the wastewater management needs to be adapted to meet the new requirements. Pilot plant results indicate that WWTP effluent qualities for groundwater recharge and irrigation water can be achieved. The evaluation of the concepts is based on the fulfillment of national limit values and SDG indicators andstakeholders' statements on possible water management solutions..

Conclusion

The results of the case study in the area of Lima indicate that urban/rural water management concepts based on a water balance analysis on water catchment level and stakeholder evaluation lead to water management options, which can improve local water use efficiency. These options do not only take into account upstream and downstream effects but their contribution to the achievement of political goals like SDG6. Nevertheless, the development of integrated water and wastewater concepts in combination with stakeholder participation are labor intensive and time consuming. They require an inter- and transdisciplinary approach, thus the application of different methods like literature reviews, interviews, stakeholder dialogues, transect walks, modeling, water sampling and monitoring activities. This variety of different methods is strongly needed for plausibility checks of the input data.

Acknowledgment: The authors would like to thank the German Federal Ministry of Education and Research (BMBF) for funding the project TRUST (02WGR1426A, www.trust-grow.de). The responsibility for the content lies with the authors.

Greywater Cooling Tower-
Wastewater Treatment in Façade Structures

Meike Lenzen, Technische Universität Berlin Campus El Gouna, Egypt,
Carsten Riechelmann, Technische Universität Berlin Campus El Gouna,
T. Zinati Shoa, Technical University of Berlin
Matthias Barjenbruch, Technische Universität Berlin

1. Introduction:

The freshwater availability in countries differs immensely. Today 43 countries suffer from water scarcity [1], which means the rarefication of water due to natural conditions or the lack of water infrastructure (economical). The current population growth rate and climate change effects are going to worsen this situation in the future. Especially in arid and semi-arid regions, the focus on reusing wastewater is already an important target. Furthermore, the increasing energy demand and the desire for cleaner air is growing, so that the need for interdisciplinary technical solutions is pressing. The trickling filter-cooling tower combines wastewater treatment, reuse, evaporative cooling and green façade with each other to increase the sustainability of the different systems. A pilot plant is operating at the Egyptian branch of TU Berlin, where in average a higher temperature and less rainfall play a significant role in the wastewater treatment.

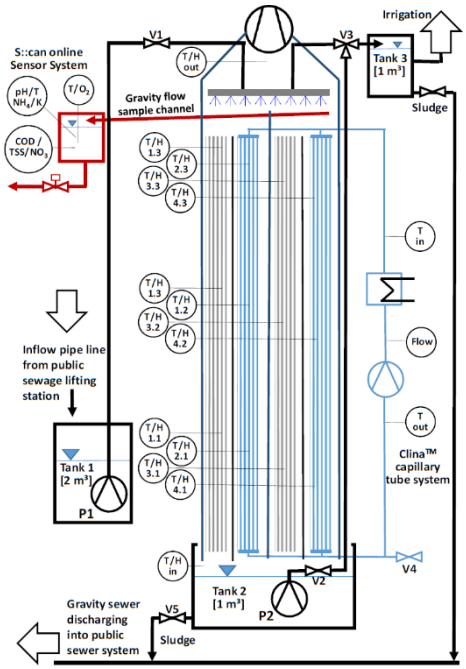


Figure 1: Flow chart of test plant in El Gouna

2. Material and Methods:

It was developed to be mainly used in informal settlements, which is why it is using simple technologies (2 pumps and a trickling filter), which need less maintenance than other wastewater treatment technologies. The whole system is built in a scaffolding structure that was designed to hold balcony like structures to implement a façade greening test system for water reuse. With this approach, a flexible construction that can adopt to any kind of existing buildings while offering a new green space behind an automatically irrigated planting system is demonstrated. The flow chart in Figure 1 shows the set-up of the test plant in El Gouna. Due to the missing

separation of wastewater the system instead of using greywater receives low loaded raw sewage with an average of 100 mg/l BOD_5 with a daily flow of 1.5 m^3. After sedimentation on the bottom of the structure, the water is pumped up to the roof and sprinkled over the trickling filter to a second sedimentation tank on the ground. After this, the water is recirculated in the system until it is stored in a tank on the roof. The water is partly evaporating during the passage over the biofilm which is cooling the reactor.

3. Results and Discussion:

Over a period of one month in May/June 2018 wastewater quality parameters where summarized and compared with the Egyptian standards for wastewater reuse [3]. An effluent quality of BOD5 < 60mg/l and TSS<50mg/l was observed, which offers the opportunity for wastewater reuse for Fodder crops and trees according to the Egyptian reuse standards [2]. Furthermore, up until now a stable temperature difference of 10-12°C between the treatment column and the environment was measured, which indicates the potential to support an air conditioning unit to decrease the energy consumption.

	Grade A	Grade B	Grade C
BOD mg/l	<20	<60	<400
TSS mg/l	<20	<50	<250
Potential number of the colonic group in 100 cm³	<1000	<5000	N/A
No. of eggs of nemetoda No./l	<1	<1	N/A

Figure 2: Grades of treated wastewater (HCWW, 2011)

4. Conclusion:

The presented approach seems suitable for a wide range of urban areas in arid and semi-arid regions. At this moment it seems like the length of the column is not important for the cooling effect, but further investigations on this needs to be done. A construction with the same height as the building seems to bring a lot of benefits: (a) pressure tank on the roof, (b) unproblematic exhaust air outlet, and (c) catchment of water from all floors. Furthermore, the hygienic parameters as legionella and coliform bacteria have to be moved more into the focus of the next studies.

References:

[1] Global Water Institute, (2013)

[2] AbuZeid, K., Elrawady, M., CEDARE (2014), “2030 Strategic Vision for Treated Wastewater Reuse in Egypt”, Water Resources Management Program – CEDARE

[3] HCWW, 2011: Holding Company for Water Supply and Wastewater, 2011, Governorates data Sheets

A CASE STUDY OF 7 YEARS OPERATION OF A^2/O-MBR IN XIAN SIYUAN UNIVERSITY

Li Dong , Ma Qinghua, Hao Jingyuan, Zhang Xuemei, Fu Bo, Qin Baolan

Xi'an Siyuan University, Xian, China,

To protect the ecological environment is to protect the productive forces, and to improve the ecological environment is to develop the productive forces. Since September 2011, a 2000m^3/d wastewater treatment plant using A^2/O-MBR process in Xi'an Siyuan University has been running steadily for nearly 7 years. The total 4.154 million cubic meters of wastewater have been treated without changing of membrane modals, 3.544 million cubic meters of water have been reclaimed and reused. This case study has proved that as long as understanding and balancing the relationship between biological nitrogen and phosphorus removal, strengthening the membrane fouling control operation, the goal of better reflect the intrinsic requirement for community sustainable development can be achieved.

Based on understanding of membrane filtration and big data treatment process, instead of using traditional “scatter plot”, this study made full use of the seven years' practical and quantitative data related to membrane performance change during the operation of system and try to make more clear and accurate statistics and effective analysis. The A^2/O-MBR wastewater treatment plant of this study basically adopts the operation mode of constant flux operation. TMP has been chosen as membrane cleaning main indicator, and the membrane operation time as the secondary indicator. This causes A^2/O being continuous operation, and MBR being a batch operation. Therefore, it needs a creative way to answer how to use industrial operation data to characterize the membrane fouling and how the average value and the degree of dispersion of the data vary with the running time.

By considering the water temperature, natural precipitation, and wastewater amounts, the April and May of each year are chosen to be the time period of analysis. Both the Arithmetic Mean (AVERAGE) and the Standard deviation (STDEV)of the daily recorded TMP, pump frequency, reclaimed water volume and water turbidity are calculated from April 1st to May 31 accordingly. Industrial water permeability VMD is defined as the effluent volume (cubic meter) / 1000 square Meter of membrane / day / KPa TMP. The daily VMD is easy to get from the instrument recorded data. The lower the VMD is, the smaller the permeable flux is, the more serious the unrecoverable pollution is, and the greater the attenuation of the performance of the membrane reactor is. Therefore, the TMP, reclaimed water volume, and VMD are calculated and studied each year in order to revealed the

attenuation of MBR caused by unrecoverable pollution. From the reclaimed water volume vs operation year curve, it seems like that a new MBR system has to go through three periods. First, MBR enters the running-in adaptation period, then it reaches an optimal operation period, and then gradually decay and degenerate. It can be seen the reclaimed water volume, at these three period, increases first, reaches the maximum value, and then decreases. With the increase of MBR reactor operation time, MBR began to have unrecoverable pollution, which is indicated by the VMD decreasing and TMP increasing. The annual decreasing of VMD is about 0.45. The annual increasing of TMP is about 1.12 KPA.

At the beginning of the establishment of the university in 2001, it was confronted with the shortage of water resources because of the lack of water supply and drainage infrastructure. At that time, the university should not only stand on the protection of the environment, take the road of sustainable development, but also consider the conservation of fresh water resources, solve the water and drainage of tens of thousands of teachers and students, and use limited funds for running this university. The A^2/O-MBR system of 2000m^3/d was upgraded from original traditional bio. Although the total operating costs, including electricity, cleaning medicine, waste water treatment and 25 km pipelines for reclaimed water reuse repairs, labor and welfare, are at 1.22-1.27 yuan per cubic meter. membrane depreciation is considered, After the distribution of the sales fee (at this time, the depreciation cost accounts for more than 70% of the cost of reclaimed water production), the unit water cost, excluding tax and return on assets, is 4.19 yuan per cubic meter. After membrane depreciation and apportionment are completed, tax and return on assets are excluded The cost of water per unit system is still 2.82 yuan per cubic meter. Therefore, there is still a difficult way to achieve government foresight, policy promotion, financial support, and the absorption of social funds to develop the reuse of sewage treatment and reclaimed water.

Keywords: average value; relative deviation; Industrial permeability; unrecoverable pollution; process parameter; membrane depreciation.

Finding sustainability pathways in wastewater management systems in an inter-disciplinary and participatory manner in Latin America

L.Benavides[1], T. Avellán[1], S. Caucci[1], A. Hahn[1], S. Kirschke[1], A. Müller[1]

Wastewater management in Latin America faces great challenges to reach a sustainable state. Although enough infrastructure has been built to treat around 40% of the produced wastewater, only between 15-20% is effectively treated, and abandoned or defective infrastructure is a common sight. Data and detailed knowledge about current conditions and needs at specific sites is quite fragmented, when existing. This leads to the challenge in decision making for choosing future sustainable wastewater infrastructure and management options. This study presents a comprehensive framework to 1) thoroughly understand current conditions 2) involve stakeholders and different data/knowledge holders and 3) point to pathways to improve waste water management in the Americas. This inter-disciplinary framework brings together different strands of knowledge from both the social and the natural sciences, and builds on systems thinking and ideas of co-design, information sharing and the importance of improving data gathering in developing countries.

Through a literature review we compiled an extensive dataset useful to assess baseline conditions of wastewater management systems across four dimensions of sustainability, namely environmental, technical, economic and social. A first result of our research is this extended set, which can be useful to other projects needing to assess the status quo of wastewater management systems in the Americas by adapting the set to the different realities and needs of their sites. In our study cases, the extended set was vetted, enriched and adjusted in a participatory manner with local stakeholders to respond to local specificities and needs, creating a site-specific baseline data set. Once the baseline set was agreed upon, data for each of the case studies was gathered through literature reviews and field work including expert interviews and on-site measurements.

Baseline conditions were then contrasted with target states. The sustainability of the wastewater management system is discussed based on distance-to-target values. Target states for indicators were drawn from regional, national and international rules and regulations, as well as from stakeholder consultation.

This work presents the framework itself, including its different toolkits (quantitative datasets, qualitative questionnaires) and the results of its preliminary testing in two pilot sites in

Guatemala and Mexico. The locally-adapted datasets, distilled from the extended set, allowed to understand the wastewater management system's dynamics and drivers in a site-specific manner, and draw suggestions on which dimensions - and discrete aspects within these dimensions - are necessary to work on in order to improve sustainability.

The overall framework and the pilot site application are a useful first step towards an integrated and comprehensive methodology to assess baseline conditions and sustainability performance for wastewater management systems and identify different qualities of pathways to drive these systems into more sustainable behaviours.

Key words: *assessment framework, sustainability assessment, baseline assessment, co-design, stakeholder involvement, wastewater management.*

[1] United Nations University, Institute for Integrated Management of Material Fluxes and of Resources

MBR - The Corner Stone Of Water Reuse Adoption

Sylvain Donnaz, Suez International, Treatment Infrastructure, France;
Stephen Katz, Suez Water Treatment Solutions, Canada;
Miguel-Angel Sanz, Suez International, Treatment Infrastructure, France

Membrane Biological Reactor (MBR) is a widespread and ultimate technology in the field of wastewater treatment for Biological Nutrient Removal (BNR) as secondary stage. The MBR technology has also widely imposed itself when it comes to provide very high and reliable water quality (as such as tertiary stage), very low enclosed footprint and advanced architectural integration.

The growing needs in megacities for environmental integration with advanced odors management, retrofitting-extension of existing infrastructures and water reuse schemes tend to promote MBR as the most effective, efficient and sustainable solution.

In certain regions with hydric stress, the development of water reuse has promoted the MBR technology because of its outstanding water quality, reliability and performance.

This paper will highlight and describe some of the best MBR integration when coupled within water reuse flowsheet worldwide: several in the USA, France, Mexico and China.

In the West Texas City of Abilene (USA) has been in operation since January of 2015: the Hamby WRF Indirect Potable Reuse Project (12 MGD). The treatment flowsheet includes MBR technology, with 60% of the filtrate treated with reverse osmosis, and the other 40% treated through ozone oxidation and biologically active filtration.

The Brightwater Wastewater Treatment Facility (117 MLD daily average flow to 217 MLD peak hourly flow) has been commissioned in September 2011. King County's Wastewater Treatment Division services about 1.4 million people in the Seattle, Washington area (USA).

The Huai Fang Water Reclamation Plant project (located South of Beijing) has chosen the MBR technology (600 MLD; handling the wastewater produced by over 3 million people) equipped with the ultrafiltration-membrane bioreactor technology and

ozone system used to treat the wastewater to produce optimum quality water, thereby contributing to the conservation of the natural environment receiving the outflow. At ground level, an artificial water lake uses reclaimed water for enhancing the natural environment. The effluent quality of the plant is designed to achieve "the urban sewage treatment plant water pollutant discharge standards of Beijing" (DB11/890-2012) requirements. The wastewater treated by the Huai Fang plant can be re-used for city management projects or discharged into wetland and watercourse. This plant, that is built underground, improves the quality of the water environment and produce sound environmental benefits in Beijing southwest region.

The Achères Biosav project (located downstream of the Paris' Seine river, one of the largest WWTP in the world; 250 MLD of UFMBR) has chosen to integrate the ultrafiltration MBR technology in hybrid configuration together with its existing secondary process (BAF). Designed in hybrid configuration (BAF + MBR) to improve the membranes' capital cost (CAPEX), the global energy efficiency (OPEX) and the final treated water quality. While treating 13% to 17% of the total flow (250,000 m3/d @95%ile), the MBR treatment line guarantees 95%ile Total Suspended Solids (TSS) of 1 mg/L, Biological Oxygen Demand (BOD) of 5 ppm Total Nitrogen (TN) of 10 mg/L and Total Phosphorus (TP) of 0.3 mg/L. The combination of both technologies allows extending the treatment capacity of the plants within a limited footprint to improve and preserve the surface water receiving body. In addition, MBR technology provides an excellent water quality, which is used by ancillaries in the entire Achères plant as industrial water.

The Chapultepec Mexico City MBR project (15 MLD; 105,000 PE) implements Indirect Potable Reuse scheme using UFMBR for multipurpose water reuse. UFMBR is combine with UF-RO-UV for groundwater recharge.

Drip irrigation biofouling with treated wastewater: Influence of hydrodynamic conditions on microbial communities and pathogen persistence

Kévin Lequette, LBE, Univ Montpellier, INRA, Narbonne, France; Nassim Ait-Mouheb, IRSTEA, Montpellier, France; Nathalie Wéry, LBE, Univ Montpellier, INRA, Narbonne, France

Context: Clogging of drip-irrigation systems supplied by with Treated wastewater (TWW) results in the association of chemical, physical and biological phenomenon (Rizk et al., 2017). The clogging is closely related to the flow along the labyrinth channel of dripper. In the literature, this flow along are described as turbulent flow and heterogeneous: a main flow with high velocity in channel center and vortex zones at the labyrinth corners (Ait-Mouheb et al., 2018; Al-Muhammad et al., 2016). This flow behaviour influences the biofilm development kinetics (Zhou et al., 2014) and also the microbial community of biofilm (Besemer et al., 2007). In addition, a previous study indicated the presence of health bacteria of health interest in dripper biofilms supplied by treated wastewater (unpublished results). The objective of this study is to better understand the effect of flow conditions on the biofilm development and on the microbial communities in drippers fed by TWW. The biofilm fouling mechanisms were studied using Optical Coherence Tomography method (OCT) and by characterizing the associated microbial communities by qPCR and by high throughput sequencing (MiSeq Illumina). Quantification of bacteria of health interest (e.g. *Legionella*, *Escherichia coli*) was performed to evaluate the effect of hydraulic parameters on the accumulation of these bacteria in biofilms.

Methods: A drip irrigation system at lab scale has been set up with commercial flat drippers (1, 2 and 4 $L.h^{-1}$, Figure 1) having different hydraulic parameters (inlet Reynolds number, shear stress, flow rate, channel dimension). The drip irrigation system was supplied by treated wastewater with a frequency of twice a day during one hour. The total measurements period was equal to 4 months. The drippers were introduced in a transparent tube allowing an optical access along dripper channel and the experiment period.

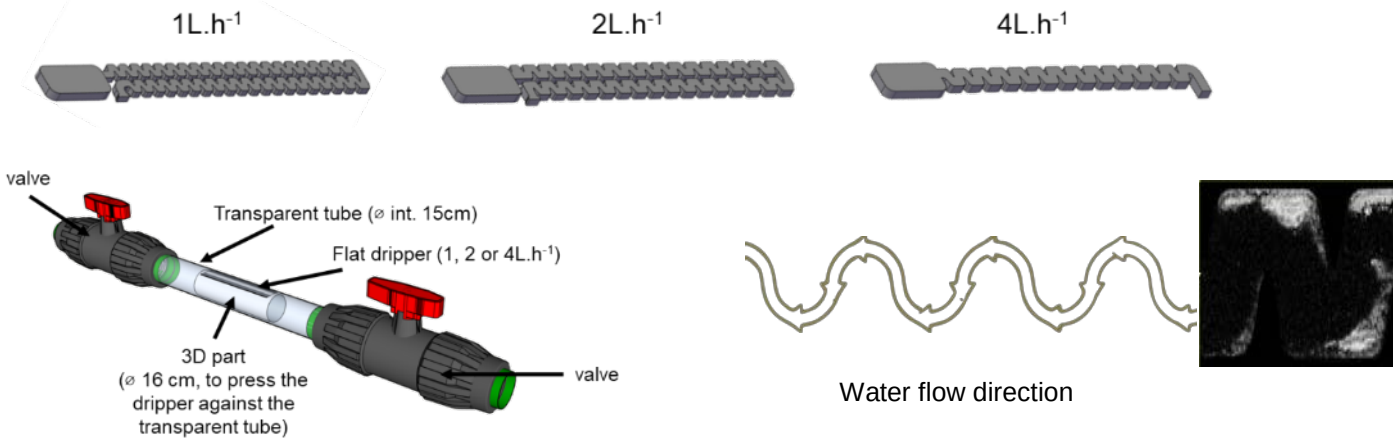


Figure 1 Commercial flat drippers (top), the dripper system allowing the optical access (bottom-right) and an OCT-scan (xy scan following z axis) of the first baffles of a 4L.h^{-1} dripper after 4 months (bottom-left). The biofilm is represented by the white-grey part.

Results: First, the biomass quantity of dripper biofilms, represented by DNA concentration, increased with irrigation events between the 3 drippers (dripper flow rate: 1L.h^{-1}:325±48, 2L.h^{-1}:387±164, 4L.h^{-1}:346±34 ng DNA/dripper, Figure 2). Secondly, using the OCT method, the measurements showed that the biofilm growth are delayed in time with increasing the dripper flow rate and the biofilm appeared mainly at the inlet channel and in vortex zones of first baffles. The lower water velocities and the decrease of shear stress in these areas can promote the biofilm growing. Finally, in comparison between 3 flow topologies, the biofilms in the 1 L.h^{-1} drippers appeared more porous, with fragmented parts whereas density of biofilms in drippers 2 and 4 L.h^{-1} were higher. Microbial analysis, *Escherichia coli* and *Legionella* spp quantification are actually in progress. These results will allow to better understand the bioclogging of drip irrigation systems, the potential accumulation of pathogens and help to improve the cleaning procedures and the dripper

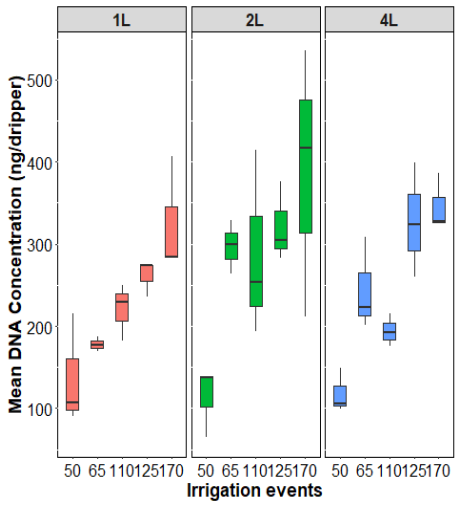


Figure 2 Evolution of the DNA quantity with the number of irrigation events for the three type of drippers

geometry to limit the clogging.

