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P232 – Using plant data to estimate biodegradable COD fractions – Case Study KwaMashu WWTP

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Introduction

The kwaMashu WWTW in eThekwini, South Africa, is a conventional wastewater treatment plant with a nominal capacity of 50 ML/d. It has primary settlers and anaerobic digesters, but is not configured for P removal. A modelling study is under way in preparation for a planned upgrade to 80ML/d. The upgrade is planned to improve nutrient removal, and tertiary treatment to recover potable water is also being considered.

When the configuration of an existing plant is to be changed, the most critical part of the model calibration is the influent wastewater fractionation. Furthermore, due to the complexity of the systems involved, model calibration protocols typically involve the sequential calibration of the various subsystems starting with the influent characterization. As a result, errors in the influent characterization are propagated through the other calibration steps (Grau et al., 2007).

In general, raw sewage COD and TSS measurements are available from routine monitoring data. However, treatment models require the fractionation of raw COD and TSS into, at minimum, soluble biodegradeable and unbiodegradable organic components, particulate biodegradable and unbiodegradable organic components and an inorganic particulate component. The constantly varying characteristics of wastewater make experimental determination of an adequately representative set of components using protocols such as those recommended by the IWA Guidelines (Reiger et al., 2012) difficult, time-consuming and expensive, which constitutes a significant barrier to the adoption of modelling by many municipalities, including eThekwini. Biodegradable organic fractions in raw and settled sewage are typically determined via BOD measurements (Hulsbeek et al., 2002) or respirometric methods (Vanrolleghen, 2002). Both of these methods take days to get results for a single sample and most municipalities simply do not have the equipment or experienced personnel to undertake these type of characterization studies. Furthermore, translating laboratory results to full scale WWTP plants can be quite challenging due to important differences between the two types of systems (Sin et al., 2005).

Compliance and process operation monitoring generate large sets of measurements of COD, TSS, FSA etc, but these are insufficient for determining the wastewater characteristics required by models. Furthermore, they tend to include many errors and inconsistencies, as they are seldom evaluated critically. Nevertheless, a *probabilistic fractionator* tool that we have developed (Brouckaert et al., 2016) has proved effective for certain modelling purposes. This combines routine measurements with estimates based on literature and plant experience to determine a probable composition expressed in terms of model components. The probabilistic fractionator, which is included in the PWM_SA model implemented in WEST (MikebyDHI), is similar in concept to the influent characterization methodology developed by Grau et al. (2007) but includes only the components required for the PWM_SA model as well as a simpler fitting procedure. However, routine measurements on the influent wastewater contain no information on important parameters, such as biodegradability, so for this the probabilistic fractionator must rely entirely on estimates.

In this study, we explore the possibility of extending the probabilistic fractionator by including routine process measurements with the routine influent measurements, and coupling the fractionator with a simplified plant-wide steady state model, so as to obtain a more accurate fractionation of the influent. This technique could make wastewater treatment modelling accessible to a wider range of municipalities.

Methodological Approach

Data collection

Routine monitoring data for 2018 were provided by eThekwini Water and Sanitation (EWS) from their laboratory information system and plant operating records. June and July were a period of little rain and relatively stable plant operation, so these data were selected for modelling. Table 1 shows an extract from the plant sampling schedule for three sampling points, giving an indication of the available data. Influent flowrate was the only daily measurement. Combined AS and AD sludge production was available as monthly totals, however, there was no data available on any of the internal flows including the activated sludge wasting rate.

Table 1 Sampling schedule for kwaMashu WWTP.

