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

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Publication date:
2019

Document Version
Peer reviewed version

Citation (APA):

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

Elham Ramin

Carina Schneider, Anders Damgaard, Claus Hélix-Nielsen, Xavier Flores Alsina, Pedram Ramin, Krist V. Gernaey, Maj M. Andersen
Eco-industrial Park

Source: Lee in Chiu 2015
Example – Kalundborg (DK)


Source: Symbiosis Center Denmark
GECKO Project

• Danida funded 2-year pilot research project

• Duration: April 2018- March 2020

• Aims to provide the scientific knowledge base to develop a national strategy for designing and projecting high-circular eco-industrial parks (industrial symbiosis) in Kenya

Objectives:

• Business research (WP2)

• Governance research (WP3)

• Technical feasibility studies of selected symbiosis solutions (WP4)

• **System modeling of symbiosis solutions** (WP5)
Ruarka industrial park
Ruaraka industrial park

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food (animal based)</td>
<td>9%</td>
</tr>
<tr>
<td>Food (vegetable based)</td>
<td>17%</td>
</tr>
<tr>
<td>Beverages</td>
<td>6%</td>
</tr>
<tr>
<td>Textiles</td>
<td>3%</td>
</tr>
<tr>
<td>Paper</td>
<td>3%</td>
</tr>
<tr>
<td>Chemicals</td>
<td>20%</td>
</tr>
<tr>
<td>Pharma</td>
<td>6%</td>
</tr>
<tr>
<td>Minerals</td>
<td>9%</td>
</tr>
<tr>
<td>Metals</td>
<td>6%</td>
</tr>
<tr>
<td>Plastics</td>
<td>15%</td>
</tr>
<tr>
<td>Waste collection</td>
<td>6%</td>
</tr>
<tr>
<td>Waste</td>
<td></td>
</tr>
</tbody>
</table>

Rainfall in Kenya

Groundwater level in Nairobi

(Source: UNEP-NET)
# Case Study

<table>
<thead>
<tr>
<th>Companies</th>
<th>Units</th>
<th>Water use m³/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Cooling Boiler</td>
<td>1000 500</td>
</tr>
<tr>
<td>B</td>
<td>Washing</td>
<td>126</td>
</tr>
<tr>
<td>C</td>
<td>Boiler</td>
<td>150</td>
</tr>
<tr>
<td>D</td>
<td>Process</td>
<td>550</td>
</tr>
<tr>
<td>E</td>
<td>Process Boiler</td>
<td>420 200</td>
</tr>
</tbody>
</table>
Existing Situation

Ground water → Process unit → Effluent treatment

Ground water → Process unit → Effluent treatment
Symbiotic Relationship

Ground water

Process unit

Reused water treatment

Effluent treatment

Ground water

Process unit

Reused water treatment

Effluent treatment
# Water Treatment for Reuse

<table>
<thead>
<tr>
<th></th>
<th>Chemical Treatment</th>
<th>Ultra Filtration</th>
<th>Forward Osmosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD removal</td>
<td>80%</td>
<td>50%</td>
<td>90%</td>
</tr>
<tr>
<td>TSS removal</td>
<td>50%</td>
<td>80%</td>
<td>90%</td>
</tr>
<tr>
<td>TDS removal</td>
<td>10%</td>
<td>20%</td>
<td>95%</td>
</tr>
<tr>
<td>Unit cost</td>
<td>0.1 $/m³</td>
<td>0.2 $/m³</td>
<td>0.4 $/m³</td>
</tr>
</tbody>
</table>
Cost Functions

Total cost = Annualized capital cost + yearly operating cost
1. Water supply: Borehole drilling + Equipment + Pumping
2. Network = Pipes + Pumps + Treatment Units
   12% discount rate
   20-year life time
   - Maintenance: 5% of capital cost
Optimization – Model Superstructure

- Fresh water
- Treatment unit
- Process unit
- Mixer
- Splitter
Optimization – Deterministic Approach

Non-Convex Mixed Integer Nonlinear Program (MINLP)

\[
\begin{align*}
\min_x & \quad f(x) \\
\text{subject to:} & \quad Ax \leq b \\
& \quad A_{eq}x = b_{eq} \\
& \quad l_b \leq x \leq u_b \\
& \quad c(x) \leq d \\
& \quad c_{eq}(x) = d_{eq} \\
& \quad x_i \in \mathbb{Z} \\
& \quad x_j \in \{0, 1\}
\end{align*}
\]
Optimization – Metaheuristic Approach

Non-dominated sorting genetic algorithm – NSGA II (Deb et al, 2002)

Advantages
• Not problem specific
• “Hill climbing” method
• Higher stability

Disadvantage
• Premature convergence
• Near optimum solution

Further improvements
• Initialization of population
• Adjusting GA parameters

Solutions – Pareto Front

- Solution 1
- Solution 2

![Graph showing Pareto Front](image)

- Fresh water consumption %
- Total cost $ / m³

Map showing locations A to E.
Solution 1

Flow | Pipe diameter
---|---
> 100 m³/d | 90 – 160 mm
50 – 100 m³/d | 50 – 75 mm
< 50 m³/d | < 40 mm
Solution 2

Company

<table>
<thead>
<tr>
<th>Unit</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Flow

- > 100 m³/d: 90 – 160 mm
- 50 – 100 m³/d: 50 – 75 mm
- < 50 m³/d: < 40 mm

Pipe diameter

- > 100 m³/d: 90 – 160 mm
- 50 – 100 m³/d: 50 – 75 mm
- < 50 m³/d: < 40 mm

Company

- A
- B
- C
- D
- E

Solution 2

Fresh water consumption % vs. Total cost $ / m³
Improving Economic Viability

Challenges
- Data quality
- Static versus dynamic
- The resilience measure
- Flexibility

- Heat recovery?
- Resource recovery?
Denmark

Symbiosis Center Denmark

Kenya

Google image
Conclusions

• Metaheuristic optimization approach shows high potential in water saving using water reuse network in an existing Kenyan industrial site

• The economic burden of water reuse can be decreased by recovering heat and valuable components from water (resource recovery)

• The metaheuristic approach can be used to perform uncertainty and flexibility assessments of water reuse networks
A New Danida project in South Africa:
Evaluation of Resource recovery Alternatives in South African water (ERASE)
Thank you for your attention!

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