Risk Assessment Study Of Biofilm & Chlorine Stability In Recycled Water Distribution System

Andrzej Listowski [a*], Arumugam Sathasivan[b], *Long Nghiema*[a] , *Saravanamuth Vigneswaran (Vigi)*[a]

[a] *School of Civil and Environmental Engineering, University of Technology Sydney, NSW 2007, Australia.*
[b] *School of Computing, Engineering and Mathematics Western Sydney University, Sydney, Australia*

ABSTRACT:

Water used by humans should be free of any organism that might pose a health risk. Recycled water, similarly to potable water must undergo various disinfection processes before being allowed to distribution and water supply system. Water disinfection methods are intended to remove harmful contaminants such as pathogenic bacteria, viruses, helminths, and protozoa, so it is suitable for its intended use and meets required microbial standards. Most popular water disinfection methods for recycled water include: chlorination, ozonation and UV light. The efficacy of a chemical or physical disinfection process largely depends on a number of factors including; the method of application, staging of treatment process, shielding by solid particles, reactant that consume disinfectant, mixing, time of exposure and uniformity of exposure of contaminants to disinfectant. Although the process of disinfection substantially reduces the number of microorganisms, some microbes will survive and would re-grow under favourable conditions. Distribution networks apart from transporting water are also storage, a potential for continued biocidal activity and accumulation of contaminants. Consequently from the time the water leaves treatment plant, travels from the source to the consumer, its quality may significantly differ. Controlling free residual chlorine, ensure compliance with regulatory requirements and satisfying public safety needs are the most important operational requirement of the Water Reclamation and Management Scheme (WRAMS) in Sydney.

Decline in water quality in distribution network is attributed to organic and inorganic, living and dead material attached to various biotic and abiotic surfaces and forming biofilms, from which cells may be released into the water flow. The organisms in

biofilms tend to become more resistant to disinfectants, but tend to consume remaining free chlorine, can influence the colour, taste and odour of water. The presence of biofilm in water pipelines can cause a wide range of water quality and operational problems. As long as particulates in the pipe remain inert and deposited as biofilm there is no problem, however the problem rapidly arises when as a result of transient flow surges or turbulence the sediment is disturbed and mobilised, mixed with water and eventually delivered to the customer's tap.

There is no shortage of information in regard to water disinfection methods at treatment facilities or at source. However, when it comes to understand mechanisms responsible for declining disinfectant level or to employing effective methods to maintain required level of disinfectant in distribution water, information is rather scarce. This paper describes investigations of chlorine stability in recycled water system using data collected in field, analytical investigations, results of the ice pigging program, pilot-scale biofilm reactor system and water quality simulation modelling.

The decomposition of disinfectants (free and combined chlorine) in water pipeline depends on various physico-chemical and biological factors. This study relied on actual measurements and samples obtained at the outlet of the treatment plant, chlorination facility, recycled water storage, distribution network and customer's taps. The comprehensive analytical program included a wide spectrum of physicochemical parameters such as; pH, TDS, Colour (True), Turbidity, Ammonia as N, Nitrite as N, Nitrate as N, Nitrite + Nitrate as N, Organic Nitrogen as N, Total Kjeldahl Nitrogen as N, Total Nitrogen as N, Total Phosphorus as P, heterotrophic plate count at 37°C (HPC), Free Chlorine and Total Chlorine. The investigations also considered different pipe materials, pipe diameter, flow velocity, pressure distribution and time of residence.

This study concluded that the majority of bacteria in the recycled water system occur in biofilms rather than in water phase. Chlorine decay in the water system occurred mainly due to inorganic and organic compounds such as metal depositions and bacterial activities. Aquatic microbe including primary and opportunistic pathogens present in water are well-adapted to the low nutrient level and can survive in the distribution system under variable conditions. The survival time for many pathogens in biofilms is uncertain and likely varies depending on the organism.

As compared to traditional measurements, confocal laser scanning microscope (CLSM) provided differential recording of multiple biofilm parameters with their subsequent visualization and quantification. In addition, discoloured water factors such as metal deposition within biofilms including Fe, Mn were observed and the results illustrate that the discoloured water event is a common occurrence in recycled water chlorinated systems. In all the samples, organic chloramine was found to be the dominant chlorine species within the recycled water distribution system. According to monitoring data biofilms did not grow as fast as expected due to the presence of chlorine, organic chloramine, other unknown inhibitors and/or high flow rate.

The biofilm contain bacteria able to precipitate metals such as Manganese, which subsequently degrades the aesthetic water quality and contributes to the accumulation of material on the pipe walls.

Analysis of the water samples obtained from ice pigging indicate, that a desired chlorine residual was maintained through the distribution system, despite the presence of elevated HPC and turbidity concentrations.

Chlorine is an effective anti-bacterial agent; however it requires contact with the bacteria for it to be effective. Bacteria located in pipe biofilms are known to be substantially more resistant to disinfection than those in the water phase; allowing biofilm bacteria to survive disinfection processes which could be expected to kill them if present in the water phase.

The study confirmed absence of any toxic materials in the recycled water system also shown from the pigging samples, provides assurance as to the safety of the customers, and the long-term efficacy of the treatment plant and management of the system.

Reference:

1. Ashoka Mahapatra, et al (2015) Study of Biofilm in Bacteria from Water Pipelines, Journal of Clinical and Diagnostic Research. 2015 Mar; 9(3): DC09–DC11.

2. Chlorine residual boosting in distribution water, (2001) Water and Wastewater Digest, Dec 2001.

3. Thanh Que Trinh, (2017). Biofilm growth and chlorine stability in the recycled water distribution system. Master of Philosophy Thesis, Western Sydney University, March 2017

4. Andrzej Listowski (2015). Biofilm study in recycled water distribution system at Sydney Olympic Park. Internal report.
5. A Sathasivan, K C Bal Krishna (2017). Investigation of recycled water pipelines in Olympic Park for bacterial regrowth control. Internal report.

6. Toru Nagatani, et al (2008). Residual Chlorine Decay Simulation in Water Distribution System. The 7th International Symposium on Water Supply Technology, Yokohama 2006, November 22-24, Yokohama, Japan.

SHAREBOX – Developing a secure management platform for shared process resources

Nicole Heine, DECHEMA e.V., Frankfurt a.M./Germany; Georgios Chalkias, IRIS Technology Group, Castelldefels/Spain

Creating an optimum symbiotic ecosystem where companies are able to effectively and confidently share resources.

The European Project SHAREBOX develops a secure platform for the flexible management of shared process resources that provide plant operations and production managers with the robust and reliable information that they need in real-time in order to effectively and confidently share resources (plant, energy, water, residues and recycled materials) with other companies in an optimum symbiotic ecosystem.

Delivering next generation Industrial Symbiosis; a flexible resources sharing platform that identifies new synergy opportunities.

SHAREBOX, a 4-years project funded by Horizon 2020 and SPIRE will:

- Develop a secure platform for the flexible management of shared process resources.
- Bring to market a secure platform with intelligent decision support tools for the flexible management of shared process resources.
- Provide plant operations and production managers with the robust and reliable real-time information needed to optimise symbiotic connections (plant, energy, water, residues and recycled materials) with other companies in a symbiotic ecosystem.
- Enable next generation Industrial Symbiosis through the “smart” identification and realization of new cross-sectorial interactions.
- Optimise existing Industrial Symbiosis or synergies among multiple companies on a single industrial production site.

The research project receives funding from the European Community‘s Framework programme for Research and Innovation Horizon 2020 (2014-2020) under grant agreement no. **680843.**

Fluorite removal by modified activated aluminum for wastewater reuse

YungLung Chen, Ching-Yu Yang, ChihPin Huang

Institute of Environmental Engineering

National Chiao Tung University, Hsinchu, Taiwan, ROC

Abstract

Treatment of fluoride-containing wastewater is traditionally treated by chemical precipitation with $CaCl_2$. However, the traditional treatment frequently accompanies with excessive residual calcium ions, resulting in membrane fouling, and is unfavorable for water recovery. Therefore, combination of $CaCl_2$ and activated alumina (AA) as a two-stage defluoridation method has been applied to improve the water recovery. Unfortunately, removal efficiency of the fluoride-containing wastewater by AA is limited due to the limitation of sorption sites; surface modification of AA is thus required to enhance treatment efficiency in problem solving. The study aimed to investigate the operating parameters using AA after the surface modification by acidification for the treatment of fluoride-containing wastewater, and to evaluate its feasibility of regeneration by NaOH. Results show that the amount of adsorbate increased due to an increase of protonation on the surface of AA after acidification with HCl or H_2SO_4. The defluorination efficiency was strongly affected by acid concentration. Both types of acidified AAs revealed better adsorption capacity with the pH ranged between 5 and 7 and reached to the equilibrium of adsorption after 2 hours. Furthermore, their removal efficiency was also affected by the surface charge of the adsorbent. Particularly, ion-type conversion or an increase of pH could result in the competition between hydroxide and fluoride ions. By regenerating with NaOH and acidified AA by H_2SO_4, the regeneration efficiency could be around 85%, and the consumption of aluminum was less than 1%. With comparison of traditional defluoridation methods, applying $CaCl_2$ and modified AA as a two-stage defluoridation could not only improved water recovery efficiency, but also saved the energy and chemicals costs.

Keyword: water **reclamation,** activated alumina, adsorption, defluoridation

The influences of biological carriers on the performance of anammox process：comparison of GAC and PVA-gel beads

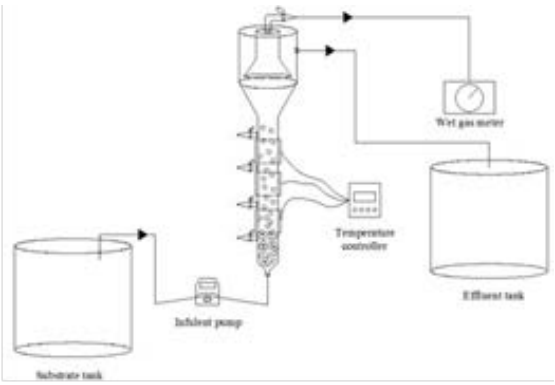
Xinying Zhang, College of Environment and Resources, Fuzhou University, Fuzhou, Fujian, PR China; Zongren Li, College of Environment and Resources, Fuzhou University, Fuzhou, Fujian, PR China; Jian Zhang, Fujian Provincial Academy of Environmental Science, Fuzhou, Fujian, PR China.

1. Introduction

Anaerobic ammonium oxidation (Anammox) is considered to be an efficient, cost-effective and environment friendly ammonium removal process. However, the extremely slow growth rates of anammox bacteria, long doubling time and harsh requirements for environmental factors, resulted in a great hindrance in the widespread application of the anammox process. In recent years, researchers have paid more attention to promoting the start-up of anammox reactor by adding biological carriers. In this study, Granular activated carbon (GAC) and PVA-gel beads as these two types biological carriers were used in anammox reactors. There are three main research aspects as follows: (1) the effects of these two types of biological carriers on the nitrogen removal performance and start-up of anammox were compared; (2) comparison on the effects of adding two types of biological carriers on microbial immobilization and microbial activity in anammox system; (3) comparison of microbial population succession in anammox systems with two types of biological carriers added. Therefore, this study can provide a theoretical basis for the selection of anammox biological carriers.

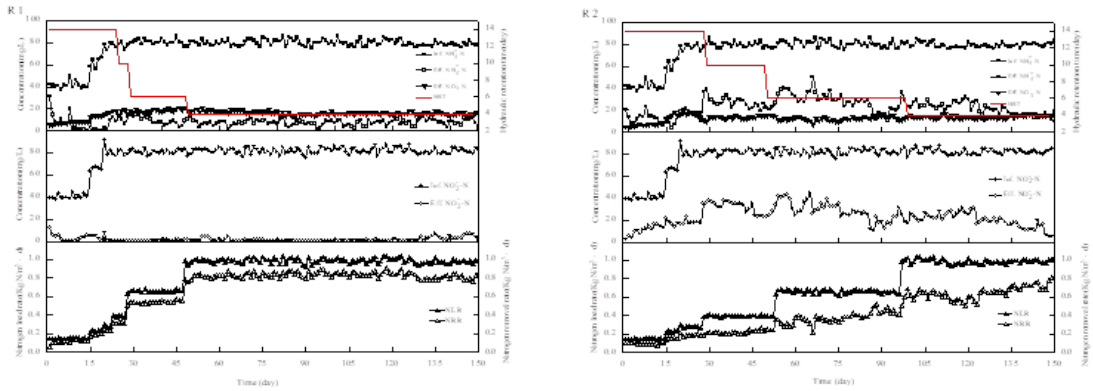
2. Material and methods

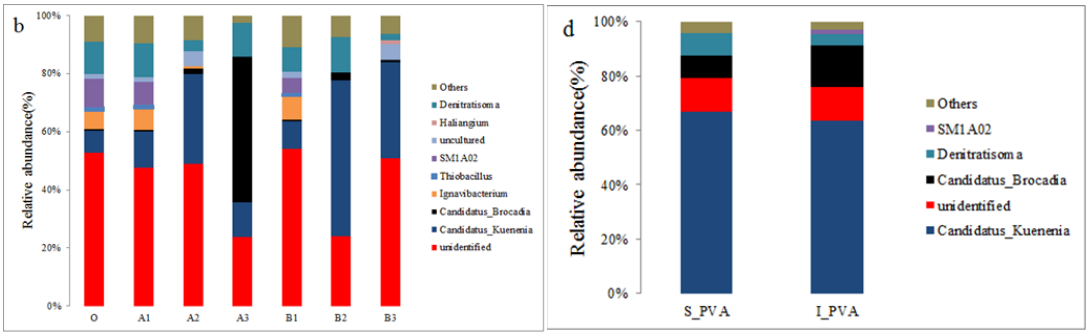
The study was conducted with two UASB reactors (R1 and R2) of the same specification.



The size distribution , specific anammox activity (SAA), hydrazine-oxidizing enzyme (HZO) activity, content of Heme c of the anammox granules were also analyzed.

3. Results and discussion





4. Conclusion

GAC and polyvinyl alcohol (PVA)-gel beads were added to two lab-scale UASB reactors with the same size (R1 and R2) and their effects on the start-up of the anammox process were compared. After 150 days of operation, two reactors have been started-up successfully and achieved high nitrogen removal performance. The results showed that GAC was helpful to the formation of granular sludge, while PVA-gel beads will sink at the bottom of the reactor under the longHRT condition, and it was not easy to attach to the anammox bacteria. *Candidatus Kuenenia* and *Candidatus Brocadia* were dominant bacteria in all sludge samples. The relative abundances of *Candidatus Kuenenia* in R2 and PVA-gel beads were 33.13% and 66.98%, respectively, while that of the *Candidatus Brocadia* was in R1 was 50.74%. Moreover, *Candidatus Brocadia* prefers to exist in granular sludge.

Assessments of recycled water sources for recreational water replenishment in urban area

Hao-Bin Chen, National Taiwan University, Taipei, Taiwan;
Tai-You Ou, National Taiwan University, Taipei, Taiwan;
Gen-Shuh Wang, National Taiwan University, Taipei, Taiwan;

Background

Due to the world wide scarcity of water resources, the utilization of reclaimed water has become one of the main solutions to water shortage and an important indicator of sustainable urban environment. Under the multiple influences of global climate change, it is also necessary to encourage the uses of recycled water and assess the feasibility and development of reclaimed water for different users. However, there are still some unsolved problems related to the potential adverse effects caused by wastewater reuses. The release of organic pollutants (and emerging contaminants) from wastewater effluent into receiving waters may induce water quality problems and concerns due to their potential health threats.

To resolve this problem, advanced treatments such as ozonation or UV/H_2O_2 have been considered as treatment alternatives in some wastewater treatment plants. However, treatment efficiency of these advanced treatment processes can be reduced by the presence of biological organics like microbial cells. For example, during the ozonation process, the concentration of organic carbon in water could be increased by 120% when treated contains microbial cells. When UV/H_2O_2 process is adopted to treat water contains cells of activated sludge or algae, results from previous study also showed that organic matter was released from the cells within the activated sludge and algae. Although those intermediate organics can be further mineralized when treatment time is prolonged enough, the concentrations of dissolved carbon and nitrogen can still be increased and lead to increases of trihalomethane (THM) and haloacetic acids (HAA) formation potentials (FP). This on-going study intends to assess the potential applications of LPUV/H2O2 and UVC-LED/H2O2 in treating biologically treated wastewater elffluents for replenishment of recreational water in urban areas.

Materials and Methods

UV/H_2O_2 process was adopted to treat the organic matters in wastewater effluents and the potentials of subsequent disinfection by-products were measured. Tested water was obtained from a wastewater treatment plant in Taipei. The UV/H_2O_2 treatments were conducted with a 5 L glass reactor, low pressure UV lamps (50000 m/cm^2/s) were used test the feasibility of LPUV/H_2O_2 process for improving quality of treated wastewater. The initial H_2O_2 concentration in the reaction was 0.025% (V/V, equivalent to 10.75 mM of H_2O_2).

Results

1. After UV/H_2O_2 oxidation and DBPFP tests, the results of this study showed that LPUV lamps combined with H_2O_2 can effectively promote the dissociation of H_2O_2 to hydroxyl radicals and mineralize the organic matter in biologically treated wastewater. As expected, the use of multi-lamp system provide higher oxidation capacity: the rate of H_2O_2 dissociation in 4-lamp systems is 1.56 times faster than 2-lamp systems in the first 60 minutes of reaction and the efficiency of dissolved organic carbon mineralization is about twice of the 2-lamp system.
2. With the increase of oxidation time, both the THMFP and HAAFP increase in the beginning stage of oxidation first and then decrease. In the first 10 minutes of oxidation, both THMFP and HAAFP rose to the maximum; the THMFP decrease after 20 minutes of oxidation, however, reduction of HAAFP need more than 30 minutes of oxidation time. This indicates that, when UV oxidation time is not enough, the intermediate organics favor the formation of HAAs after chlorination.
3. With the increase of the oxidation time, the concentrations of DBP precursors increase at the beginning stage of oxidation and then decrease. The profiles of DBP precursors during the UV/H_2O_2 processes showed that the proportion of THMs precursors was higher than that of HAAs. However, during the UV photolysis the proportion of THMs precursors decreased first and then increased again with the increase of oxidation time; as a comparison, the proportion of HAAs increased first and then decreased. After a longer contact time, the majority of DBPs precursors in water belong to the category of THMs precursors.
4. In the coming months, the authors will test the suitability of using recycled water at different environmental conditions including replenishment of treated water in a natural pond inside the NTU campus. The changes of pond water qualities will be monitored. In addition, UVC-LED will be used in the 2nd phase study to assess the feasibility of using UVC-LED/H_2O_2 system for water quality improvements. .

Indirect methods based on stochastical modelling for peracetic acid decay estimation in wastewater

Jacopo Foschi, Riccardo Delli Compagni,
Matteo Cascio, Andrea Turolla, Manuela Antonelli
Politecnico di Milano, Dep. of Civil and Environmental Engineering, Milano, Italy

Introduction

Optimal control of wastewater disinfection, aimed at ensuring system reliability to minimize microbial risk, is essential in case of wastewater reuse. When peracetic acid (PAA) is used as disinfectant, natural loss of reactant occurs, with dependence on the wastewater matrix characteristics [1,2]. An accurate description of PAA decay in a specific wastewater matrix is usually carried out by laboratory experiments. In the present work, two indirect methods based on stochastical modelling for PAA decay estimation are explored, as effective, simple and fast alternatives to direct characterization. Both methods are based on monitoring data collected from the disinfection reactor. The final goal is to provide proper tools for real-time control.

Materials and methods

Two different methods to estimate PAA decay are developed using a pilot-scale disinfection reactor fed with secondary effluent in a WWTP (500,000 PE) located in the area of Milan (Italy), whose disinfection section is used for full-scale validation.

The first method is designed for the real-time estimation of PAA decay kinetics. The disinfection contactor is an open-chicane reactor, equipped with a probe for residual disinfectant measurement. A particle filter (PF) [3] has been developed, which continuously updates the PAA decay kinetic parameters estimation relying on the measurements of PAA residual concentration. Moreover, the *a-posteriori* probability density function of the estimates is computed, according to a Bayesian approach.

The second method aims at estimating PAA decay from bacterial counts in the disinfected effluent. The tool relies on the Integrated Disinfection Design Framework (IDDF) [4] as estimator of disinfection performance, given a hydrodynamic model of the contactor and a dose-response relation for bacteria inactivation. Through the IDDF model, the backward operation of PAA decay estimation is performed as a function of the outlet bacteria concentration and operating conditions of the process. The uncertainty of the estimator is accounted by a Monte Carlo approach.

Results and discussion

Firstly, the validation of the PF as a real-time estimator of PAA decay kinetic parameters has shown positive results. As reported in Figure 1a, the PF can follow the parameter trend accurately, also providing time-varying confidence bounds of the estimation. In detail, the *a-posteriori* probability distribution function of decay rate is provided at each time. Secondly, bacterial counts data resulted as a promising indirect way to estimate PAA decay during disinfection contact time. The IDDF model has been operated backward and an example result is reported in Figure 1b. The average lost PAA dose over the disinfection contact time has been estimated and, via Monte Carlo approach, the uncertainty coming from the assumed dose-response curve and variability related to operating conditions has been effectively propagated.

(a) (b)

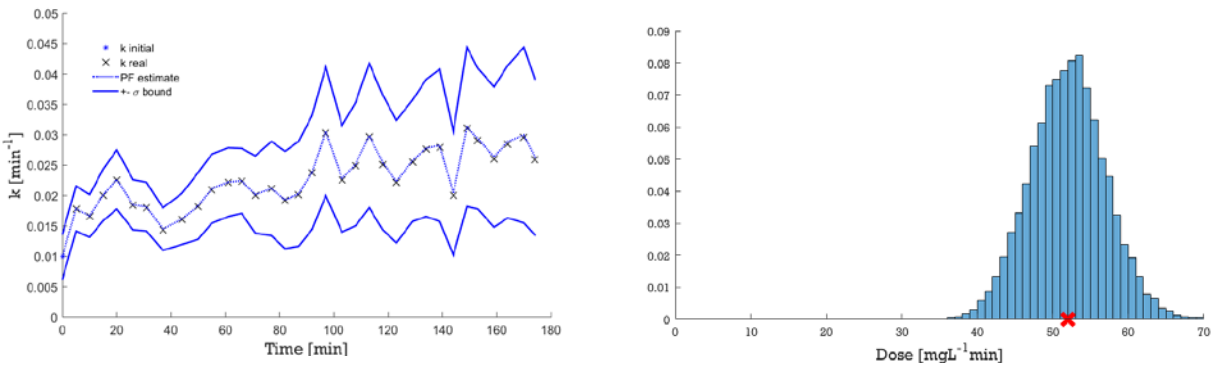


Figure 1 Time trend of PAA decay rate (k) and PF estimation (a).
Example of loss of PAA dose estimation (52 $mgL^{-1}min$) resulting from an observed 2.5 log reduction (b).