	MON	**TUE**	**WED**	**THU**	**FRI**
Raw sewage	pH, sett sols, susp solid, total solids, NH3, COD		sett sols, susp solids, NH3, COD, PO4		pH, sett sols, susp solids,, NH3, COD
Primary effluent	sett sols, susp solid, PV4, NH3, COD		susp solids, NH3		sett sols, susp solids NH3, COD
Aerated basins	pH, susp solids, NO2, NO3, DO, temp, NH3	susp solids	susp solids, NO3, DO, temp, NH3	susp solids	pH, susp solids, NO2, NO3, DO, temp, NH3

Model selection and fitting

A simplified version of the plant wide steady state model (Ekama, 2009) was set up to track the organic and particulate components through the plant from the raw sewage to the secondary effluent and sludge filter cake. The purpose of the model was twofold:

1. To estimate the missing internal flows; specifically: the flow to the anaerobic digesters (ADs) and the waste activated sludge (WAS) flow which determine the hydraulic retention time of the ADs and the sludge retention time (SRT) of the activated sludge (AS) plant respectively.
2. To estimate the biodegradable organic fractions of the influent based on the overall reduction in solids and COD.

The plant measurements and parameters used in the fitting procedure are listed in Table 2. The secondary effluent solids flux was included as an adjustable parameter to represent the secondary clarifier performance. The upper and lower bounds for the overall mass balance parameter were set to correspond to the 95 % confidence interval on the standard error of the mean observed values.

The simplified model and optimization were coded in R, a free statistical computing software that all municipalities would have access to. Uncertainties in the parameter values were estimated from the Hessian at the optimum point. The set of parameters which were practically identifiable from the available data were then determined using a sequential regression procedure. Finally, the optimized parameters were used to set up a full model of kwaMashu WWTP in WEST (MikebyDHI).

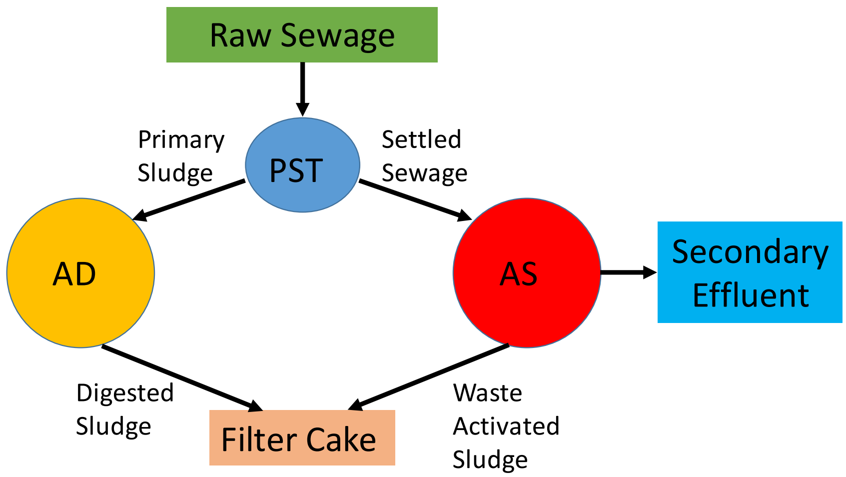

Figure 1 Simplified plant-wide steady state model.

Table 2 Fitted measurements and fitted parameters.

Fitted measurements	**Fitting parameters**
Raw COD flux	Overall mass balance:
Raw TSS flux	Secondary effluent solids flux, Fitted raw COD
Settled sewage COD flux	
Settled sewage TSS flux	Internal flows:
Secondary effluent COD flux	AS wasting rate
Secondary effluent TSS flux	Flow split between AS and AD (f_setsew)
Reactor MLSS	
Primary sludge % TS	Influent fractionation:
Dry sludge cake produced	Unbiodegradable soluble COD fraction (f_codus)
Sludge cake % IS	Soluble COD fraction (f_codf)
Digester %TS	Unbiodegradable particulate COD fraction (f_codup)
	Biodegradable influent particulate COD/g (fcv_XBinf)
	Settled sewage fractionation
	Fraction of influent solids in the settled sewage (f_ns_PST)
	Fraction of influent ISS in the settled sewage (f_ns_iss)
	Fraction of influent unbiodegradable particulate COD in the settled sewage (f_ns_codup)