Conclusions

Two effective, simple and fast tools for indirect estimation of PAA decay have been proposed as support to PAA disinfection control. These innovative methods allow the exploitation of both real-time monitoring information from installed sensors and existing databases about bacteria inactivation on wastewater effluent. The presented efforts move towards a better integration of available data into the disinfection process control in the view of facing the current challenges for wastewater reuse.

References

[1] Domìnguez Henao L., Delli Compagni R., Turolla A., Antonelli M., Influence of inorganic and organico compounds on the decay of peracetic acid in wastewater disinfection, Chemical Engineering Journal 337 (2018) 133-142.

[2] Domìnguez Henao L., Cascio M., Turolla A., Antonelli M., Effect of suspended solids on peracetic acid decay and bacterial inactivation kinetics: Experimental assessment and definiition of predictive models. Science of the Total Environment 643 (2018) 936-954.

[3] Baraldi P., Cadini F., Mangili F., Zio E., Model-based and data-driven prognostics under different available information, Probabilistic Engineering Mechanics 32 (2013) 66–79.

[4] Bellamy W.D., Finch G.R., Haas C.N., Integrated disinfection design framework, AWWA Research Foundation and American Water Works Ass., 1998.

Efficient aeration for biological wastewater treatment

S.F. Reinecke[1], E. Mohseni[1], R. Herrmann-Heber[1], U. Hampel[1,2]

[1]Helmholtz-Zentrum Dresden-Rossendorf, Germany; [2]Chair of Imaging Techniques in Energy and Process Engineering, Technische Universität Dresden, Germany

Introduction:

In developed countries wastewater treatment is responsible for about 1% of the total electric energy consumption, where deep tank aeration in the activated sludge process uses up to 80% of the total energy budget. However, mass transfer and mixing are still the limiting factors for the energy efficiency of biological wastewater treatment (Wang, et al. 2010). The bubble size is of a great importance for the mass transfer efficiency. It determines the surface area to volume ratio, which affects the volumetric oxygen transfer coefficient k_La and the oxygen absorption. The optimum diameter of bubbles in the typical aeration tanks is known to be between 0.75 and 1 mm to achieve 95% oxygen absorption from the bubbles (Motarjemi and Jameson 1978). However, the bubble size of conventional fine-bubble aeration systems is between 2 and 5 mm (Hendricks 2016) which results in a limitation of the oxygen absorption from the injected air bubbles below 50% (Mohseni, et al. 2019).

Toward increasing the efficiency of the aeration process, we propose two approaches. First, we suggest optimum diffuser concepts following the goal of bubble generation in the optimal range. Therefore, we studied the initial gas dispersion performance of diffuser concepts based on micro-orifices and needles with very fine orifice diameters in the range from 37 µm to 225 µm (Mohseni, et al. 2019). Our study revealed that micro-orifices generate significantly smaller bubbles (see Fig. 1), and thus an up to 22% higher oxygen absorption at up to 51% less power demand (see Fig. 2). However, it was observed that small initial bubbles with diameters below 1 mm coalesce to bigger bubbles right above the orifice. A controlled bubble formation shows further potential to prevent the bubble coalescence and achieve optimum bubbles.

Ideal dispersion of the generated bubble swarms in the bulk liquid by dynamic aeration is part of the second approach to further improve the mass transfer efficiency. We investigated the mass transfer of pulsed aeration modes in comparison to constant flow aeration in a test geometry in a numerical study. An increase of oxygen mass transfer rate by up to 24% and a potential reduction of the

gas flow rate by 16% is determined compared to continuous aeration. Thus, air demand in compression and energy consumption can be reduced when dynamic aeration is applied. The intended combination of both approaches will be evaluated in further experimental investigations.

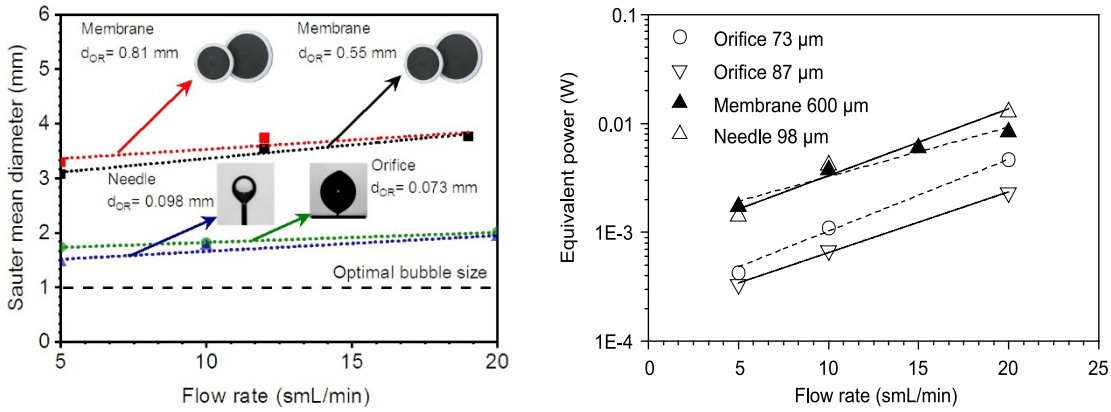


Fig. 1 Performance of micro-orifices, needles and industrial rubber membrane diffusers (Mohseni, et al. 2019): (left) bubble Sauter mean diameter and (right) equivalent power demand to compress the air per orifice.

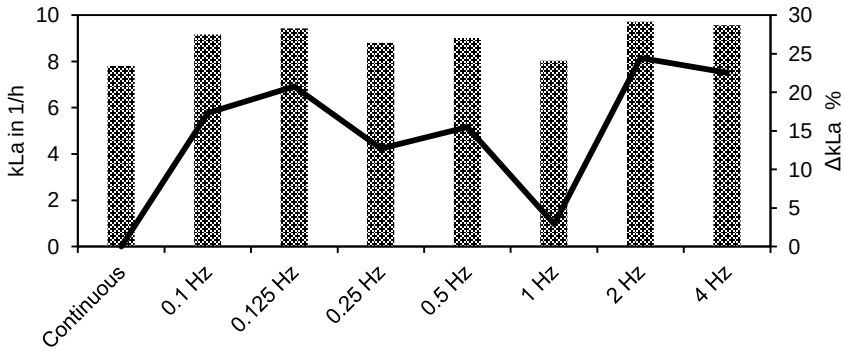


Fig. 2 Comparison of volumetric mass transfer coefficients (bar chart) its relative changes (line plot) for continuous aeration and dynamic aeration.

References:

Hendricks, D. (2016). Fundamentals of water treatment unit processes: Physical, Chemical, and Biological, CRC Press.

Herrmann-Heber, R., et al. (2018), "Dynamic Aeration for Improved Oxygen Mass Transfer and Mixing in the Wastewater Treatment Process", IWA World Water Congress & Exhibitions 16-21 Septemberg 2018, Tokyo, Japan.

Mohseni, E., et al. (2019), "Bubble Generation by Micro-Orifices with Application on Activated Sludge Wastewater Treatment", Chem Eng Proc – Proc Int, DOI:10.1016/j.cep.2019.04.011.

Motarjemi, M. and Jameson, G. J. (1978). "Mass transfer from very small bubbles—the optimum bubble size for aeration." Chem Eng Sci **33**(11): 1415-1423.

Wang, L. K., et al. (2010). Advanced biological treatment processes, Springer Science & Business Media.

Risks of inhalation exposure of reclaimed water and toxicity removal by oxidation treatments

Yun Lu, Jinling Xue, Jinshan Zhang, Yunru Ren, Jiayang Kong, Environmental Simulation and Pollution Control State Key Joint Laboratory, School of Environment, Tsinghua University, Beijing, China

Abstract

The non-potable reclaimed water has been used in urban area for a significant amount. However, the potential health concern remains unclear. The major exposure route of the non-potable reclaimed water is from the aerosols inhalation during the applications such as car wash, garden irrigation, water fountain, etc. Since the reclaimed water contains a wide levels of endotoxins (also called LPS), which is the most potent stimulant of mammalian innate immune system, inflammation in lung was hypothesized as an adverse health issue and was tested in a mouse model.

Intensive inflammation was found in the lung after acute inhalation exposure of reclaimed water, and the polymorphonuclear cell proportion in bronchioalveolar lavage was identified as the most sensitive endpoint. To screen the main risk factors in reclaimed water, firstly large molecules or particles (>10KD) were proved to contain all the inflammation inducing abilities through molecular size-fractionation. Then different water samples from 5 different reclaimed water plants were tested, and endotoxin activities of which were proved to have significant positive correlation with inflammatory responses. The similar dose-response relationships of reference endotoxin samples with reclaimed water helped to determine the major role of free endotoxin in the induction of inflammation. Ultimately, free endotoxin was further confirmed as the main risk factor in acute inhalation exposure by excluding all other large molecules with a polymyxin B affinity chromatography. In a long term exposure, epithelial apoptosis was seen in the airway epithelial cells. High level of TNF-α and TGF-β was also observed in the lavage, and myofibroblast cells accumulated under the airway showing the sign of early fibrosis. It is noteworthy that most of the reclaimed water have higher endotoxin levels compared with the human acute exposure threshold, which suggests the necessity of regulating endotoxin for reclaimed water.

The possible treatments of endotoxin were also investigated. The reclaimed water is usually disinfected by common oxidative reagents, like ozone and chlorine,

before it reaches the end user. It was found that both ozone and chlorine could not remove the endotoxin activity of reference LPS determined by classical LAL assay. But they could partially remove the inflammation inducing ability in mice. This suggests that biochemical reaction-based LAL assay cannot faithfully measure the toxicity removal of endotoxin. Ozone and chlorine oxidized carbohydrate ring and reduced the size of LPS aggregate, which was proposed as the major cause of toxicity removal. The bacterial bound LPS has very low endotoxin activity. However, disinfection can release the LPS and increase both the endotoxin activity and toxicity, though the excessive oxidation was able to decrease the inflammation inducing ability after the initial boost of toxicity. The advanced oxidation treatment, combined UV and chlorine (UV/Cl) process, was also tested. It could remove significantly more toxicity with the higher oxidability of hydroxyl radical compared with ozone and chlorine, but was still not able to remove all the inflammation inducing ability of endotoxin. Furthermore, the reclaimed water contains dissolve organic matter, gram-negative bacteria and free endotoxin, all of which can consume the oxidants. This makes the toxicity removal even more difficult for all three disinfection treatments. Technologies other than oxidation are necessary to control the endotoxin-based health risk in the reclaimed water.

DO CONVENTIONAL WASTEWATER TREATMENT PROCESSES EFFECTIVELY REMOVE EMERGING CONTAMINANTS FOR WATER REUSE PURPOSES?

Maipato Thoola[1, 2], *Sanele Mazibuko*[1, 2], *Lakesh Maharaj*[2]

[1]*University of Pretoria, Pretoria, South Africa*

[2]*Umgeni Water, Pietermaritzburg, South Africa*

South Africa has been experiencing severe drought conditions with certain areas even classified as disaster zones. As result, there are considerations of alternative sustainable water sources including re-use of wastewater. Water re-use is considered suitable particularly in areas with limited water sources both in urban and rural settings. However, among the challenges associated with the treatment of wastewater for re-use purposes is the increasing presence of emerging contaminants as diverse chemical molecules are commercially introduced into global markets, and wider populations to improve quality of life in fields of personal hygiene, treatment of various diseases, commercial and industrial applications, and agriculture. Herein, using three emerging classes of environmental concern as a case study, their degree of removal from wastewater are examined. The ECs classes are; namely: engineered nanomaterials, antibacterials (viz.: triclosan and triclocarban), and antiretroviral drugs [active pharmaceutical ingredients used for human immunodeficiency virus (HIV) therapy] given their wide use, and rapidly increasing detected concentrations in the environment. Secondly, challenges related to effective removal of these emerging contaminants are discussed, and a set of recommendations to address the identified gaps including the development of the required human capacity with multidisciplinary approach as an attempt to support effective management of emerging contaminants are highlighted. The research programme is co-funded by the WRC and Umgeni Water.

Keywords: Antiretroviral drugs, Direct reuse, Emerging contaminants, Engineered Nanomaterials, triclosan, triclocarbon.

Fenton based advanced oxidation processes for organics removal in reverse osmosis concentrate

M.Y. Wu [1,2], Q.Q. Cai [1,2], B.C.Y. Lee [1,2], S.L. Ong [1,2] and J.Y. Hu [1,2*]

[1] **Sembcorp-NUS Corporate Laboratory, National University of Singapore, Sembcorp-NUS Corporate Laboratory c/o FoE, Block E1A, #04-01, 1 Engineering Drive 2, Singapore 117576**

[2] **Department of Civil & Environmental Engineering, Faculty of Engineering, National University of Singapore, Block E1A, #07-01, 1 Engineering Drive 2, Singapore 117576**

*: Corresponding author, ceehujy@nus.edu.sg

Abstract

Reverse osmosis (RO) has been widely applied in direct reclamation of secondary effluent in industrial wastewater treatment. Reverse osmosis concentrate (ROC) comprises 10 to 20% of the feed water volume and contains almost all the contaminants presented in the original wastewater at levels of 6 to 7 times higher. Treatment of ROC to decrease the overall chemical oxygen demand (COD) is desirable to increase the water recovery as well as to meet stringent discharge standard.

Advanced oxidation processes (AOPs) have been demonstrated as promising technologies for organics removal and biodegradability enhancement in ROC. Fenton based AOPs are cost-effective technologies for ROC treatment. In the present study, both classic Fenton and fluidized bed reactor (FBR) – Fenton were adopted. Process optimizations of the two Fenton processes were firstly conducted with batch studies, and optimum operation conditions were determined based on the COD removal in ROC. Classic Fenton and FBR-Fenton achieved similar optimum COD removal in ROC, with 37% for 1-hour classic Fenton, and 39% for 1-hour FBR-Fenton. The sludge production in FBR-Fenton was 35% lesser than that in classic Fenton process. Sludge production in FBR-Fenton was also evaluated with different bed expansion rate. Impacts of media materials used in FBR-Fenton such as granular activated carbon, sand, zeolite and plastic are assessed in terms of COD removal efficiency and sludge production. Continuous flow studies of the two Fenton processes were subsequently conducted for ROC treatment. With the optimum operation conditions determined in the batch studies, classic Fenton achieved average COD removal efficiency of 31%, and FBR-Fenton achieved 30%.

Keywords: Reverse osmosis concentrate, Classic Fenton, FBR-Fenton, COD

Treatment of phenol production wastewater with combined catalytic ozonation-biological process

L. Jothinathan [1,2], G.L. Oh [1,2], W.H. Low [1,2], S.L. Ong [1,2] and J.Y. Hu [1,2*]

[1] Sembcorp-NUS Corporate Laboratory, National University of Singapore, Sembcorp-NUS Corporate Laboratory c/o FoE, Block E1A, #04-01, 1 Engineering Drive 2, Singapore 117576

[2] Department of Civil & Environmental Engineering, Faculty of Engineering, National University of Singapore, Block E1A, #07-01, 1 Engineering Drive 2, Singapore 117576

*: Corresponding author, ceehujy@nus.edu.sg

Abstract

Modern industrial processes produce a variety of xenobiotic organics, which causes the wastewater to be largely non-biodegradable due to their recalcitrant and/or toxic nature. Direct treatment of industrial wastewater through biological system may not be possible due to inhibition or toxicity contributed by the xenobiotic compounds. Ozonation is a well-known and widely applied advanced oxidation process (AOP) for industrial wastewater pretreatment in which ozone molecules (as a strong oxidant) break down recalcitrant and toxic organic compounds into smaller molecules allowing them to be easily degraded during further biological treatment.

In this study, the phenol production wastewater was pre-treated with ozonation process followed by anaerobic and aerobic biodegradation processes. The phenol production wastewater had COD with a range of 3500 – 5500 mg/L, BOD_5/COD with a range of 0.40 – 0.50 and phenolic compounds with a range of 400 – 1200 mg/L. Ozonation batch studies were performed to compare the pretreatment efficiency of three ozonation processes, including conventional, microbubble and coupled microbubble-catalytic (GAC) ozonation processes. At 120 mins, the overall COD removal efficiency was found to be 40%, 63% and 72% for conventional ozonation, microbubble ozonation and microbubble-catalytic ozonation, respectively. Among the three ozonation processes, only microbubble-catalytic ozonation was able to achieve effective removal of organics, and it was selected as the pre-treatment technology in the continuous flow studies. Continuous combined microbubble-catalytic-biological system were operated to pretreat the phenol production wastewater, COD reduction and refractory compounds abatements were monitored throughout the entire system.

Keywords: Phenol production wastewater, microbubble, catalytic ozonation, biological process, removal efficiency

Effects of Water Matrices on Radical Distribution in the UV/monochloramine Process for Potable Water Reuse

Zhuozhi ZHONG, Ran YIN, Yingying XIANG, Chii SHANG;

The Hong Kong University of Science and Technology, Hong Kong, China

Abstract: The UV/monochloramine (UV/NH_2Cl) process, which produces hydroxyl radicals and reactive chlorine species, has emerged as an advanced treatment technology to remove micropollutants in wastewater for potable water reuse. This study investigated the effects of NH_2Cl, Cl^-, HCO_3^- and effluent organic matter (EfOM) on the concentrations and distributions of radicals in the UV/NH_2Cl process under the conditions relevant to the advanced treatment of secondary effluents. Steady-state concentrations of $HO^\bullet$, $Cl^\bullet$, $Cl_2^{\bullet-}$ and $ClO^\bullet$ increased with increasing NH_2Cl dosage. Cl^-, HCO_3^- and EfOM decreased the concentrations of $HO^\bullet$, $Cl^\bullet$ and $ClO^\bullet$. $Cl_2^{\bullet-}$ concentrations were higher in the presence of EfOM, but decreased with increasing EfOM concentration. The wastewater matrices had less effects on the degradation of micropollutants that were primarily attacked by $HO^\bullet$ and $Cl_2^{\bullet-}$.

Keywords: UV/NH_2Cl; radical distribution; potable water reuse

1 Introduction

Potable water reuse (PWR) serves an important function in alleviating the increasing water scarcity (Patton et al., 2016). Accordingly, there is increasing significance in the control of micropollutants (MPs). As a state-of-the-art strategy for MP abatement, the UV/NH_2Cl process has been found to effectively degrade MPs such as 1,4-dioxane under conditions relevant to PWR (Patton et al., 2016). However, the formation and transformation of radicals under the influence of wastewater matrices remain unclear (Patton et al., 2016). This study aims to investigate the effects of NH_2Cl, Cl^-, HCO_3^- and EfOM on the concentrations and distributions of $HO^\bullet$, $Cl^\bullet$, $Cl_2^{\bullet-}$ and $ClO^\bullet$ radicals in the UV/NH_2Cl process under the conditions relevant to potable water reuse of secondary effluents.

2 Material and Methods

The experiments were conducted at 22 ± 2 °C using a 550-mL cylindrical borosilicate glass reactor with a low-pressure UV lamp (254 nm, GPH 135T5 L/4, 10 W, Heraeus) at pH 8.8 ± 0.2. The photon flux and effective path length were determined to be 3.45 μE L^{-1} s^{-1} and 3.7 cm, respectively. NH_2Cl was prepared by slow addition of NaOCl to a $NH_4H_2PO_4$ solution pre-adjusted to pH 8.5 by NaOH addition, until a Cl_2:N molar ratio of 1:1 was reached. EfOM was obtained by solid phase extraction of the secondary effluents collected from a wastewater treatment plant in Hong Kong. Nitrobenzene, benzoic acid, phenol and 1,4-dimethoxybenzen as the radical probing compounds were analyzed using a high-performance liquid chromatography system equipped with a Waters symmetry C18 column.

3 Results and Conclusions

The degradation of four probe compounds in the UV/NH_2Cl process followed pseudo first-order kinetics. And their degradation rate constants were obtained and used to calculate the steady-state concentrations of four radicals (i.e., $[HO^\bullet]_{ss}$, $[Cl^\bullet]_{ss}$, $[Cl_2^{\bullet-}]_{ss}$ and $[ClO^\bullet]_{ss}$) using competition kinetics. Supplementary test results showed that the probe compounds were hardly degraded by UV irradiation and monochloramination alone and thus they were mainly degraded by the radicals produced. The apparent rate constants ($k_{app,i}$) thus can be expressed as: $k_{app,i} = k_{1,i}[HO^\bullet]_{ss} + k_{2,i}[Cl^\bullet]_{ss} + k_{3,i}[Cl_2^{\bullet-}]_{ss} + k_{4,i}[ClO^\bullet]_{ss}$

where $k_{app,i}$ is the apparent pseudo first-order rate constant of probe compound *i*, and $k_{1,i}$, $k_{2,i}$, $k_{3,i}$ and $k_{4,i}$ are the second-order rate constants of the compound *i* towards $HO^\bullet$, $Cl^\bullet$, $Cl_2^{\bullet-}$ and $ClO^\bullet$, respectively.

Fig. 1a shows that the concentrations of all four radicals increased with increasing NH_2Cl dosage from 5 to 15 mg/L as Cl_2. As shown in Fig. 1b, $[Cl^\bullet]_{ss}$ decreased but $[Cl_2^{\bullet-}]_{ss}$ increased with increasing Cl^- concentration. This is well explained by the reaction between $Cl^\bullet$ and Cl^- ($k = 8.0 \times 10^9\ M^{-1}\ s^{-1}$) to form $Cl_2^{\bullet-}$ (Patton et al., 2016). On the other hand, $[HO^\bullet]_{ss}$ and $[ClO^\bullet]_{ss}$ were barely affected by introducing 1-mM Cl^- but decreased when the Cl^- concentration increased to 10 and 100 mM. As for the effect of HCO_3^-, $[HO^\bullet]_{ss}$, $[Cl^\bullet]_{ss}$ and $[ClO^\bullet]_{ss}$ decreased when increasing the HCO_3^- concentration (Fig. 1c). It should be noted that $[Cl_2^{\bullet-}]_{ss}$ was not determined due to the interference of $CO_3^{\bullet-}$. As for the effect of EfOM (Fig. 1d), $[HO^\bullet]_{ss}$, $[Cl^\bullet]_{ss}$ and $[ClO^\bullet]_{ss}$ decreased with increasing EfOM concentration. Interestingly, 1-mg/L-EfOM enhanced the formation of $[Cl_2^{\bullet-}]_{ss}$ by 10.5 times, and the enhancement decreased to 4.9 and 3.6 times, respectively, when further increasing EfOM concentration to 5 mg/L and 9 mg/L. The wastewater matrices had less effects on the degradation of micropollutants that were primarily attacked by $HO^\bullet$ and $Cl_2^{\bullet-}$.

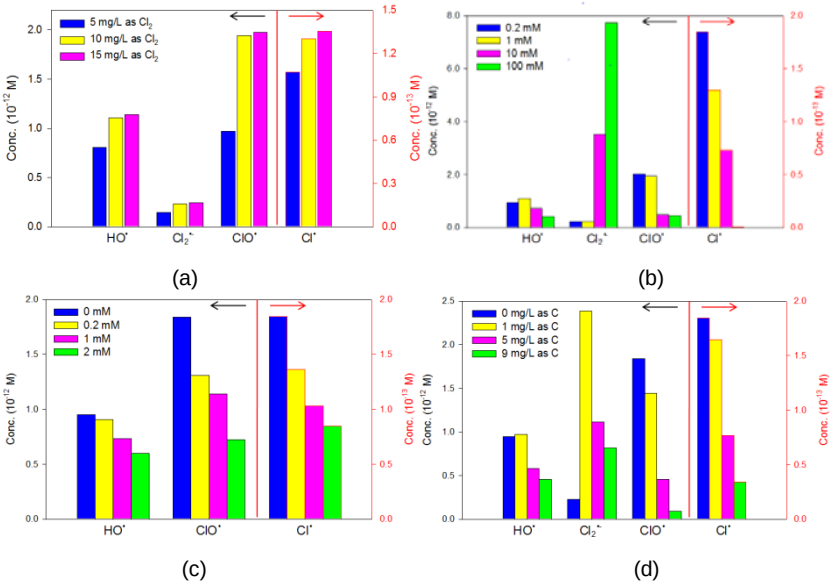


Fig. 1. The effects of (a) NH_2Cl, (b) Cl^-, (c) HCO_3^- and (d) EfOM concentrations on the radical distribution in the UV/NH_2Cl process. Conditions: pH = 8.8 ± 0.2, [NH_2Cl] = 10 mg/L as Cl_2, [Cl^-] = 0.2 mM; (a) [Cl^-] = 1 mM.

Reference:

Patton, S., Li, W., Couch, K. D., Mezyk, S. P., Ishida, K. P., & Liu, H. (2016). Impact of the Ultraviolet Photolysis of Monochloramine on 1, 4-Dioxane Removal: New Insights into Potable Water Reuse. *Environ. Sci. Technol. Lett.* **4**(1), 26–30.

Performance and Mechanisms of Ultrafiltration Membrane Fouling Mitigation in a Novel Electrochemical Membrane Reactor (EMR)

Chengzhi Hu[a, b*], Jingqiu Sun[a,b], Kai Zhao[a], Yan Liang[a], Huijuan Liu[a, b], Jiuhui Qu[a, b]
[a] Key Laboratory of Drinking Water Science and Technology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
*Corresponding author: czhu@rcees.ac.cn

Abstract

Effective strategies for fouling mitigation are highly desirable to improve the efficiency and applicability of ultrafiltration (UF) systems.[1] Applying EC as a pretreatment step is one of the promising solutions to control UF membrane fouling. The properties of flocs generated by EC have a significant influence on the structure of membrane cake layers and the extent of membrane fouling. Oxidation of HA can effectively alleviate membrane fouling due to the decrease of the molecular weight. By applying a dimensionally stable anode in an electrochemical reactor, direct oxidation would occur on the surface of the anode. In addition, if the electrolyte contained chloride ion, the chloride ion would be transformed into active chlorine and further oxidize foulants in solution. Besides, the applied electric field has also been considered as an efficient method to reduce membrane fouling, [2] which was distributed between electrodes in electrochemical system.

A novel electrochemical membrane reactor (EMR), in which electrochemical reaction (both coagulation and oxidation) were integrated into one reactor, was designed to reduce membrane fouling. The ultrafiltration (UF) membrane module was placed in the electric field zone between the electrodes in electrochemical system. EMR showed better anti-fouling performance with higher electric field due to the formation of a more polarized cake layer. The cake layer formed under higher electric field strengths showed higher porosity and hydrophilicity. Oxidation also modulated the porosity of the cake layer by breaking up humic acid (HA) molecules (i.e., carboxylic functional groups and aromatic structures). The formation of HA-floc in EC improved the hydrophilicity of the formed cake layer, leading to the enhanced alleviation of membrane fouling. Further, we proposed a novel electro membrane

bioreactor (eMBR) that coupled the electrochemical process with membrane bioreactor (MBR). The removal rate of contaminates was enhanced and the evolution of the membrane fouling was mitigated by the electrochamical reactions (electrocoagulation and electroflotation) and the effect of the electric field between the electrodes. The released iron ions effectively inhibited the evolution of membrane fouling and improved the removal rate of phosphate. The polarized cake layer under electric field on the membrane surface exhibited a higher porosity, which benefited the water permeability. The activity of the microorganism was promoted and the production of extracellular polymeric substances (EPS) were reduced due to the effect of the micro electric field.The water flux and the total phosphorus (TP) removal in eMBR was 23.1% and ~50% higher in comparison with the traditional MBR, respectively.

Keywords: Electrochemical; Electric field; Membrane fouling

References:

[1] Shannon, M. A.; Bohn, P. W.; Elimelech, M.; Georgiadis, J. G.; Mariñas, B. J.; Mayes, A. M. *Nature* **2008**, 452: 301.

[2] Fan, X.; Zhao, H.; Quan, X.; Liu, Y.; Chen, S. *Water Res.* **2016**, **88**: 285.

Visible-light-driven photocatalytic disinfection on antibiotic resistant bacteria in secondary treated effluent

Yingxue Sun, Xiufeng Yin, Chen Lliu, Yongping Ma, Ting Meng,
Department of Environmental Science and Engineering, Beijing Technology and Business University, Beijing, China

Abstract

Antibiotic resistance is an increasing concern on public health and aquatic ecosystems. Municipal wastewater treatment plants (WWTPs) have been demonstrated as an important source of antibiotic-resistant bacteria (ARB) and resistance genes to water environments. ARB have been extensively detected in the secondary treated effluent and reclaimed water ecological storage system. Recently, visible-light-driven photocatalysis has attracted extensive attention and research focus on water purification and disinfection for its high effective, economically feasible, and environmentally benign.

Visible-light-responsive graphite photocatalyst of carbon nitride (g-C_3N_4) was employed to inactivate antibiotic-resistant bacterial strains isolated form the secondary treated effluent of a WWTP in this study. Four antibiotic-resistant bacterial strains were isolated and identified as *Raoultella planticola* (NR 112011.1), *Escherichia coli* (KU 156692.1), *Escherichia coli* (NR 136472.1), *Escherichia coli* (KP 181716.1), which labeled as CIPA, CIPB, CIPD and OFLA, respectively and all presented multi-drug antibiotic resistance. Photocatalytic experiments were conducted in batch reactors under a 1000 W xenon lamp to simulate the visible light in solar irradiation. The g-C_3N_4 were synthesized with the mixture of melamine and cyanuric acid as precursors and adding barbituric acid.

The disinfection results showed that the inactivation rate of CIPA, CIPB, CIPD and OFLA were up to 0.41, 0.32, 0.36 and 0.31 log, respectively by g-C_3N_4 photocatalysis under visible sunlight irradiation (λ > 400 nm), while up to 1.26, 0.64, 0.98 and 0.64 log, respectively by g-C_3N_4 photocatalysis under UVA-visible sunlight irradiation (λ > 300 nm). The contribution of g-C_3N_4 to the visible light inactivation was 52%~63% compared to that without g-C_3N_4 catalyst, while the contribution of g-C_3N_4 to the UVA-visible light inactivation was 52%~75%.

Key words: light irradiation; visible-light-responsive photocatalyst; graphite carbon nitride (g-C_3N_4); antibiotic resistant bacteria; disinfection

Electrochemical precipitation reactor for water softening and diclofenac removal

T. Muddemann, Institute of Chemical and Electrochemical Process Engineering, Clausthal-Zellerfeld, Germany; D. Haupt, CUTEC Research Center for Environmental Technologies, Clausthal-Zellerfeld, Germany; M. Sievers, CUTEC Research Center for Environmental Technologies, Clausthal-Zellerfeld, Germany; U. Kunz, Institute of Chemical and Electrochemical Process Engineering, Clausthal-Zellerfeld, Germany

Electrochemical oxidation systems are an aspiring technology in wastewater treatment and especially reactors with boron-doped diamond (BDD) electrodes receive great attention due to the capability of the full mineralization of nearly every organic substances.

Despite the large application potential, these systems are still rarely used in sewage technology. Especially wastewater containing calcium- and/or magnesium-ions deactivates the cathode in a very short time by precipitated limestone and/or magnesium carbonate, adhering firmly on the electrode. It requires electrode-life limiting periodic decalcification strategies (e.g.: polarity reversal, addition of acids). This is unattractive for applications due to the price-intensive electrodes, which have shorter lifetimes when polarity reversal is used too often.

In the present case, this kind of precipitation was skillfully used for electrochemical softening of process water or wastewater. An electrochemical precipitation reactor was designed and investigated. Characteristic feature is the cathode side of the cell, which consist of a flexible graphite-compound (GC) cathode with a particularly smooth surface. This prevents or removes carbonaceous deposits on the cathode by periodic magnetic-induced movement and permits the electrochemical decalcification of water.

This cathode concept enables low-maintenance operation in combination with an organic-treating BDD anode or fascinates a reactor concept without a BDD, working as a pure electrochemical water softening system. In addition, the reactor enables the precipitation of further compounds triggered by a very high or very low pH value.

System, functionality and outlook

The operating mode of moving GC cathodes in combination with a BDD anode is shown in Figure 1. In addition to the BDD (or a dimensionally stable anode), the

reactor consists of a membrane and a frequency generator for cathode triggering. Two flow-fields ensure cathode movements in both directions.

Special features are the additional degrees of freedom. In addition to the classical electrochemical parameters (current, volume flow and gap distances), the movement strength and the movement profile are variable and influence the performance of the system.

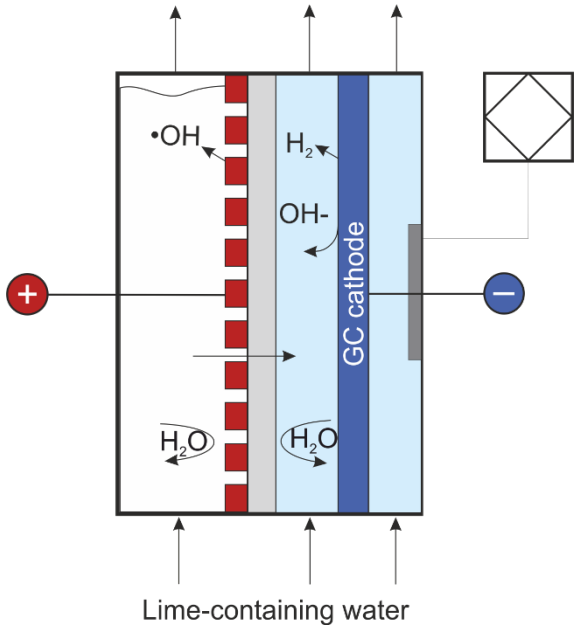


Fig. 1: Concept of the electrochemical precipitation reactor

Due to the large parameter matrix, a process parameter screening using artificial wastewater was performed to investigate the optimal operating mode.

This operating point was used to descale real wastewater and the results show that the electrochemical precipitation reactor with moving electrode is a powerful and innovative concept.

In addition to lime, other substances such as diclofenac were also successfully precipitated while the pH in the water is neutral before and after the treatment process.

Up to now, removal-rates of 70 to 95 % were achieved for water softening (44 °dH), and greater 30 % for diclofenac (50 mg/l) removal.

Due to the various optimization options, significant increases in removal-rates are expected in the future.

Removal of Perfluorooctanoic acid (PFOA) in Wastewater Using Electrocoagulation

Moon-Kyung Kim[1], Kyung-Duk Zoh[1,*],
[1]Department of Environmental Health Sciences, Seoul National University, Seoul, South Korea

Introduction

Perfluorooctanoic acid (PFOA) is a perfluorinated chemical that has been incorporated in many products such as firefighting foams, surface treatment agents, and surfactants. Due to its unique physicochemical properties such as high chemical and thermal stability, PFOA is resistant to many wastewater treatment techniques, including photolysis, biodegradation and hydrolysis (Bao et al., 2014). Therefore, it is necessary to develop effective treatment technology to eliminate PFOA from water. In this study, the electrocoagulation process with iron anode was investigated for the removal of PFOA from wastewater. We performed the experiments to examine the effects of current density, mixing speed and electrolyte concentration on the removal of PFOA. Kinetic studies for the removal of PFOA during electrocoagulation process were examined. Furthermore, we identified the inorganic and organic intermediates formed during electrolysis process of PFOA. Finally, we proposed the degradation mechanisms during electrocoagulation of PFOA

Materials and Methods

The iron plates (>99%) were purchased from a local market in Seoul, and cut into 50 × 100 × 1 mm as electrode material. PFOA was from Sigma-Aldrich. The reactor was a 0.6 L electrolytic cell with two parallel iron plates, each having a surface area of 25.0 cm^2 as submerged part. The electrodes were installed vertically in the middle of the reactor with an electrode gap of 2 cm. Before electrolysis, the electrodes were immersed in 0.1 M HCl for 1 min and then rinsed with DI water. After each run, electrode surfaces were washed thoroughly with deionized water to remove any solid residues on surfaces and dried. PFOA and shorter-chain perfluorinated byproducts were analyzed using LC-MS/MS (ABSCIEX, CA). Concentrations of ionic byproducts were determined by ion chromatography (ICS-1100, Dionex, USA) and TOC was

measured with a TOC analyzer (TOC-5000, Shimadzu, JP).

Results and Discussion

An increase in current density from 2.4 to 80.0 mA/cm^2 led to a significant increase in the removal efficiency of PFOA from 10.0 to 100.0% within 6 hours. The increase of current density might increase Fe^{2+} cation released by anode dissolution, resulting in the formation of iron hydroxide. The effect of electrolyte concentration on the removal of PFOA showed that the removal rates of PFOA increased with the increase of electrolyte concentration. Defluorination was observed by the release of fluoride ion (20%) within 6 hours while the complete removal of PFOA. Formate ($HCOO^-$) and three shorter-chain perfluorocarboxylates (i.e., PFPeA, PFHxA, and PFHpA) were also observed while 60% TOC removal was achieved during electrocoagulation of PFOA, indicating that C-C bond between C_7F_{15} was first detached during PFOA decomposition (Fig. 1). Our results imply that electrocoagulation using iron electrode can effectively degrade PFOA into shorter-chain byproducts.

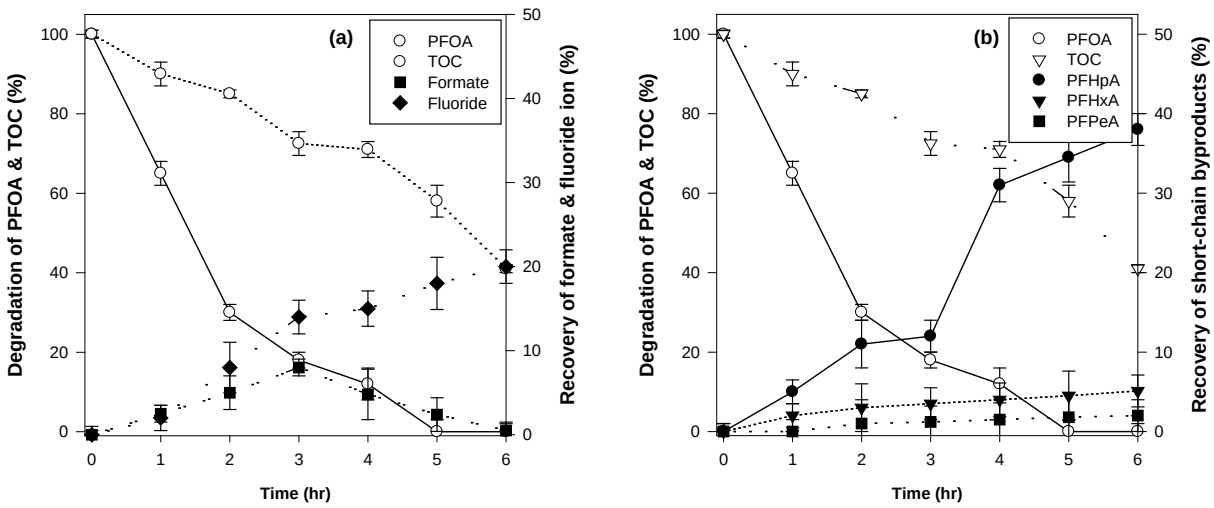


Fig. 1. Formation of (a) ionic byproducts and (b) its byproducts from removal of PFOA during the electrocoagulation process

References

Bao, Y., Niu, J., Xu, Z., Gao, D., Shi, J., Sun, X., Huang, Q., 2014. Removal of perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) from water by coagulation: Mechanisms and influencing factors, J. Colloid Interface Sci. 434, 59-64.

Wang, Y., Lin, H., Jin, F., Niu, J., Zhao, J., Bi, Y., Li, Y., 2016. Electrocoagulation mechanism of perfluorooctanoate (PFOA) on a zinc anode: Influence of cathodes and anions, Sci. Total Environ. 557-558, 542-550.

Supporting water reuse by innovative materials - BMBF Funding Measure "Materials for a sustainable water management (*MachWas)*"

Sabrina Giebner, DECHEMA e.V., Frankfurt am Main, Germany;
Katja Wendler, DECHEMA e.V., Frankfurt am Main, Germany;
Dr. Thomas Track, DECHEMA e.V., Frankfurt am Main, Germany

The funding measure "Materials for a sustainable water management – *MachWas*" of the Federal Ministry of Education and Research (BMBF) supports the research and development of materials for a sustainable water management.

Water is the most important resource for humans, nature and economy and cannot be produced or replaced by other resources. Therefore, it must be sustainably protected and managed for future generations. Primary fields of action to achieve this are the development of efficient wastewater technologies, the closing of material and water cycles, the reduction of water consumption, the elimination of anthropogenic pollutants and the better use of wastewater as a resource. Water reclamation and reuse is one of the most important water-saving strategies.

The research and development projects of the BMBF funding measure "*MachWas*" are to contribute to minimizing water consumption and maximising water availability by means of innovations and to provide effective impulses for sustainable management of water resources through new materials for water treatment and extraction technologies. The funding measure includes 13 collaborative projects involving 75 project partners in four thematic fields addressing a broad spectrum of materials:

- **Materials for membrane processes**

Membrane processes are important in water purification and treatment as well as for water reuse. Micro-, ultra- and nanofiltration as well as reverse osmosis have established themselves as alternatives to conventional separation processes in water purification and are now also regarded as key technologies for operational water cycle closure and recycling.

- **Materials for oxidative and reductive processes**

Oxidative and reductive processes focus on the elimination and immobilization of critical substances. Due to the large number of different substances usually present

in process, waste and groundwater, the selectivity of the oxidative and reductive processes is of great importance in order to enable targeted degradation in the water.

- **Adsorption materials**

In addition to filtration, adsorption plays an important role in water purification treatment and reuse. In particular, water pollution with organic, endocrine and persistent substances (e.g. pharmaceuticals and their metabolites) is of increasing concern.

- **Materials for further applications in water technology**

In order to achieve the goal of sustainable water management, material developments and processes are also promoted with the aim of reducing or removing microplastics in water cycles, coating or surface modification to reduce or avoid fouling or scaling, material developments to save and/or improve the environmental compatibility of auxiliary materials, and the development of hybrid materials or multi-purpose materials.

The accompanying network and transfer project "*MachWasPlus"* is the central contact point for the funding measure "*MachWas*" and supports the dialogue among the projects and beyond.

Innovative treatment scheme for Water reuse in the petrochemical industry

Verónica Gómez and David Arias, DOW Water Solutions, Tarragona, Spain;

Elisenda Taberna and Joan Sanz, Veolia Water Technologies, Sant Cugat del Vallès, Spain;

Carme Bosch, Montse Calderer and Xavier Martínez, Eurecat-CTM, Manresa, Spain.

Introduction

The industrial sector is a major water user, using 22% of the freshwater volume drawn in the world as well as a large hazardous waste producer subject to increasingly stringent environmental standards. Within the industrial sector, the petrochemical industry is in most world countries, the major consumer of water. As examples, this sector uses annually up to 2,725 hm^3 in Germany, 797 hm^3 in Belgium, and 201 hm^3 in Spain (Förster, 2014).

The increasing water scarcity and water pollution control in many countries have made water reuse a suitable economic means of maintaining and increasing the existing water supply, especially when compared to expensive alternatives such the development of new water sources involving dams and reservoirs. The dominant applications for treated wastewater include agricultural irrigation, landscape irrigation, industrial reuse, and groundwater recharge (Alcalde Sanz and Gawlik, 2014). Within the industrial sector, the most popular applications are for cleaning purposes and cooling towers make-up. The use of reclaimed water within the industrial sector provides economic, social and environmental benefits (Wintgens et al., 2013).