Results and Discussion

All of the parameters in Table 2 were identifiable with the exception of f_ns_iss, f_ns_codup and f_codf i.e. it was possible to obtain best fit parameters for the wasting rate, flow to the anaerobic digesters and unbiodegradable fractions of the raw sewage but not for the settled sewage fractionation. The latter may have been partly due to inconsistent performance of the primary clarifiers during June and July 2018. Figure 2 shows the results of the WEST model using the optimized parameters while Figure 3 shows the COD balance for the various process streams. In the WEST model, the non-settlable fraction was assumed to be f_ns_PST for all particulate components.

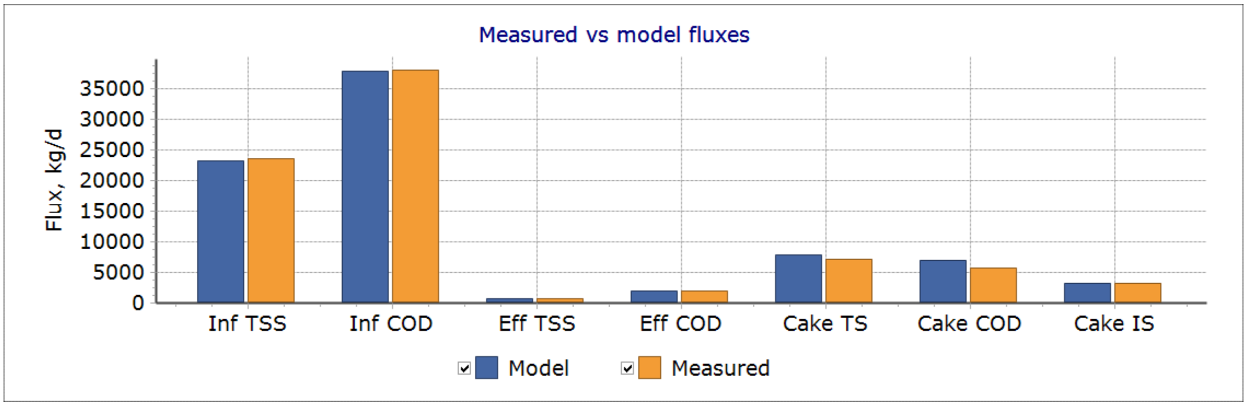

Figure 2 Agreement between model and measured fluxes of solids, COD and inorganic solids (IS).

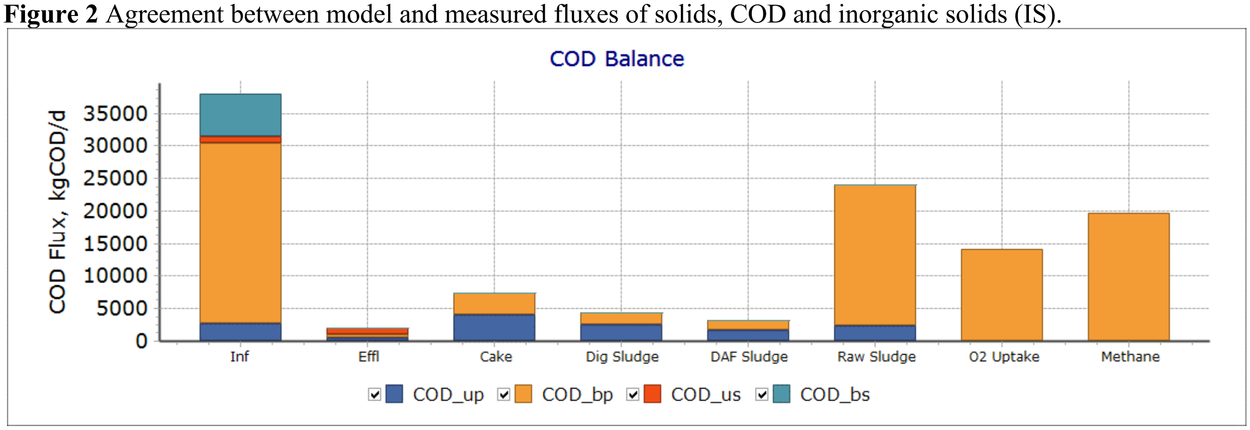

Figure 3 Model COD balance showing biodegradable and unbiodegradable soluble and particulate fractions.