The LIFE REWATCH project proposes an on-site innovative treatment for water reuse in the petrochemical industry in the Ethylene cracker plant from Dow Chemical Iberica (DCI) petrochemical complex located in La Pobla de Mafumet (Tarragona, Spain). To face this challenge, a prototype reuse scheme includes five different technologies to constitute a completely new water treatment process in the petrochemical sector: ACTIFLO® physicochemical pretreatment (coagulation-

flocculation), AnoxKaldnes® moving bed biofilm reactor (MBBR) both Veolia technologies, DOW™ Ultrafiltration (UF), DOW FILMTEC™ Reverse Osmosis (RO) and DOWEX™ Ion Exchange Resins (IER) (Figure 1).

Figure 1. Proposed scheme for wastewater treatment and reuse.

A mixture of three different effluents from the Ethylene cracker plant from Dow Chemical Iberica (DCI) petrochemical complex located in La Pobla de Mafumet (Tarragona, Spain) is the water to be treated within this demonstration project (Figure 2).

Figure 2. REWATCH prototype already installed in DOW petrochemical complex.

Experimental Phase

Previous to the prototype operation, some lab scale test were done to confirm technologies to be used and operational modes.

Coagulation-flocculation tests were performed to remove particulate matter present in the wastewater with the aim of decreasing its possible toxic effect in the biological treatment. Actiflo® jar test experiments achieved turbidity removals of 70–85%, with an initial turbidity between 3.0 and 7.3 NTU. Final turbidity of the clarified water was

<1 NTU. After optimisation, ferric chloride dose of 30 mg/L was found to be appropriate.

MBBR is aimed to decrease the organic content of the wastewater to avoid further membrane fouling. In steady states, Soluble Chemical Oxygen Demand (sCOD) degradation percentages were kept between 80 and 90%, which implies that only 10-20% of organic matter present in the wastewater mixture was refractory to biological treatment. The calculated maximum sCOD that the tested system could degrade was 4.96 ± 0.01 kg/(m^3 d) at 23 ± 2°C. When feed wastewater was changed to raw wastewater (without Actiflo® pre-treatment) the sCOD degradation percentages were maintained at 84.5 ± 4.7 % and those percentages were also maintained when feed wastewater effluent proportions were changed to a different wastewater mixture (81.4 ± 3.1 %).

The ultrafiltration step is aimed to remove solids from the effluent to condition it for the next reverse osmosis step. DOW™ Ultrafiltration XP Fiber have proved in different contexts to offer up to 35% higher permeability in comparison with the standard fibers at 30-40% lower trans-membrane pressure with challenging waters. Considering the fouling potential of the water that will reach the UF section in the innovative scheme of the REWATCH project, DOW™ Ultrafiltration XP Fiber was defined as the best option to be installed in this section.

Two different RO elements (DOW FILMTEC™ FORTILIFE™ CR100 and DOW FILMTEC™ BW30XFR in tailor made prototype format, with a diameter of 2.5‘ and a lenght of 40‘) were tested to define the most suitable one for the treatment of the ethylene cracker wastewater. Results obtained from the side by side trial reveal that DOW FILMTEC™ FORTILIFE™ CR100 allowed decreasing the cleaning frequency in comparison to DOW FILMTEC™ BW30XFR by presenting a lower initial differential pressure and a slower evolution of this parameter over time. Considering a differential pressure trigger of 3.5 bar, the combination of this two different advantages mentioned before decreased downtime to clean, which can be directly related to less cleanings per unit of time and ultimately increasing cost savings. From the results obtained, an average reduction of a 37% in cleaning frequency was achieved, with a maximum reduction of up to 54%. Considering the water

characteristics that will be fed to the REWATCH prototype, the DOW FILMTEC™ FORTILIFE™ CR100 biofouling resistant membrane seems to be the best RO membrane available in the market to be installed in the innovative scheme under the scope of the REWATCH project.

The resins used in the experiments at bench-scale were the following: DOWEX™ MARATHON™ 1200H: Strong Acid Cation (SAC) Exchange Resin and DOWEX™ MARATHON™ A-OH: Strong Base Anion (SBA) Exchange Resin. Water quality specifications for boiler feed water (BFW) were monitored in terms of conductivity and content of iron (Fe), cupper (Cu) and silicon (Si). Operation conditions were 25ºC and 26.5 BV/h.

The prototype has been already installed in DOW petrochemical complex and will start working in the next few weeks to fulfill one year of operation.

Major impacts and benefits of the proposed reuse scheme

The key goal of the project is to decrease the freshwater consumption by the petrochemical industry leading to a more efficient use of water resources. A deployment of the REWATCH solution at industrial scale in DOW Tarragona would represent a nearly 25% reduction of their annual freshwater consumption. Additionally, to have an onsite water treatment and recycling scheme entails energy consumption savings due to the fact that water transportation is avoided.

References

Alcalde Sanz, L., Gawlik, B.M., 2014. Water Reuse in Europe. Relevant guidelines, needs for and barriers to innovation. JRC Science and Policy Reports., JRC Science and Policy Reports. https://doi.org/10.2788/29234

Förster, J., 2014. Water use in industry. Cooling for electricity production dominates water use in industry [WWW Document]. Eurostat. Stat. Explain. URL http://ec.europa.eu/eurostat/statistics-explained/index.php/Archive:Water_use_in_industry (accessed 1.24.18).

Wintgens, T., FHNW, Smith, D., 2013. Water Reuse Report. Scientific Reports.

Improvement of energy efficiency of electrochemical industrial wastewater treatment

D. Haupt, CUTEC Research Center for Environmental Technologies, Clausthal-Zellerfeld, Germany; T. Muddemann, Institute of Chemical and Electrochemical Process Engineering, Clausthal-Zellerfeld, Germany; U. Kunz, Institute of Chemical and Electrochemical Process Engineering, Clausthal-Zellerfeld, Germany; M. Sievers, CUTEC Research Center for Environmental Technologies, Clausthal-Zellerfeld, Germany

Maximizing the reuse of industrial wastewater is necessary to save water bodies, especially in regions with water scarcity. Unfortunately, the energy demand for water recycling increases with closing the water cycle due to integration of energy-intensive water purification steps such as e.g. evaporation. Therefore, the improvement of energy efficiency supports the water reuse by reduced CO_2 emissions in the water-energy nexus.

A highly promising approach is a new electrochemical reactor, consisting mainly of a boron-doped diamond electrode (BDD) as anode and a gas diffusion electrode (GDE) as cathode (Fig. 1 (B)). Besides the generation of OH radicals on the BDD's surface, a simultaneous generation of H_2O_2 on the surface of the GDE results in a double efficient use of the applied power for generating oxidizing agents. Another benefit of this electrode combination is the lowered cell voltage and consequently power consumption.

First pretests show a 20 % reduction in cell voltage for BDD/GDE (3.8 V) compared to a BDD/BDD (4.8 V) system (Fig. 1 (B) and (A), respectively).

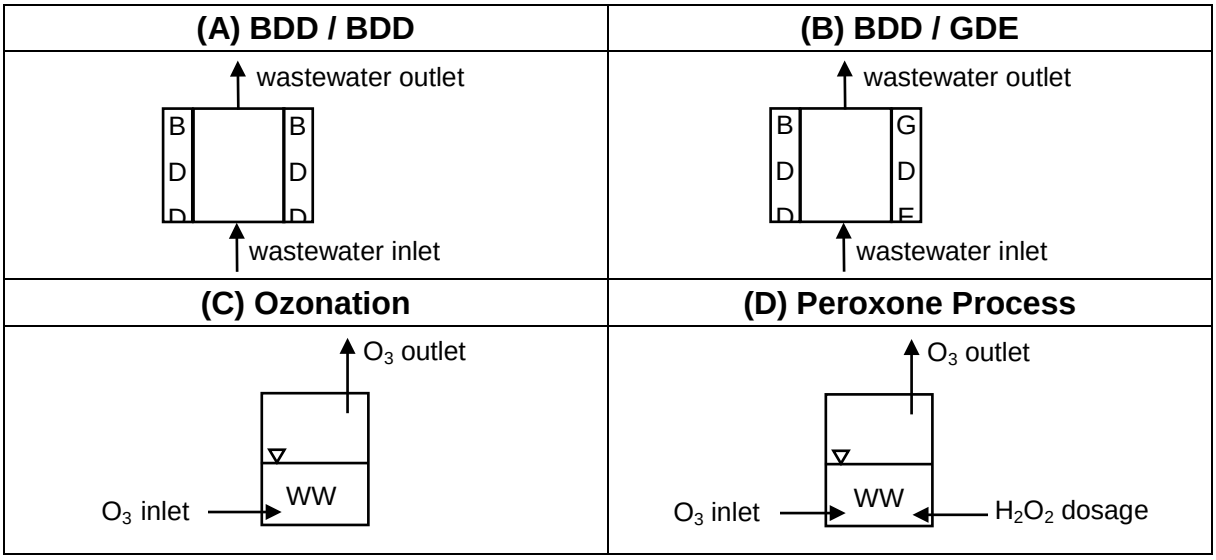


Fig. 1: Schematic of evaluated advanced oxidation processes

To evaluate this new electrochemical concept, a comparison was made between two standard AOPs – ozonation (Fig. 1 (C)) and peroxone process (Fig. 1 (D)) – regarding COD degradation and power demand. First results with artificial wastewater show that the BDD/GDE reactor performs the highest COD removal rate (38 %) within four hours, followed by peroxone process (26 %) and ozonation (17 %). The specific energy demand is the lowest for the BDD/GDE reactor (94 kWh/kg COD), followed by ozonation (125 kWh/kg COD) and peroxone process (134 kWh/kg COD). All these values are very high caused by low chemical degradability.

For that reason, the new electrochemical concept with a BDD/GDE reactor seems to be a promising approach for industrial wastewater treatment due to the reduced energy demand based on the 200 % use of the applied energy and its improved oxidation potential. Many industrial wastewaters have a high electrical conductivity, which makes it even more attractive for industrial applications as the cell voltage depends mainly on the conductivity of the electrolyte. Additionally, the required space for the electrochemical reactor is very low in comparison to other AOPs.

The electrical energy per order (E_{EO}) concept is used to quantify the energy demand of the different (E)AOPs, as it quantifies the needed energy to degrade a decimal order of a certain substance. According to Abdessamad et al. (2015) e.g. the specific energy demand for textile wastewater treatment with a BDD/BDD system is 430 kWh/kg COD, which results in an E_{EO} of 0.35 kWh/m^3. Results with model compounds and industrial wastewater will follow to evaluate the BDD/GDE system in comparison to the other AOPs.

Is Biochar adsorbent a viable option for removal of emerging contaminants from treated wastewater?

Sandeep R Yanala, University of Nevada, Reno, USA; Krishna R Pagilla, PhD, PE, BCEE, University of Nevada, Reno, USA.

Emerging Contaminants, especially, pharmaceutical and personal care products (PPCPs) are hardly removed from the conventional wastewater treatment plants and hence end up in environment causing ill effects. The goal of this work is to remove PPCPs from municipal wastewater using biochar, a low cost adsorbent, by conducting fixed-bed sorption experiments. Native biochar from slash materials of Jeffrey pine forest was hand ground and sieved to effective size of 0.25mm (sieve no. 60) by following ASTM standard (2014) before filling it in layers into the glass column adsorption set-up. Also, chemical activation of native biochar using 1N KOH was performed. Fixed-bed experiments were conducted by pumping the filtered treated effluent, collected from a wastewater treatment plant, through native biochar/KOH-biochar/granular activated carbon (GAC) that were filled in glass columns of 1 cm diameter and 50 cm length at 2.5 ml/min so as to maintain an empty bed contact time (EBCT) of 15 minutes approximately. Leaching experiments were also conducted prior to sorption experiments, using distilled water, to know the TOC leaching capacity of biochar and also to make sure leaching does not interfere with sorption results. Total organic carbon (TOC) was used as a surrogate for PPCPs present in water, difference in TOC values of influent to effluent provides for the capacity of biochar to adsorb PPCPs. It is found that the activation of biochar using KOH has significantly increased its pH to 9.74 over native biochar (pH of 7.4-7.5) whereas bulk density was around 320 mg/cm^3 and remained the same. This finding suggests that KOH, a strong base, was adsorbed on to the surface and macro, micro pores of biochar so as to alter its pH. But the amount adsorbed might not be significant enough to change its weight. Leaching experiments showed that the TOC leached by native biochar is negligible when compared to KOH-biochar. Initially, TOC leached from KOH-biochar into distilled water was as high as 215 mg/l. As a result, DI water was flushed for 32.5 hours continuously to reduce the TOC leaching to 1.3 mg/l. Fixed bed experiments for TOC removal were conducted, after leaching experiments, using native biochar, KOH-biochar and GAC separately, and

breakthrough curves were plotted. It is observed that, even though KOH-biochar removal efficiency for TOC was better at the beginning, both native and KOH-biochar reached their respective saturation capacities within 100 minutes of continuous pumping whereas GAC never reached its saturation capacity during 46 hours of continuous pumping, instead it reached C/C_o ratio of 0.15 only at the end. The saturation capacities obtained for native and KOH-biochar are 0.05mg/g and 0.13mg/g respectively. For TOC removal, the obtained values are quite low when compared to the adsorption capacities mentioned in the literature. However most of the work in literature was limited to batch experiments which are not enough for the practical operation of full scale sorption processes. Furthermore, biochar employed was generally made from controlled lab conditions which might lead to increase in its production cost. The use of commercial scale biochar along with continuous-flow system in this work are more closely aligned with real application. Surprisingly, the results obtained suggest that biochar may not be a potential adsorbent for PPCP removal contradicting the work that has been published till now. The opposing results might be due to the methodology employed or feedstock and preparation method used for the biochar. Also, as TOC was employed as a surrogate, leaching of TOC from biochar itself may interfere with the results obtained. Hence, the next phase is to test for PPCP removal from treated water. A total of 16 PPCPs are to be tested in influent and effluent of fixed bed experiments to know the adsorption capacity of each of the PPCPs by biochar. For the analysis of PPCPs, solid-phase extraction (SPE) and ultra-high performance liquid chromatography–tandem mass spectrometry (UHPLC-MS/MS) will be used. For the SPE, samples will be extracted using AutoTrace 280 automated SPE system from Dionex and 200 mg hydrophilic-lipophilic balance (HLB) cartridges. The mass spectrometry will be performed in an Agilent 6460 triple quadrupole mass spectrometer where each pharmaceutical compound will be optimized by finding its two abundant fragment ions and their respective collision energies. The results of PPCP analysis are expected to be ready to include during paper submission and for subsequent oral talk.

Water Structures & Membrane Systems
- Rising Performance with Catalytic Water Treatment -

Authors: Jan Koppe[1], Gioia Battagello[1]

MOL Katalysatortechnik GmbH, Leunastraße 6, DE-06258 Schkopau, Germany

Abstract:

Nearly every chemical process involves at least one separation or purification step. A wide range of separation technologies have been developed by engineers for facilitating the recovery of selected products. From the first scientific description of the membrane process, membrane technologies have grown from laboratory-scale systems to important industrial processes. Today, at various places in the world, membrane systems are used for saving high quality water as well as for providing potable water in challenging areas.

In every filtration and dissolving process, the water is accompanied by changes of concentrations within its structure. This influences the chemical potential and it is combined with precipitation reactions and scaling effects.

In technical applications, the combination of conventional chemicals with a suitable heterogeneous catalyst is able to reduce the risk of performance decreasing deposits. This will result in clean surfaces and a markedly raised efficiency of the whole facility. At the same time the difference pressure will decrease, the normalized flow rate will rise, and the CIP time intervals will be extended.

Benefits on customers´ facility:

- ✓ Rising life time of membranes & filter units
- ✓ Increasing performance of added chemicals
- ✓ Reducing energy consumption & minimizing maintenance efforts

This lecture will focus on the principles of membrane process and will show possibilities for making these processes more efficient and economical. After a short theoretical introduction on membrane processes, possibilities for increasing performance in industrial membrane systems will be shown together with industrial reference objects.

Water Reuse and Desalination Concepts to Increase Water Availability

Christina Jungfer; Thomas Track, DECHEMA e.V., Frankfurt a.M., Germany

With a view to water we are facing major global challenges today. Water shortages are up to date and the availability of water is already limited and regionally decreasing. Not only typical water scarcity regions are confronted with these challenges. Densely populated industrial areas, where water is needed for public water supply, agriculture and industry, can also facing water stress due to usage competition. Sufficient supply of water of adequate quality is essential for all sectors - for human physical wellbeing as well as for sustainable regional development and for an intact environment. This challenge has to be addressed globally, but solutions have to be developed and demonstrated locally.

Increasing water availability by water reuse and desalination is addressed by the actual German funding measure WavE (www.bmbf-wave.de/en). With a funding volume of around 30 mio Euro, interdisciplinary teams of water users and supply, research and practice are working in 13 application oriented joint research projects. Aim is to develop future-oriented technologies and management concepts to increase water availability and decrease dependency of fresh water resources from different sectors. With the intention to provide references for the implementation in Germany and abroad the projects are addressing three thematic areas:

Reuse of treated municipal wastewater

Depending on the scenarios on focus, multiple reuse routes are addressed in this thematic area, each having the application in mind. Technologies and management concepts are under development. With flexible process chains different water qualities and quantities can be produced for variable applications in different sectors. A multibarrier treatment process concept based on sequential aquifer recharge is created. For application in agriculture hydroponic systems process engineering solutions are developed using treated municipal wastewater. Further an integrated system solution generates irrigation water via wastewater ponds.

Reuse of water in industry

Several industry sectors are addressed to identify technology and management solutions for direct application: reuse of wastewater in mining industry, extended

cooling water circuits in steel industry, utilisation of problematic process and wastewater from oil/gas and ceramics industry, recycling of saline process water in chemical industry, or recycling water of pre-treatment and dip painting facilities in automotive industry. Beside that, solutions for cross-sectoral issues are on focus, including the management concepts for water reuse in industrial parks and for the treatment of concentrates.

Use of saline ground- and surface water

Technology solution are being provided also for saline ground and surface water e.g. in coastal regions. Efficient membranes with reduced fouling potential are under development to improve the treatment of groundwater. Energy efficient treatment combinations are being developed by using modular concepts for salt and arsenic removal of saline groundwater.

Cross cutting topics are also addressed, e.g. the risk management in water reuse or the management of salts and residuals.

The funding measure WavE is financed by the German Federal Ministry of Research and Education (BMBF) within the focal topic “Sustainable Water Management” as part of the framework programme “Research on Sustainable Development”.

An innovative bioreactor for sustainable industrial wastewater treatment finalized to water reuse and resource recovery

M. Concetta Tomei[1], *Domenica Mosca Angelucci*[1]

[1]*Water Research Institute, C.N.R., Monterotondo Stazione (Rome) Italy*

Introduction and objectives

Many industrial wastewater are characterized by high concentrations of inorganic species and toxic organic molecules, making challenging their biological treatment due to strong inhibition of their constituents on the biocatalysts. Well acclimatized cultures and powerful technologies are required. Two-Phase Partitioning Bioreactors (TPPBs) have been proven to be an effective platform for xenobiotic removal. Main feature of TPPBs is to partition toxic concentrations of xenobiotics from a cell-containing aqueous phase by means of an immiscible phase (organic solvents or granular polymers) and to deliver these substrates back to the cells because of metabolic demand. In this study, we tested a novel configuration of a TPPB operated with a polymeric tubing as an extractive membrane bioreactor (EMB), thus able to achieve, besides the gradual delivery of organic substrates, the additional benefit of separating the "hostile" wastewater from the biomass. Objective of the study is to demonstrate the feasibility of the tubing-TPPB for the treatment of toxic wastewaters: it was applied to the treatment of tannery wastewater and hyper saline wastewater under severe loading conditions. In the first case, from the biologically treated wastewater valuable metals can be easily recovered and reutilized in the production cycle. Similarly, in the second case, the concentrated salt solution can be reused as brine in the production process.

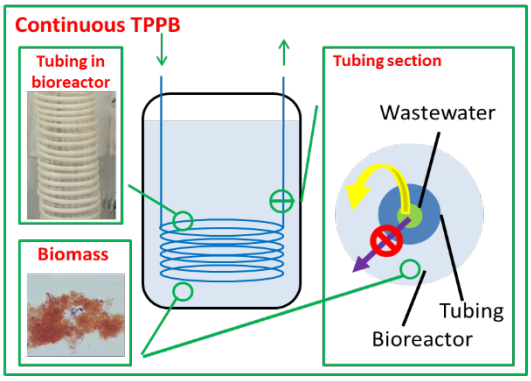


Fig.1 Schematic representation of the tubing-TPPB.

Bioreactor and principle of operation

In the tubing-TPPB (whose schematic representation is shown in Fig.1), the wastewater flows inside the tubing, and the organics move across the tubing walls toward the bioreactor side where their biodegradation occurs. This configuration is suited to treat "hostile" industrial wastewaters characterized by high salinity, extreme pH

values, and toxic inorganic species, along with organic contaminant(s), in that only organics will diffuse through the polymer to the microbial phase while ionic species like metals and salts are retained inside tubing.

Experimental

Synthetic tannery wastewater consisted of a solution of 1-2.5 g L^{-1} of 4-chlorophenol (4CP) and potassium dichromate (as source of Cr) to give a Cr concentration of 100 mg L^{-1}. High saline wastewater was prepared with an aqueous solution of 2,4-dimethylphenol (DMP) (1.2 g L^{-1}) added of NaCl (100 g L^{-1}). Polymer tubing made of Hytrel 8206 and G3548 (DuPont, Canada) (length 3.5-5.5 m) was employed as the partition phase for tannery and saline wastewater testing respectively. Mass transfer (MT) and biological (BT) tests were performed with continuous tubing feed and lasted 24h. The bioreactor (work volume of 2-4 L) was equipped with a magnetic stirrer, an oximeter to control dissolved oxygen concentration (3-4 mg L^{-1}) and a thermostat (temperature controlled at 27 °C).

Results and conclusions

A summary of the results is shown in Fig. 2. MT tests, performed to investigate the mass transfer of organic and inorganic molecules across the tubing walls, demonstrated the almost complete transfer of organics trough the polymer tubing after 24 h (Fig.2). No dichromate and NaCl transfer occurred, since the inorganics were completely recovered in the tubing effluents, with negligible (<3%) differences between influent and effluent concentrations. This finding was also confirmed in all biotic tests, with excellent removal efficiencies (>99%) of target organics (both 4CP and DMP) and simultaneous separation of the inorganic species. This selective removal was obtained without any contact between the biomass and the polluted stream flowing inside the tubing. The system achieved biodegradation efficiencies within the range of 89-92% in 24 h, while the fraction retained by the polymer itself has been always <

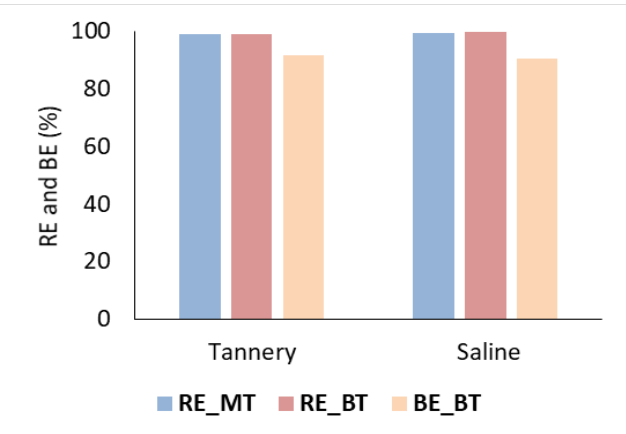


Fig.2 Overview of the removal (RE) and biodegradation (BE) efficiencies at 24 h obtained in MT and BT tests for the organic compounds.

1-6 % of the fed amount, so demonstrating that the effective biodegradation of the organics transferred across the polymer walls and not only the sorption took place.

Nitrate removal from secondaty effluent using solid-phase denitrification process with external microorganisms

*Wei QIN and Xianghua Wen**

School of Environment, Tsinghua University, Beijing 100084, China

Email: qinweistory@126.com

1. **Introduction**

Nitrogen is an important pollutant which results in water eutrophication and environmental pollution. While the reused water, as the major recharge sources to urban rivers, still contents a large quantity of nitrogen due to condition limitation of different treatment processes[1]. Therefor, it is of great importance to conduct researches on advanced nitrogen removal from secondary effluent. Solid-phase denitrification is a promising approach to remove nitrate from secondary effluent. And synthetic biodegradable polymer poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) were regarded as ideal carbon sources for constant supply of reducing power and less secondary organic pollution[2]. But there are few literatures published related to models of PHBV and its corresponding structural parameter setting. In the present study, PHBV with different models were screened for the optimum carbon source and biofilm carriers firstly. Then, the denitrification potential of optimum carbon source were estimated. Finally, the effect of activated carbon fiber filled in reactor during denitrification process was explored.

2. Experimental set-up and procedures

Seven laboratory-scale denitrification reactors with columns and oblate spheroids of PHBV and activated carbon fiber/gravel as carbon source were constructed and operated to remove nitrate from the secondaty effluent. Each reactor consisted of Plexiglas with an effective volume of 0.5 L. Reactors were fed with synthesized secondary with nitrate concentrations of 10-25 mg/L, and were operated at hydraulic

detention time (HRT) of 90-20 min for 100 days after inoculated with anaerobic sludge for three days. These reactors were divided into eight treatment groups as listed in Table 1.

Table 1 Experimental set-up used for denitrification studies

Groups	PHBV				Activated carbon fiber		Gravel	
	3001	A1	A2	3020	bottom	top	bottom	top
G1	+				+	+		
G2		+			+	+		
G3			+		+	+		
G4				+	+	+		
G5				+	+			+
G6				+		+	+	
G7				+			+	+

3. Results and Conclusions

1. Judged by nitrate removal, among the four tested PHBVs, PHBV 3020 exhibited the highest nitrate removal efficiency, then PHBV A2 and PHBV A1, PHBV 3001 was the worst. The nitrate removal of PHBV 3001 and A1 were below 50% at a HRT of 90-60 min; PHBV A2 was 60%-95% at a HRT of 60-30 min; PHBV 3020 was above 98% under the same conditions. A major reason of poor results of nitrate removal by 3001 and normal A1 was lower concentration released dissolved organic carbon.

2. The reactor filled with PHBV 3020, as the optimum carbon source, was operated at HRT range of 60-20 min, corresponding to nitrate loading rate of 0.3-1.7 kg•N/m3•d for 60 d. The data suggested that denitrification rate of PHBV 3020 could be 0.3-1.7 kg•N/m3•d at HRT of 60-30 min with very low nitrite accumulation (below 0.5 mg/L) during stable operation.

3. The data from G4-G7 operated at HRT of 40 min and 30 min indicated that put the activated carbon fiber in the bottom and top of the reactors played an important role for the stable denitrification performance of the reactor. The nitrate removal efficiency decreased to 80% and 50% when activated carbon fiber only be set at either thebottom or the top, and no activated carbon fiber filled, respectively. Nitrite

accumulation in the effluent was also observed accordingly.

4. References

1. L.J. Feng, K. Chen, D.D. Han, et. al, Bioresource Technology, 2017,**224**, 236-245.

2. L.B. Chu and J.L. Wang, Chemosphere, 2016,**155**, 463-470.

Ultrasonic TiO_2 solar photodecomposition and biocarbon sorption processes to remove amoxicillin and cephalexin from binary systems.

N. Ortiz. Institute of Nuclear and Energy Research – IPEN, São Paulo –Brazil presenting author T.S. Nicolau, J.P. Souza, F. Maichin. Institute of Nuclear and Energy Research – IPEN, São Paulo –Brazil A. Silva. Carbosolo Desenvolvimento Agrícola Ltda - Cietec, Av. Lineu Prestes, 2242 – USP, São Paulo - Brazil

Abstract: The cephalexin (CEPH) and amoxicillin (AMOX) antibiotics are the most indicated in the medical prescriptions in Brazil, as the antibiotics used for public health assistance and also for veterinary medicine. Nowadays Brazil is a higher protein animal producer in the world. After the metabolization, the antibiotics discharge in the sewage system and manure composition on rural areas; act as secondary pollution sources for surface water resources. The integrated processes applying the ultrasonic waves before the solar photodecomposition and biosorption showed the maximum removal percentage of 91.47% for AMOX and 90.62% for CEPH. Considering the binary systems with the 17:83 proportion percentages of AMOX and CEPH the removal percentage was 89.15% and 97.90% respectively. The use of low-frequency ultrasonic waves before the solar photodecomposition increased the TiO_2 surface area and effectiveness and enhanced the removal efficiency for both cephalexin and amoxicillin alone and in binary mixtures.

Keywords: ultrasonic waves, adsorption, titanium dioxide, solar/TiO_2, antibiotics, biocarbon, amoxicillin, and cephalexin.

Introduction

The antibiotics used in medicine started a new era for a better quality of life and public health. In spite of those results, the prescription of such pharmaceuticals formulations is mostly extensive for bacterial infections and treatment of humans and animals. The continuous release of an enormous amount of antibiotics to the environment for pharmaceuticals industries, hospitals, domestic sewage, and livestock excretion accelerate the adaptation and the bacteria resistance. The conventional water treatment methods remove only a

small portion of the antibiotics because of their non-biodegradable nature, and thus the remaining part of it runs off to surface water. The use of low-frequency ultrasound to increase the TiO_2 surface area followed by solar photodecomposition and biocarbon adsorption showed promising results as low cost, and well know treatment process and affordable material for the rural areas application.

Methods

The antibiotics standard solutions were prepared with amoxicillin and cephalexin, and diluted in different initial concentrations. The ultrasonic source application was in the time interval from 1 to 5 minutes followed by the suspension preparation using the TiO_2 anatase powder and antibiotics solutions. After that, the system was installed in a solar radiation chamber (solar lamp) with the collection of the suspension aliquots for every 20 minutes in a falcon tube with the biocarbon. The tubes were shaking and centrifuged at 1500 rpm for 15 minutes. The measurement of the supernatants was at UV – Visible Spectrophotometer.

Discussion and conclusions

The integrated process using ultrasound, solar photodecomposition/TiO2, and biosorption showed promising results for antibiotics alone systems and the binary mixture of CEPH and AMOX. The removal percentage increases accordingly with ultrasound time having 91.47% of amoxicillin and 90.62% of cephalexin as the best removal percentage using 5 minutes and 100 min in the solar chamber. All results indicate the ultrasonic application followed by TiO2/solar photodecomposition and biocarbon adsorption have better agreement with pseudo-second-order kinetics.

Acknowledgments

The National Council for Scientific and Technological Development (CNPq) by PIBIC program and São Paulo Research Foundation (Fapesp).

Using microstructured yeast as biotemplate for TiO_2 deposition applied on amoxicillin solar photodecomposition.

N. Ortiz. Institute of Nuclear and Energy Research – IPEN, São Paulo –Brazil*
presenting author
F. Maichin., M.V. Macedo Institute of Nuclear and Energy Research – IPEN, São Paulo –Brazil

Abstract: The indication of amoxicillin (AMOX) is the most frequent by the public health assistance in Brazil. After the body metabolization, the antibiotic is discharged by excretes in the sewage system; also acting as secondary pollution sources for surface water resources. The microstructured yeast culture (biotemplate) enhances the TiO_2 surface area before the amoxicillin solar photodecomposition. The maximum removal percentage was 56% of AMOX with pseudo-second-order kinetics. The use of the low-frequency ultrasonic source in the TiO_2 slurry dispersion after the yeast culture enhanced the TiO_2 surface area and its effectiveness during the antibiotics solar photodecomposition

Keywords: ultrasonic source, titanium dioxide, solar/TiO_2, amoxicillin and yeast biotemplate.

Introduction

The antibiotics discovery and their use in medicine enhanced the human quality of life and worldwide public health. In spite of those medicine improvements, the prescription of such pharmaceuticals is extense for bacterial infections in humans and animals. The massive release of these compounds in the environment is the collateral effect for pharmaceuticals industries, hospitals, domestic sewage, and livestock excretion. The presence in the environment of such compounds accelerate the bacteria resistance and the conventional water treatment methods remove only small portion due to their non-biodegradable nature, and thus the remaining part of it runs off to surface water resources.

Methods

The antibiotics standard solutions were prepared and diluted in different initial concentrations. The ultrasound application in time interval of 2 minutes applied at TiO_2 anatase suspensions followed by its addition on the yeast culture. The

Saccharomyces cerevisiae was reproduced and evaluated at its best condition using an optical microscope. After that, the culture was filtered, dried and added the ultrasonic TiO_2 to the yeast suspension. The final suspension was heated and calcined at 100°C for overnight to obtain TiO_2 molded microstructures. After the addition of the AMOX solution, the system was installed at a solar radiation chamber (solar lamp) with the collection of the suspension aliquots for every 20 minutes in a falcon tube. After shaking the tubes, became the centrifugation at 1500 rpm for 15 minutes. The measurements of the supernatants were at UV – Visible Spectrophotometer

Results and conclusions

The results of the photodecomposition kinetics studies provide valuable insights into the kinetics models: The pseudo-second-order equation (1) best fit the experimental results:

$$\frac{t}{q_t} = \frac{1}{K_2} + \frac{1}{q_e} t \qquad (1)$$

Where: K_2 is the kinetics decomposition rate, the plottering the t/qt for t (min) (Figure 1), and the calculation predicted decomposition capacity qe.

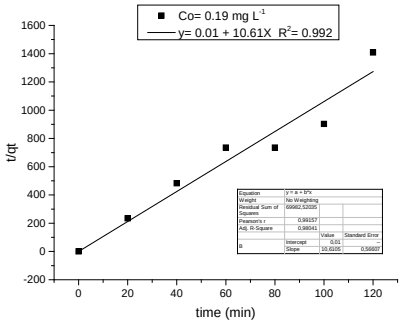


Figure 1: The pseudo-second-order kinetics

All results indicate the use of biotemplate increases the TiO_2 surface area and showed promising results for amoxicillin solar photodecomposition with the removal percentage of 56%, the decomposition rate K_2 =100 g.mg^{-1}.min^{-1} and qe= 0.094 mg g^{-1}

Acknowledgments

The National Council for Scientific and Technological Development (CNPq) by PIBIC program and São Paulo Research Foundation (Fapesp).

Ciprofloxacin degradation and CIP resistant E.faecium inactivation by UV-LED/chlorine process

*Tae-Kyoung Kim, Taeyeon Kim, Hyoin Park, Inhye Lee, Kyung-Duk Zoh**
Department of Environmental Health Sciences, Seoul National Univeristy, Seoul, Korea

Abstract

Ciprofloxacin and ciprofloxacin resistant bacteria are emerging concerns which threaten public health due to heavy antibiotic usage and resistance development of bacteria in water environment. To tackle this problem, we studied energy efficient treatment method which driven by UV-LED/chlorine process. Ciprofloxacin degradation followed the pseudo-first order kinetics, and excessive chlorine dosage have negative effect on ciprofloxacin removal rate. Alkaline pH showed the best ciprofloxacin removal efficiency compared to acidic and neutral pHs. Excessive hydroxyl (OH) radicals mainly contributed to ciprofloxacin degradation during the UV-LED/chlorine process at neutral pH, while reactive chlorine species (RCS) played a major role in acidic and alkaline pHs. The cleavage of piperazine, cyclopropyl, and quinolone moiety are considered as the principal degradation reactions. Seven byproducts, two chlorinated byproducts and two anions such as chlorate and chloroform were detected as byproducts, and these intermediates induced the evolution of acute toxicity to V.fischeri. Complete detoxification was achieved after the UV-LED/chlorine process for real wasetwater with ciprofloxacin. UV-LED/chlorine process showed the best E. faecium disinfection ability among the treatment methods. Finally, EE/O value calculated during the reaction showe the extremely low EE/O value. For these reasons, the UV-LED/chlorine process is promising in the aspect of removing antibiotics itself and antibiotic resistence bacteria (ARB).

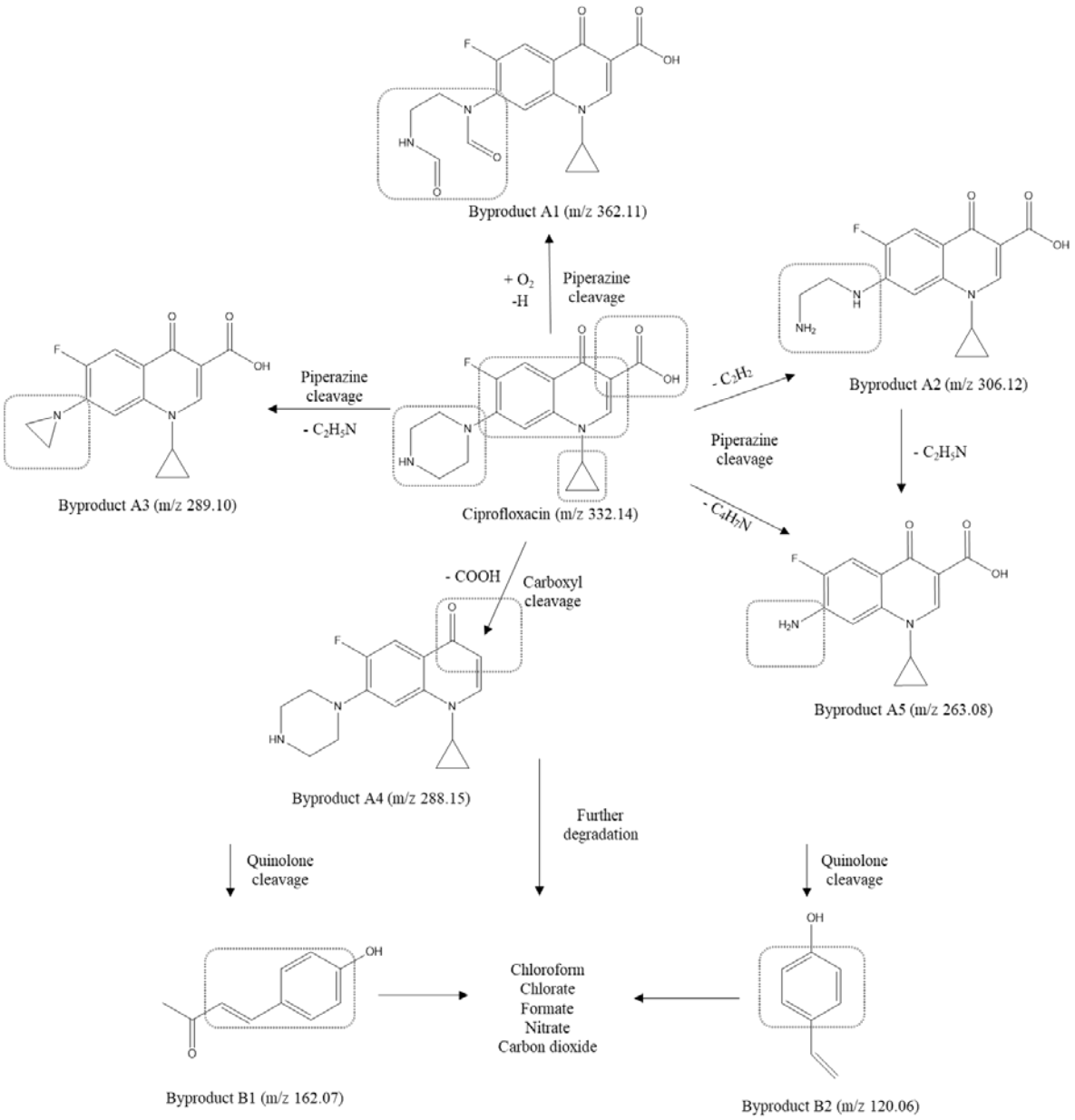


Fig. 1. Proposed degradation pathways of CIP by UV-LED/chlorine process

Hybrid systems based on ultrafiltration membranes and powdered activated carbon for advanced waste water treatment

G. Hoffmann, University Duisburg-Essen, Germany; J. Koti, University Duisburg-Essen, Germany; P. Berg, inge GmbH, Germany; S. Panglisch, University Duisburg-Essen, Germany

Introduction

Adaptation of membrane-based purification processes and/or combination with other treatment processes has been recently the focus of engineering research also in water reuse. In practice, ultrafiltration (UF) and microfiltration (MF) membranes are no longer a stand-alone process; instead, they become a part of a processing chain that is defined by the treatment objective. For instance, UF / MF membranes could be combined with powdered activated carbon (PAC) adsorption in order to achieve advanced water purification as required in water reuse, i.e. removal of organic micro-pollutants (via PAC adsorption) as well as separation of pollutants particles (besides PAC) and bacteria (via membrane filtration). Utilization of synergetic effects of such a hybrid process and scaling up from bench-scale experiments to the technical scale, taking into account the different boundary conditions, are the main objectives of this study.

Bench-scale experiments

A laboratory scale out/in MF membrane unit (provided by PALL®) operated in dead-end mode) was employed. PAC was dosed into the feed of the membrane causing the generation of a PAC layer on top of the membrane surface. For each experiment the filtration time was set to 60 min and the specific dosage of PAC to 0.7 g per m² membrane independent on the PAC dosage time which was varied from 1 to 60 min. In each case the totally dosed PAC was equivalent to a continuous dosage of 5 mg/L. Depending on the dosage time, the PAC layer was established very fast (e.g. more or less one-time dosage in 1 min) or developed slowly (e.g. continuous dosage for 60 min). Synthetic model water containing 5 mg/L diclofenac (DFC) was used as feed solution. Besides the influence of different PAC dosage times, influences of further operating parameters, e.g., average particle size of PAC (conventional vs. finely-grinded), on the efficiency of the hybrid purification process were investigated. For example, the study revealed that higher loading of the PAC could be achieved with decreasing dosing time (cf. Figure 1).

This can be interpreted by two effects: firstly, as shorter the dosage time as higher the establishment of the equilibrium concentration of DFC in contact with the face of

the PAC layer on top of the membrane surface (so called filter-effect). Secondly, shorter dosage time due to longer average retention time of the PAC. Moreover, higher PAC concentrations were revealed to form agglomerates that are negatively influencing the purification process. This can be explained by de-accelerating the adsorption kinetics by longer diffusion paths within agglomerates and/or poor distribution of PAC near the membrane surface.