The advantage of using sludge production and reactor solids data in the estimation of influent COD fractions is that it provides a check on the influent characterization in the early stages of the WWTP model calibration, helping to prevent the propagation of errors through subsequent steps. The modelling tool can also be used in data reconciliation because it imposes best fit mass and COD balances on the available data. Discrepancies between fitted and measured or expected values can indicate problems with the original data which can investigated further. Furthermore, the results of the parameter selection can help identify ways of improving data collection for use in modelling. For example, the raw filtered COD and IS content of settled sewage and/or MLSS are not routinely measured at treatment plants but could easily be done at any analytical laboratory to obtain better estimates of f_codf and f_ns_iss.

The multivariate parameter estimation can also be carried out in WEST using the full plant wide model, however it is extremely slow and cumbersome, since the sequential parameter selection would have to been managed manually. The simplified steady state model provides a convenient and much faster way to find the best fit parameters for the COD and solids balances. Furthermore, while the COD fractions are estimated using a steady state model, the results can also be applied to dynamic modelling. The steady state model fractions are used as initial estimates of the COD fractions in the probabilistic fractionator which then uses these estimates along with routine influent measurement data to generate the dynamic model influent.

Conclusion

We have developed a modelling tool which estimates COD fractionation and other mass balance parameters from plant data using a simplified version of the plant wide steady state model. This can greatly facilitate setting up models of treatment plants from routine monitoring data even when some critical operating data such as the sludge wasting rate is missing or unreliable. The tool can also be used to help improve monitoring programs to provide data that is useful for modelling, process optimization and design. The influent fractionation and calibrated plant model of kwaMashu WWTP will be used by the eThekwini municipality as a benchmark against which the current plant performance is evaluated, and in the design of the proposed upgrade.

Opinion

The COD fractionator tool addresses a significant barrier to modelling in practice, making the benefits of modelling available to a wider range of municipalities.

References

Brouckaert C., Brouckaert B., Singh A. and Wu W. (2016) *Wastewater Treatment Modelling for Capacity Estimation and Risk Assessment.* WRC Report No. TT 678/16. Water Research Commission, Pretoria, South Africa.

Ekama, G. (2009) Using bioprocess stoichiometry to build a plant-wide mass balance based steady-state WWTP model. *Water Research*. 43(8):2101–2120. DOI: 10.1016/j.watres.2009.01.036.

Grau P., Beltrán S, de Gracia M. and Ayesa E. (2007) New mathematical procedure for the automatic estimation of influent characteristics in WWTPs. *Water Science and Technolo*gy 56 (8): 95 – 106.

Hulsbeek J., Kruit J., Roeleveld P. and van Loosdrecht M. (2002) A practical protocol for dynamic modelling of activated sludge systems. *Water Science and Technology* 45(6):127-136.

Reiger L., Gillot S., Langergraber G., Ohtsuki T., Shaw A., Takacs I. and Winkler S. (2012) *Guidelines for Using Activated Sludge Models.* IWA Task Group on Good Modelling Practice. IWA Publishing.

Sin G., Van Hulle S., De Pauw D., van Griensven A. and Vanrolleghem P. (2005) A critical comparison of systematic calibration protocols for activated sludge models: A SWOT analysis. *Water Research* 39: 2459–2474.

Vanrolleghem P (2002) *Principles of Respirometry in Activated Sludge Wastewater Treatment*. Department of Applied Mathematics, Biometrics and Process Control, University of Ghent.