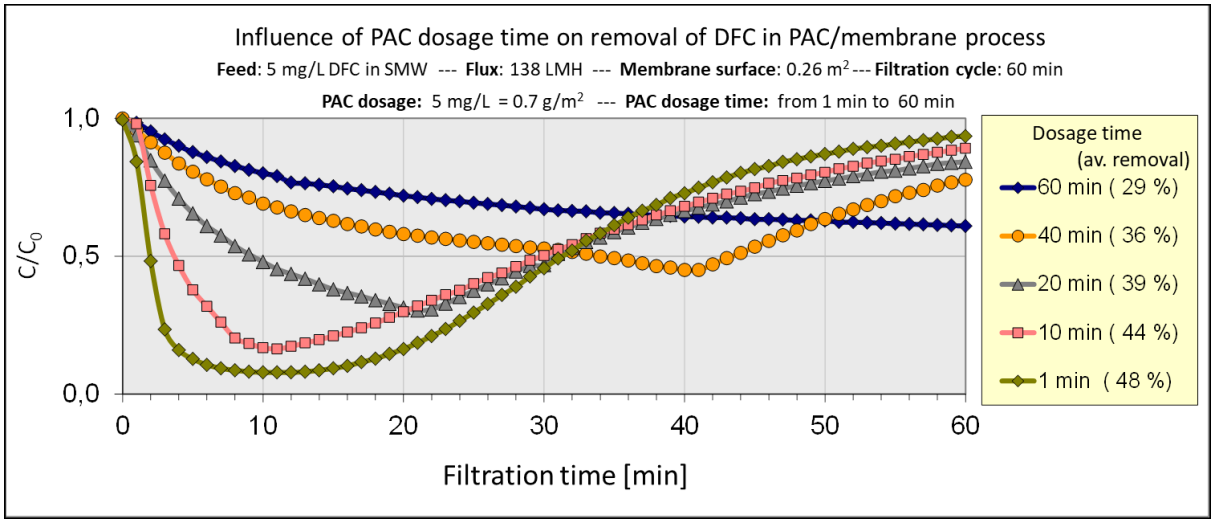


Figure 1: Removal of DFC at different PAC dosing times in PAC/membrane system

Pilot-scale experiments

The pilot study with hybrid PAC-UF system has been conducted in a technical center located at a wastewater treatment plant of the Emschergenossenschaft, Germany. Knowledge gained at the bench-scale experiments was transferred to technical scale aiming to achieve optimum removal of micro-pollutants and stable performance. The pilot unit provided by inge watertechnologies GmbH and equipped with a 80 m^2 module containing inside-out Multibore® polyethersulfone fibers has been fed with secondary effluent. The system has been operated at a flux of 60 L/(m^2.h), a filtration time of 45 min, and besides PAC dosage, with a prior coagulation step using polyaluminumchloride (4 mg Al/L). Removal of UV active matter (UV_{254}) was measured employing an online UV probe. A one-time PAC dosing was again compared with continuous dosing (see Figure 2). Generally, the commonly used equivalent PAC dosage of 10 mg/L showed a relatively low removal of UV_{254}, which might be related to the low adsorption of UV active matter. However, it can clearly be seen that no significant benefits of shorter dosing times of PAC originate under the experimental conditions. This might be attributed to the formation of agglomerates caused by dosing of PAC from a highly concentrated stock solution. Furthermore, at cycles 1 – 3, the adsorption of UV_{254} was found only during PAC addition time,

thereafter no removal of UV_{254} was seen, which was not the case in bench-scale experiments. Another reason could be the additional coagulation step which was not conducted in bench scale and might influence the adsorption process negatively. Therefore, further research will be devoted towards a more efficient and optimized hybrid water purification system.

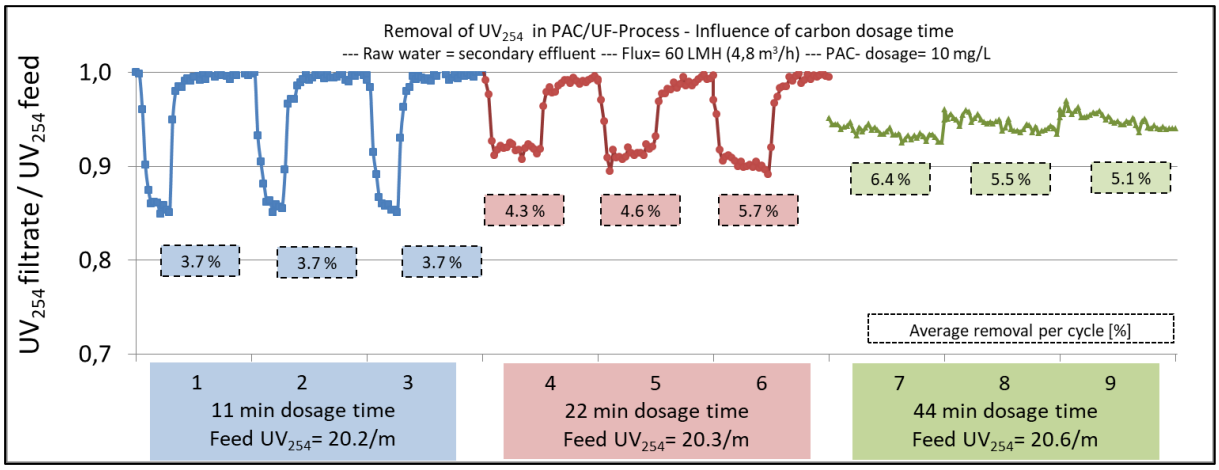


Figure 2: Removal of UV_{254} in PAC/membrane hybrid system at pilot scale

Removal of micro-pollutants and closing the water cycle using hollow fiber nanofiltration

Roberto Negrini, Robert Gerard, Erik Roesink

NX Filtration, Enschede, The Netherlands

Introduction

We see in our surface waters more and more persistent chemicals, medical residues, insecticides, pesticides, nano-plastics, anti-biotic resistant bacteria, viruses, in general so-called micro-pollutants. This forms a real treat for our environment and finally for our health. Good news is that we do see more and more "public" awareness, and several solutions are discussed here. At the one had we see that very broad one is trying to avoid, that micro-pollutants end up in the environment, but there is also a broad commitment, that we should come up with acceptable, affordable technical solutions to avoid further pollution of our environment. If we take for example residual medicines and nano-plastics, we can conclude that these end up merely in our surface waters. Since the existing sewage water treatment plants are not capable of removing these compounds, we can argue that is close to impossible to stop this problem by avoiding these compounds coming in our sewage systems. This means that we have to start seriously to treat municipal effluent, in order to avoid further deterioration of our environment. In some areas of the world, this awareness is already translated into legislation, e.g. in Swiss and parts of Germany. Most chosen technologies applied here are based on adsorption (activated carbon) or advanced oxidation (O3, UV/H2O2). In this presentation we will introduce a new, innovative, concept based upon hollow fiber nanofiltration, including smart solutions for concentrate treatment.

Hollow Fiber Nanofiltration

Already in the end of the last century at the University of Twente, hollow fiber nanofiltration membranes were developed based upon the same technology as most spiral wound reverse osmosis and nanofiltration are still produced: interfacial polymerization, leading to thin film composite membranes based upon a thin selective polyamide layer. However, as known polyamide has a very restricted chemical resistance, and the interfacial polymerization process is less suitable for thin hollow fibers. The Layer by Layer concept was intensively studied more or less in parallel at RWTH (Wessling, Menne) and a bit later at the University of Twente (J. de Grooth, W. de Vos)).

NXFiltration, a spin-off from the University of Twente, founded in 2016, is now producing on industrial scale Layer-by-layer nanofiltration membranes.

This new generation hollow fiber nanofiltration membranes demonstrate high retentions towards low molecular weight organics (micro-pollutants), but do have a relatively high passage for salts, so that low trans membrane pressures can be applied, and consequently low operational costs can be realized.

First Results

These membranes are already evaluated from the very beginning of NXFiltration on several municipal effluent streams, and demonstrate that a very stable process is possible, and a high retention for micro-pollutants can be realized. Typical results (see Figure 1.) are obtained using a pilot plant at the municipal treatment plant at Aarle-Rixtel, The Netherlands.

NXFiltration is also working on the development of an efficient method for treating the concentrate stream from the NF process. A schematic overview can be seen in Figure 2. The basic idea here is to lead the concentrate stream back into the bioreactor, in order to create more resident time in the bioreactor, but also to enable the micro-organism to adapt. To enhance biological degradation of retained micro-pollutants in the concentrate stream, ozon can be applied, and/or an immobilized bioreactor concept.

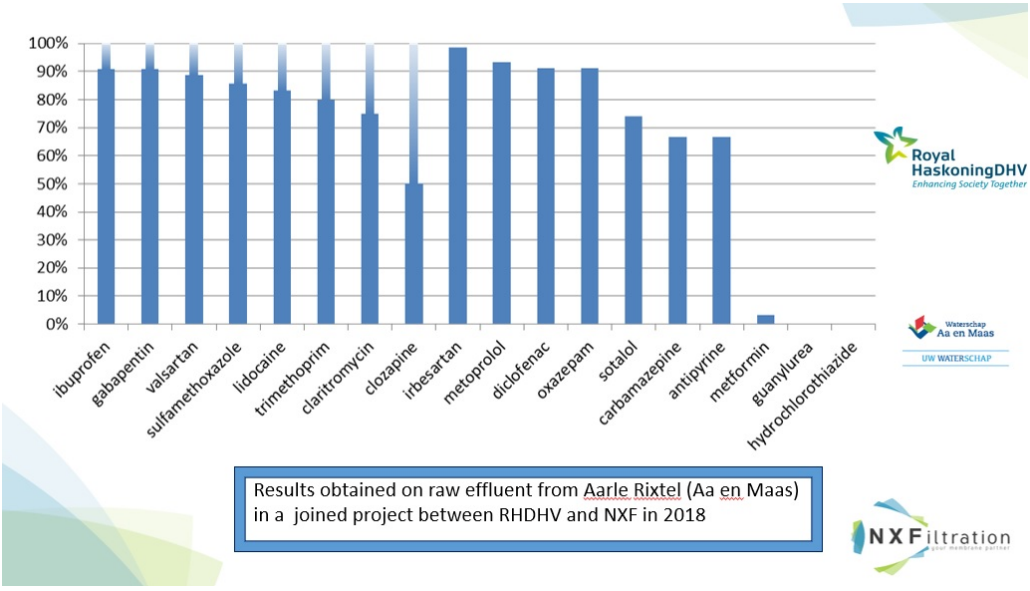


Figure 1: micropollutant removal of dNF80 membranes

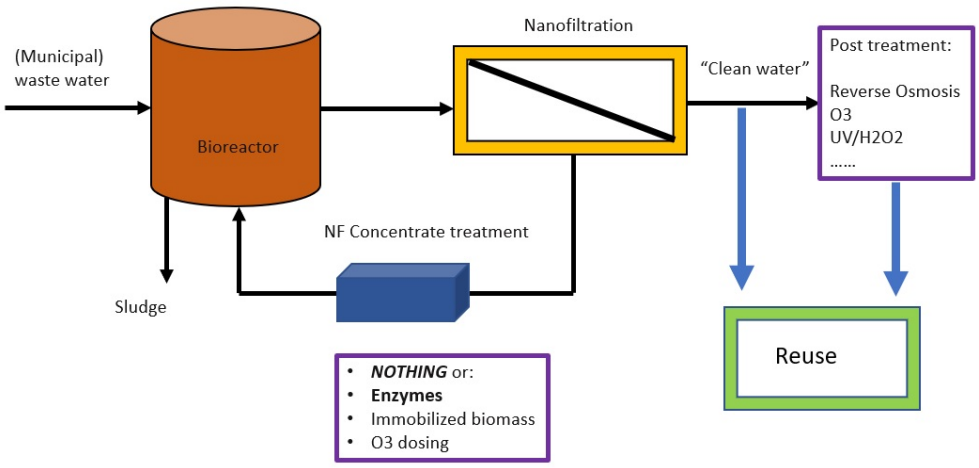


Figure 2: process flow scheme of NF concentrate treatment

Biomass and lipid production of autotrophic oleaginous *microalgae* using leachate of saline-alkali land from Shandong Province

YiTian HE[1]; Yu HONG[1,]; Xiaoya LIU, Wenping GU*

1 Beijing Key Lab for Source Control Technology of Water Pollution, Beijing Forestry University, Beijing 100083, PR China

** Corresponding Author, Email address: yuhong829908@gmail.com*

Abstract: In this study, biomass and lipid production of three oleaginous microalgae (*Chlorella* sp. HQ, *Chlorella vulgaris*, and *Scenedesmus* sp. LX1) autotrophically cultivated in leachate of saline-alkali land from Shandong Province were investigated to explore the feasibility that utilizing saline-alkali land leachate to cultivate microalgae. Results showed that the parameters including total organic carbon (TOC), total nitrogen (TN), total dissolved solids (TDS), and salinity of the leachates cultivated with these three microalgae were in different degrees of decline, which proved that leachates could be purified by microalgae and especially *Scenedesmus* caused obvious decline of TDS and salinity. All the three microalgae could grow in the leachates, among which *Chlorella* sp. HQ kept the maximal density of 1.65×10^{7} cells·mL^{-1}, and its lipid production (50.53±0.89 mg·L^{-1}) and content (50.53±5%) were much higher after 25 d of cultivation. Next, only *Chlorella* were used for leachate cultivation efficiency analysis. Two leachates with two different salinities (L1: 0.18% and L2: 0.25%), tap water, reclaimed water, and standard culture medium (SE) were all used to culture microalgae for the efficiency comparison. During cultivation, pH values of these five kinds of water were gradually increasing and finally stable at around 8. After 45 d, the order of algal density is L2(2.27×10^{8} cells·mL^{-1})>L1(1.59×10^{8} cells·mL^{-1})>SE(1.11×10^{8} cells·mL^{-1})>reclaimed water(5.99×10^{7} cells·mL^{-1})>tap water(4.27×10^{7} cells·mL^{-1}). The lipid content of *Chlorella* in L2 was 58.67±1.65% as the third lower than in tap water and reclaimed water, which might be due to nutrient deficiency in the latter two. Based on the comprehensive comparison, *Chlorella* sp. HQ was more suitable to be cultivated in leachate of saline-alkali land and the cultivation efficiency of leachate is much better than microalgal culture medium considering not only biomass but also lipid content. Hence, using leachate of saline-alkali land is promising to save cost of microalgal cultivation and synchronously the leachates can be purified.

Keywords: *Chlorella* sp. HQ, leachate of saline-alkali land, biomass, lipid content, water purification

Reuse focused water reclamation technology in urban areas: An analysis of Indian scenario

Abstract:

In a recent research finding carried out for four major cities in Gangetic plains of India, namely Kanpur, Allahabad, Varanasi and Lucknow, with the help of a decision support tool called Water for Development Planning Index (WDPI) based on Pressure, State and Response (PSR) model, it has been observed that all these cities are found in Critical condition (base year 2015), with WDPI= 3-5, on 1-10 scale (WDPI < 3: Poor; 3-5: Critical; 5-8: Fair, and > 8 Excellent). With business as usual (BAU) approach, the situation is forecasted to deteriorate further in 2030 and 2040, indicating less availability of water for development planning and increasing stress on water sector. Using the possible options of augmentation of water resources, including reduction in extra water extraction, increased surface runoff storage, rooftop harvesting through rain-tanks, rooftop harvesting through groundwater recharge and reuse of treated wastewater in targeted way, it appears feasible to improve the condition of the three cities to Fair (WDPI=5-8) category by 2030, except Allahabad, which may attain this state by 2040.

The present paper starts with outlines of the methodology for WDPI development and application of its various modules. With a brief description of Pressure, State and Response (PSR) model applicable for urban water sustainability, the indicators used for measuring them have been selected. Eight major reuse options such as Irrigation with unrestricted application, Industrial, Gardening and Recreational, Fire fighting, Discharge to Water Bodies, Toilet and Car Washing, Outdoor Bathing and indirect drinking water source have been considered. Activated Sludge Process (ASP), Up-flow Anaerobic Sludge Blanket (UASB), Trickling Filter (TF) Moving Bed Bio-film Reactor (MBBR), Sequencing Batch Reactor (SBR) Reverse Osmosis (RO), Waste Stabilization Pond (WSP) have been examined as potential waste water treatment or water reclamation methods. Suitability to meet discharge standards, capital cost, operation and maintenance (O &M) cost, power requirement, land area requirement, treated effluent discharge, sludge disposal requirement and resource recovery potentials in terms of reuse of methane gas have been considered as parameters affecting the choice of waste water treatment technology. With no targeted approach for reuse of reclaimed water currently in practice in Indian urban environment, scenario have been examined with stepped increase in reuse potential as 5, 10 and 20% in

2020, 2030 and 2040. It is observed that improving the reuse of reclaimed water have significant effect on availability of water for development planning and overcoming the water stress in urban areas. A paradigm shift that the choice of sewage treatment plant capacity and technology selection should be done based on reuse potential of treated waste water and quality standards required for that reuse in decentralised manner has been proposed. Waste water treatment technology selection (WWTTS) may be done based on reuse potential of the urban area. There appears a need to develop and use site specific appropriate technology of water reclamation to meet the reuse based quality requirements. Reuse of water for construction industry, flushing of drains and river side ground water recharge to supplement the base flow are some of the emerging application areas in Indian conditions.

Water Reuse Under the Perspectives of the Water-Energy-Food Nexus and the Water-Soil-Waste Nexus

Andrea Müller, TU Dresden[1] & UNU-FLORES[2], Dresden, Germany; Tamara Avellán, UNU-FLORES, Dresden, Germany; Jochen Schanze, TU Dresden, Dresden, Germany

[1]Technische Universität Dresden; [2]United Nations University – Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES)

Keywords: Nexus Approach, WEF Nexus, WSW Nexus, water reuse.

Water reuse may be a feasible option to reduce freshwater demands since it provides a source of water through sanitation and wastewater treatment. Nexus thinking considers connections, trade-offs and synergies between the involved resources and/or sectors. In the case of the Water-Energy-Food (WEF) Nexus it relates the water, energy, and food sectors; whereas in the Water-Soil-Waste (WSW) Nexus interlinkages are addressed between water, soil, and waste resources. Water reuse affects different resources and sectors at different levels and scales. Therefore, understanding the interdependencies of the different resources and sectors to identify connections, trade-offs and synergies is important for the design and implementation of water reuse measures.

The aim of this contribution is to explore how water reuse relates to and may benefit from the WEF and WSW nexus approaches. Accordingly, first, current concepts of water reuse and the WEF and WSW nexus are analysed based on a literature review and document analysis. Second, the relationships between the involved resources and sectors involved in water reuse measures on the one hand, and the WEF and WSW nexuses on the other hand, are mapped. Third, those relationships of water reuse resources and sectors that are common to both nexus approaches are identified.

As results it is shown that water reuse is inherently related to the specific water management context and mainly focuses on: the wastewater source (municipal, industrial, agricultural), wastewater treatment, and water reuse (for irrigation, industrial use, basin recharge, etc.). These three realms engage different resources and sectors through services. Furthermore, it can be depicted that within the WEF Nexus, water reuse provides: (1) an alternative source of water; (2) the option of

bioenergy production; (3) nutrients and water for agricultural use. Regarding the WSW Nexus, water reuse serves for: (1) an increase of water resources by reducing the need of freshwater resources; (2) an improvement of soil nutrient content; (3) a reduction of the untreated discharge wastewater that can contaminate freshwater sources. Additionally, the WEF Nexus relates not only to sectors but also concretely to the services for the provision of water, energy and food, based on resources processing such as water, soil and waste.

The above functions of water reuse help analysing the relationships with both nexus approaches. (1) Wastewater source: relates the water sanitation sector with a resource when perceiving wastewater as a resource that needs further treatment. (2) Wastewater treatment: relates the water and energy sectors through the processes that allow wastewater treatment by providing different water qualities (depending on the process), possible energy generation options and by-product (stabilised sludge). (3) Water reuse: relates the water supply sector with other sectors such as the agricultural sector (irrigation and soil enhancement), the water supply sector (urban blue and green areas), the water resource management sector (basin recharge), etc. Thus, there is an evidence for the meaning of the institutional and organisational context, defining specific relationships between sectors with their resource management and service supply.

The results indicate the relevance of the two nexus approaches, which facilitate an understanding of the interlinkages between the involved resources and sectors with their services at different levels and scales. This is relevant for the design and implementation of water reuse measures when pointing towards multipurpose solutions.

Using Treated Sewage Effluent to increase water security in Qatar

Husam Baalousha, Fanilo Ramasomanana
Qatar Environment and Energy Reserach Institute (QEERI),
Doha, Qatar

Qatar is an arid country with limited water resources. With no surface water and an average annual rainfall of about 80 mm per year, Qatar relies on desalination to meet the increasing water demand. The groundwater aquifer receives around 50- 60 million m^3 per year as natural recharge, whereas abstraction is around 250 million m^3 per year, mainly used for agriculture. Despite the scarcity of water, the consumption in Qatar is the highest in the world with an average of 500 litters per capita per day, which is totally met by desalination, whereas the aquifers are using mainly for agriculture.

As a result, the water table has dramatically dropped to unprecedented levels and salinity increased, in addition to other adverse environmental impacts. Stresses on the country water resources has increased over the last few decades due to increase in population. Qatar has recently focused on how to increase the food security. Food security in Qatar is constrained by water scarcity, poor soil and harsh climate.

This study explores how to increase water resources in Qatar for agriculture use and the potential of using the treated sewage effluent TSE in agriculture to increase the country self-sufficiency. At present, around 200 million of m^3 of TSE are being produced annually and only half of it is being used. In addition, large quantities of water losses occur in the distribution network that could otherwise be saved for other purposes.

Results of this study shows that Qatar may not reach 100% food security, but can reach 40% by 2030 by utilising the TSE, reducing losses in the network and rationing of consumption.

Water and energy nexus in agricultural water supply for the water-energy-food nexus approach

Eunhee Choi, Rural Research Institute, KRC, Ansan, Republic of Korea,
Seungheon Lee, Rural Research Institute, KRC, Ansan, Republic of Korea
Seungoh Hur, National Institute of Agricultural Sciences, RDA, Jeonju, Republic of Korea

Keywords

Water-Energy-Food Nexus, sewage reuse, desalination, water footprint

Abstract

Global resource security crisis is emerging as the demand for essential resources such as water, energy and food increases due to climate change, population growth, urbanization and resource depletion, and the supply and demand of these resources are becoming unbalanced, Therefore sustainable securing and utilization of limited resources is necessary to cope with such future environmental changes. However, not only in Southeast Asian countries including Korea, but also in the world, over 70% of the world's water supply is consumed by agriculture and about 15% is consumed by energy generation. So far, the world has been conscious of water, energy, and food as separate resources, and has produced and consumed them. However, these three resources, which are absolutely necessary for human life, are linked together and mutual crisis can be amplified. In recent years, interest in the water-energy-food nexus approach has been growing as a way to overcome the limitations of individual resource management and to manage resources in an integrated manner (Hoff 2011; FAO 2014; Daher and Mohtar, 2015).

The study for ‘Development of Water-Energy-Food Nexus platform associating with climate change impacts (Smart Nexus for Agriculture in Korea, SNAK) aims to build a platform that includes a system that applies and evaluates user - based scenarios and climate change scenarios simultaneously based on modeling of individual resources and linkage analysis system of resources.

System dynamics for Nexus built at SANK is composed of simulated resource usage by production system, water resource, energy supply system and carbon emission simulation part according to energy use. In order to simulate resource usage, water footprint per unit production, energy use for supplying water, and energy footprint for

treating wastewater are essential, which can be applied to field data and sub-model simulated values. In this study, the parameters required for platform construction were collected and verified by 3 type of agricultural irrigation water: agricultural water supplied through the reservoir, the agricultural water supplied through sewage reuse system and the agricultural water supplied through brackish water desalination system

In case of agricultural water supplied through the irrigation into the reservoir, energy consumption per unit irrigation water is difference in regions. In Gangwondo, 422.5 kWh are needed for one thousand ton of irrigation water but in Gyunggido, 75.7 kWh are needed. Because of its geographical characteristics, Gangwondo do is able to supply 70% of its total water supply from the reservoir, while the remaining 30% is supplied with water through two or three agricultural water distribution systems due to the nature of many mountainous areas, so Energy consumption per unit water discharge is much higher than other areas.

In case of brackish water desalination system for agricultural purpose, 1,214 kwh/10^ 3 ton of water are used for generating agricultural water excluded irrigation. In case of sewage reuse, 0.58 kw/ton are consumed.

The database will be used to construct the system dynamics model.

Reference

Daher, B. T. & Mohtar, R.H., (2015) Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative resource planning and decision-making, Water International, Vol. 40(5-6), 748-771

Hoff, H. (2011). *Understanding the nexus: background paper for the Bonn211 Nexus Conference: The Water, Energy, and Food Security Nexus.* Stockholm Environment Institute, Stockholm, Sweden

FAO (2014)Walking the nexus talk: Assessing the water–energy–food nexus in the context of the sustainable energy for all initiative. Retrieved from http://www.fao.org/3/a-i3959e.pdf

Acknowledgement

This work was carried out with the support of “Cooperative Research Program for Agriculture Science and Technology Development (Project No: PJ01343505)” Rural Development Administration, Republic of Korea.

Energy recovery from solids produced in biological domestic wastewater treatment.

Claire GERENTE, Audrey VILLOT, Sary AWAD, Yves ANDRES

IMT Atlantique, GEPEA UMR CNRS 6144, 4 rue Alfred Kastler, 44307 Nantes Cedex 3, FRANCE

Claire.gerente@imt-atlantique.fr ; yves.andres@imt-atlantique.fr

In the World Water Development published by UN in 2015 (UN Report 2015) it was clearly state that “Water flows through the three pillars of sustainable development – economic, social and environmental”. Moreover, in addition to provide safe drinking water sources to people the water resources conservation is one of the main challenges of the century. With the increase of the world population estimated to be 9.5 billion people by 2050, and the migration of peoples from rural areas to urban location in 2050 it was estimated that 66 % of the world population will live in megacities (UN-Habitat, 2016). Today most megacities are located in developing countries and this trend will continue as several large cities in Asia, Latin America and Africa are projected to become megacities by 2030. The fastest growing urban centers are the small and medium cities with less than one million inhabitants. Previous studies have investigated the effect of wastewater treatment plant onto the surfaces water quality of the rivers used for producing the drinking water and used as final environmental reservoir for discharging the treated wastewater for the megacities (i.e. Yoon et al 2010). In the same time the largest increases in energy demand will take place in developing countries where the proportion of global energy consumption is expected to increase from 46 to 58 percent between 2004 and 2030 (FAO, 2010). In this context the wastewater treatment plants need to be built with an integrative approach developed in biorefinery technologies, treating the wastewater by the well developed unit operations used in the primary, secondary and tertiary step of the plant but also recovering energy from the by-products such as grease or sludge. To decrease the energy demand and to limit the GHG emission related to the wastewater management the collected organic residues could be transform in energy by pyrolysis, gasification, anaerobic digestion (Elsayed et al, 2015), hydrothermal liquefaction and transesterification (Awad et al, 2014) methods to produce fuels from organic waste.

The aim of the presented paper is to contribute to solve the water reuse bottlenecks by Energy and nutrient recovery from the activated sludge wastewater treatment process. The figure 1 gives a general overview of the proposed biorefinery approach mostly focuses in the energy and nutrients recovery. A 600 000 pe wastewater treatment plant will be used as example.

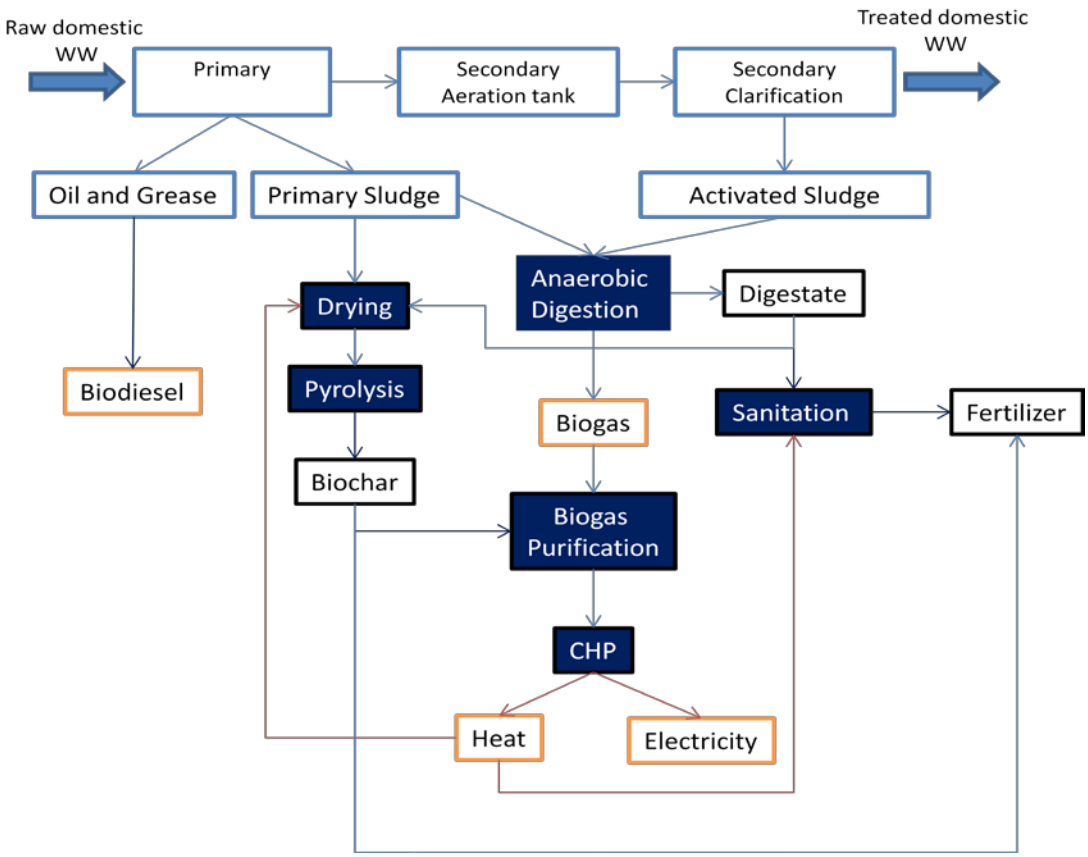


Figure 1: Integrative approach for energy recovery from solids produced in biological domestic wastewater treatment process.

References

Awad S, Loubar K, Tazerout M, 2014 Experimental investigation on the combustion, performance and pollutant emissions of biodiesel from animal fat residues on a direct injection diesel engine. Energy 69 (2014) 826-836

Elsayed M., Andres Y., Blel W., Gad A., 2015, Methane Production By Anaerobic Co-Digestion Of Sewage Sludge And Wheat Straw Under Mesophilic Conditions, Int. J. Scientific & technol Res. 4, 06

Yoon Y, Ryu J, Oh J, Choi B-G , Shane A. Snyder S A, 2010, Occurrence of endocrine disrupting compounds, pharmaceuticals, and personal care products in the Han River (Seoul, South Korea). Science of the Total Environment 408 (2010) 636–643

Life Cycle Assessment of heat recovery systems for use with drain water from commercial kitchens

Isabel Schestak, Bangor University, Bangor, UK; Jan Spriet, Trinity College, The University of Dublin, Dublin, Ireland; David Styles, Bangor University, Bangor, UK; Prysor Williams, Bangor University, Bangor, UK;

Introduction

Small-scale heat recovery from drain water using in-line heat exchangers has proven to be a viable measure for saving energy for water heating in domestic showers. The use of such heat recovery systems with drain water from commercial kitchens remains largely unexplored, although the food service sector is a major user of water. Before recommending their use for this sector, environmental impacts from manufacture, installation works, operation and disposal have to be set in contrast to the energy savings achieved.

Objectives and methods

This is the first study to evaluate the environmental sustainability of a heat recovery system for harvesting the heat of commercial kitchen's drain water.

We apply a life cycle assessment (LCA) methodology to determine the environmental impacts from retro-fitting a heat recovery system into an existing plumbing system, consisting of a heat exchanger, pipework and fittings. To identify the environmental benefits from eco-design, different materials are compared: a heat exchanger made from copper, considering different shares of recycled copper input, and a heat exchanger from an innovative polypropylene-graphite (PP-GR) composite. We also compare different materials (copper, steel, polyethylene) and lengths (1, 10, 30 m) for the additional pipework required. The following impact categories are assessed: Global Warming Potential, Human Toxicity Potential, Photochemical Ozone Formation Potential, Acidification Potential, Freshwater Eutrophication Potential, Freshwater Ecotoxicity Potential, and Mineral, fossil & renewable Resource Depletion Potential.

Based on energy savings for water heating from a restaurant case study, we determine the environmental payback times for the different impact categories and

different avoided water heating energy sources, both conventional and renewables ones, e.g. natural gas, electricity, solar and geothermal energy.

Finally, water consumption figures for the UK food service sector serve to extrapolate the potential environmental savings through drain water heat recovery to a national level, assuming the installation of the copper system which is available on the market.

Results and Discussion

Installation of both the copper and the PP-GR based heat recovery systems would reduce the environmental impacts from water heating during their lifetime. The life cycle impacts from the copper system though are substantially higher, arising predominantly from primary copper production. Increasing the share of recycled copper contributes to lower the environmental burdens throughout all impact categories. Impacts from the heat recovery system combining a PP-GR heat exchanger with pipework from polyethylene proved to be the most environmentally friendly design option, exhibiting 82 to 99% less environmental impacts than a comparable copper system using 35% recycled copper for heat exchanger and pipework. In the case study, the life cycle impacts of the PP-GR system would be paid back completely within two years across all impact categories, even when replacing renewable energy sources. Payback of the copper system depends on the energy source that is substituted and is best for electricity, solar and geothermal energy. Extrapolation of the findings to all UK commercial food outlets shows potential yearly savings of up to 551 kilotons of GHG emissions, which make up about 0.1% of the UK's current emissions.

Conclusion

The findings show the potential for environmental benefits from the expansion of decentralised drain water heat recovery to the food service sector. Material choice, including recycled material, should be taken into consideration to maximise the environmental savings. Further field studies with heat recovery devices from conventional and newly developed materials spanning their complete lifetime are needed to provide more reliable data on heat recovery potentials and achievable mitigation of environmental impacts.

UV-H_2O_2-treatment of RO brine from municipal wastewater: comparison of UV-LED and LP-UV

Muhammad Umar, Norwegian Institute for Water research, Oslo, Norway; Felicity Roddick, RMIT University, Melbourne, Australia; Linhua Fan, RMIT University, Melbourne, Australia; Wolfgang Uhl, Norwegian Institute for Water research, Oslo, Norway

1. Introduction and objectives

Under water scarcity, municipal wastewater is actively being considered as a supplementary resource for irrigation or even for drinking water. However, the effluent from wastewater treatment plants (WWTPs) contains a heterogeneous mixture of organic and inorganic compounds of domestic and industrial origin. These compounds cause color, taste and odor, and are of health concern when the water is reused or recycled. Reverse osmosis is often applied for the treatment. The resultant reverse osmosis concentrate (ROC), which comprises 15-20% of the volume of the feed stream, and about five times the concentrations of all the contaminants present in the original wastewater at elevated levels. As these contaminants may be toxic and/or bio-accumulative, the disposal of untreated ROC presents a potential environmental risk.

In previous work we have shown that advanced oxidation processes provide an effective option for the treatment of the RO brine from municipal wastewater, particularly when used prior to biological treatment. The objectives of the work presented here were to compare the effectivity of a prototype reactor using ultraviolet-light emitting diodes (UV-LED reactor) with a conventional low-pressure UV lamp reactor (LP UV-lamp reactor) for the UV/H_2O_2 treatment of a highly saline ROC (EC ~22 mS/cm) obtained from municipal secondary effluent. As performance indicators sum parameters for organic compounds as colour, UV_{254}, fluorescence excitation emission spectra, molecular size distribution, biodegradability and ecotoxicity were used. The energy efficiency in terms of electrical energy per order (EE/O) was to be compared. Furthermore, it was intended to get an idea about the impact of coagulation with alum (1.5 mM Al^{3+}) prior to oxidative treatment.

2. Materials and Methods

A ROC sample was collected from a wastewater reclamation facility at a local municipal wastewater treatment plant. In the lab, in the presence of 3 mM H_2O_2, subsamples were subjected to UV-C irradiation using the LP-UV reactor (254 nm, average fluence rate 8.91 mW/cm^2) or using the UV-LED reactor (255 nm, average fluence rate 0.14 mW/cm^2). Reactor contents were sampled periodically and analyzed for water quality indicators mentioned above, using standard procedures. The biodegradability of the organics was evaluated as biodegradable organic carbon (BDOC) and the concentrations of fractions of dissolved organic carbon were determined using LC-OCD.

3. Results and Conclusions

	Raw	**Al^{3+}**	**LP UV**	**UV LED**	**Al^{3+}+LP UV**	**Al^{3+}+UV LED**
DOC	0	29	25	28	37	41
Colour	0	40	77	85	89	96
UV_{A254}	0	33	69	64	80	87

Table 1. % reductions of stated parameters after various treatments under comparable UV fluence conditions

Use of the UVC only treatment led to fairly comparable reductions of DOC, colour and UVA_{254} (Table 1) using both UV systems. The biodegradability of the ROC almost doubled after UV only treatment. The coagulation by alum targeted the large chromophoric molecules, i.e., humic substances, as evidenced from the LC-OCD chromatograms, although there was little if any reduction in the fluorescence of organics associated with the humic acid-like and fulvic acid-like matter. However, there was a steady reduction in the fluorescence of these organics with irradiation time, with greater decreases after the coagulation pre-treatment. After coagulation, there was less proportional mineralization but greater conversion of the remaining DOC to biodegradable form. Overall, there was a complementary effect for the sequential process as shown by the markedly greater reduction of humic substances which corresponded with colour, UVA_{254}, fluorescence and DOC reductions. These

results demonstrate the potential of UV/H_2O_2 oxidation followed by biological treatment for the treatment of highly saline ROC from municipal wastewater.

The 4th treatment step – Our way to reuse in Europe?

J. Scheideler* Dr. Achim Ried*

** Xylem Services Gmbh, AOP Manager, Boschstr. 4-13, 32051 Herford, Germany; jens.scheideler@xyleminc.com*

Abstract

Due to available funding (Germany) or national regulations (Switzerland) the implementation of a 4th treatment step in municipal waste water treatment plants has got momentum and several plants have upgraded their treatment scheme to remove tracer organic contaminants from the waste water. Due to the nature of the selected treatment processes - Ozone + Biological Filtration or Granulated Activated Carbon (GAC) the impact on the water quality being discharged is significant. This water achieves a purity that may make it too precious to be discharged. This paper will provide an overview about the current full scale installations and the water quality they achieve in the final effluent and puts it into the context of European and international reuse guidelines for potable and non-potable applications. As drinking water is usually not a scarce resource in Germany and Switzerland the paper will provide scenarios where reusing the water could be an attractive business case for the utilities as well as the overall public acceptation of reuse in these countries

Beneficial wastewater use: Sorghum for fodder and energy

Farah Jafarpisheh[1], John Hutson and Howard Fallowfield, Health and Environment Group, College of Science and Engineering, Flinders University, Adelaide, South Australia
[1]Presenting author

Abstract

Nowadays, water scarcity is a major issue. In rural South Australia treated wastewater is often used to irrigate trees. Using wastewater for irrigation of plants with either high levels of biomass for fodder or carbohydrate for fermentation to alcohol for biofuel may increase the economic value derived from the wastewater. *Sorghum*, with high level of biomass and sugar, is one such option. This study demonstrates the effect of wastewater irrigation on two different *Sorghum* varieties, SE1 (*Sorghum* Earthnote Variety 1), a fodder crop and SE2 (*Sorghum* Earthnote Variety 2), a sugar (fermentation) crop. SE2 showed higher growth in terms of height, number of leaves, total fresh and dry stem weight and percentage Brix. SE1 had higher fresh and dry leaf mass. Potential alcohol and energy content of SE2 was 1.9 times more than SE1.

Keywords

sorghum, wastewater, ethanol, irrigation, animal food

Introduction

Water and nutrients are critical for plant growth; the challenge is efficient delivery, maintaining growth rates and decreasing input costs (Prosser and Sibley, 2015). The agricultural sector consumes about 70% of all global freshwater reserves. In areas facing water stress, treated wastewater can contribute both water and plant nutrients (Richter et al., 2015, Markou and Georgakakis, 2011).In the early 1990s, more than 10% of the world's consumed food was generated on land irrigated with wastewater (Muñoz et al., 2009).

Sweet *Sorghum* is a fast growing crop with a growth season of 90 to 120 days (Kurai et al., 2015, Deesuth et al., 2015) which can grow in water-and fertilizer-limited areas (Ostovareh et al., 2015, Sun et al., 2015). This project investigated the effects of treated wastewater on *Sorghum* as a potential fodder and energy source.

Methods

Two plots (5.76m^{-2}) on sandy-loam soil at Mount Barker in South Australia were planted to *Sorghum* SE1 (potential animal fodder) and SE2 (potential alcohol source) on 2 Feb 2016. Plant spacing within rows was 12 cm and row spacing was 60 cm, leading to 39 plants per bed. Calibrated, automatic irrigation sprinklers delivered 1.08 L m^{-2} day^{-1}. Plant height (mm), number of tiller and leaves, total fresh and dry leaf and stem weight and Brix were measured at maturity stage after 119 days.

Results and Discussion

At maturity SE2 species had the greatest height, number of leaves, dry and fresh stem mass and Brix percentage, whereas SE1 recorded the higher total fresh and dry leaf mass (Table 1). It was estimated that SE2 had the potential to produce 2641 kg ha^{-1} of alcohol with a theoretical energy yield of 79 GJ ha^{-1} of energy. The results show that both varieties were suited to wastewater irrigation; both grew well in the absence of additional fertilizer and should be considered as alternate crops to trees.

Table 1. Growth parameters of Sorghum sp., SE1 (fodder crop) and SE2 (energy crop) at maturity.

Sorghum spp.	Height	No. of	Leaf mass, g		Stem mass, g		Brix
	cm	leaves	Fresh	Dry	Fresh	Dry	%
SE1 (fodder)	1702 ±147	34 ±8	209 ±62	57 ±24	537 ±226	121 ±58	7.2 ±0.4
SE2 (sugar)	1991 ±66	42 ±.1	178 ±23	47 ±8	828 ±10	64 ±41	11.0 ±1.8

Conclusion

Two varieties *Sorghum* were shown to have high growth rates when irrigated with nutrient rich wastewater and have the potential to produce either animal fodder or carbohydrate for subsequent fermentation to alcohol for biofuel.

References

DEESUTH, O., LAOPAIBOON, P., KLANRIT, P. & LAOPAIBOON, L. 2015. Improvement of ethanol production from sweet sorghum juice under high gravity and very high gravity conditions: Effects of nutrient supplementation and aeration. *Industrial Crops and Products,* 74**,** 95-102.

KURAI, T., MOREY, S. R., WANI, S. P. & WATANABE, T. 2015. Efficient rates of nitrogenous fertiliser for irrigated sweet sorghum cultivation during the post-rainy season in the semi-arid tropics. *European Journal of Agronomy,* 71**,** 63-72.

MARKOU, G. & GEORGAKAKIS, D. 2011. Cultivation of filamentous cyanobacteria (blue-green algae) in agro-industrial wastes and wastewaters: a review. *Applied Energy,* 88**,** 3389-3401.

MUÑOZ, I., GÓMEZ-RAMOS, M. J., AGÜERA, A., FERNÁNDEZ-ALBA, A. R., GARCÍA-REYES, J. F. & MOLINA-DÍAZ, A. 2009. Chemical evaluation of contaminants in wastewater effluents and the environmental risk of reusing effluents in agriculture. *TrAC Trends in Analytical Chemistry,* 28**,** 676-694.

OSTOVAREH, S., KARIMI, K. & ZAMANI, A. 2015. Efficient conversion of sweet sorghum stalks to biogas and ethanol using organosolv pretreatment. *Industrial Crops and Products,* 66**,** 170-177.

PROSSER, R. & SIBLEY, P. 2015. Human health risk assessment of pharmaceuticals and personal care products in plant tissue due to biosolids and manure amendments, and wastewater irrigation. *Environment international,* 75**,** 223-233.

RICHTER, E., HECHT, F., SCHNELLBACHER, N., TERNES, T. A., WICK, A., WODE, F. & COORS, A. 2015. Assessing the ecological long-term impact of wastewater irrigation on soil and water based on bioassays and chemical analyses. *Water research,* 84**,** 33-42.

SUN, X.-Z., MINOWA, T., YAMAGUCHI, K. & GENCHI, Y. 2015. Evaluation of energy consumption and greenhouse gas emissions from poly (phenyllactic acid) production using sweet sorghum. *Journal of Cleaner Production,* 87**,** 208-215.

DECHEMA
Gesellschaft für Chemische Technik
und Biotechnologie e.V
Theodor-Heuss-Allee 25
60486 Frankfurt am Main
Germany

www.dechema.de