Start-Up of a decentralized pilot plant for the anaerobic treatment of domestic wastewater

Laura Fröba, Marisela Vega, Frauke Groß, Antonio Delgado

16.09.16
Objective of the study

- autarc wastewater treatment of small settlements and megacities
- industrial scale (capacity: 200 m³/ d; PE 2000)
- saving drinking quality water by using service water (saving potential about 60%)

**domestic wastewater**
COD: 200 mg/l
NH4-N: 40 mg/l
TN: 50 mg/l
TP: 5 mg/l
E.coli: $10^6$ cfu/100ml

**anaerobic**

**domestic wastewater**

**service water**

**decentral**

**easy to use**

**self-defined limit values**
(AbwV 2016, BayBadeGewV 2008)
COD: 75 mg/l
NH4-N: 10 mg/l
TN: 13 mg/l
TP: 1 mg/l
E.coli: 900 cfu/100 ml

lab scale
0.014 m³/ d

pilot scale
2 m³/ d
20 PE

industrial scale
200 m³/ d
2000 PE
Pilot plant for treating domestic wastewater

- **three stage biological process**
  - C-reduction: anaerobic digestion  
    reactor 1 (R1) and 2 (R2)  
  - N-reduction: anaerobic Ammonium Oxidation (Anammox)  
    reactor 3 (R3)

- **pre-heating step** due to mesophilic conditions (30°C-40°C)

- **reactors:**  
  - R1 + R3: anaerobic sequencing batch reactor  
  - R2: fixed bed reactor  
  - R1 + R3: anaerobic sequencing batch reactor  
  - R2: fixed bed reactor

![Images of the pilot plant components: buffer tank, reactor 1, reactor 2, reactor 3, sand filter, activated carbon]
Pilot plant for treating domestic wastewater

- installation in office container (28 m², H: 2.50 m) → flexible, modular and space efficient (decentral)

- reactors were inoculated each with 60 liters of seeding sludge
  - R1+R2: sludge coming from a two-stage anaerobic digestion plant (Obermichelsbach, GE)
  - R3: sludge coming from a Deammonification (DEMON)-System (Fulda, Gläserzell, GE)
## Start-Up of the pilot plant

- **start-up procedure**  
  (MWW: municipal wastewater, SWW: synthetic wastewater)

<table>
<thead>
<tr>
<th>Reactor 1</th>
<th>Reactor 2</th>
<th>Reactor 3</th>
</tr>
</thead>
</table>
| **Adaptation phase**  
  100% MWW | **Adaptation phase**  
  100% MWW + organic acids  
  (acetic acid: propionic acid: butyric acid in 2:1:1) | **Adaptation phase**  
  100% SWW  
  (1000 liters of tab water added with ammonia sulfate (40mg/l) and sodium nitrite (50mg/l)) |
| **Stepwise interconnection of R1 and R2**  
  to 33%, 50%, 75% and 100%  
  → 100%: no addition of organic acids to R2 | | **Stepwise interconnection of anaerobic digestion (outlet of R2) and R3**  
  to 20%, 50%, 80% and 100%  
  → 100%: - no addition of ammonia sulfate to R3  
  - adjustment of nitrite-nitrogen (NO2-N) to ammonia-nitrogen (NH4-N) ratio |

- **Testing** of the three-stage pilot plant for 200 days of operation after start-up  
  → feeding of 100% MWW  
  → additive: sodium nitrite (R3)
Start-Up of the two-stage anaerobic digestion (R1 + R2)

- Start-up of two-stage anaerobic digestion was successful
- Self-defined service water limit value of 75 mg/l could almost be reached
Start-Up of the Anammox-stage (R3)

- Start-up of the Anammox-stage was successful
- Self-defined service water limit value of 10 mg/l could be reached
- Optimum substrate to feed ratio of the Anammox-stage in pilot scale: 1.14 mg/l
Degradation performance after 200 days of operation

**Self-defined service water limit values:**
- **COD:** 75 mg/l
- **NH4-N:** 10 mg/l

→ further optimization of 2-stage anaerobic digestion needed
→ with Anammmox-stage limit value is guaranteed
Conclusion

- start-up of the two-stage anaerobic digestion (R1 + R2)
  - for a temperature range of 34°C to 38°C
  - without automated pH-control
  - final average COD removal efficiency: 62%

- start-up of the Anammox-stage (R3)
  - for a temperature range of 28°C to 35°C
  - optimum NO2-N to NH4-N ratio: 1.14
  - final average NH4-N removal efficiency: 92%

- after testing the pilot plant for 200 days of operation
  - total COD removal efficiency is 81%
    → self-defined service water limit value of 75 mg/l could always be reached with R3 connected in downstream
  - total NH4-N removal efficiency is 96%
    → self-defined service water limit value of 10 mg/l could always reached only by R3

→ two-stage anaerobic digestion is limiting process-step, thus further optimization is needed to increase the plant´s capacity
Thank you for your attention!

Acknowledgements:
- Hans Sauer Stiftung
- Klärwerk Erlangen
- Siemens AG
- ZWT Wasser- und Abwassertechnik GmbH
- Maschienenbau Biermann GmbH
- Webfactory GmbH
Challenges of the project

- Varying concentrations (seasonal)
- Operating parameters (pH, T)
- Different wastewater composition (place of installation)
- Guarantee process stability
- Domestic purpose
- Challenges of decentral installation
- Energy- and cost efficiency
- Odourless
- Space saving
- Noise emission < 35 dB
- Easy to use
- Automated
- Robust
- Low maintenance
- Low investment costs
- Low operation costs
Concept of the pilot plant

- **Base**
- **Influent**
- **Buffer tank**

**Organic digestion (1. step)**
- **Sandfilter 3**
- **Sandfilter 2**
- **Sandfilter 1**

**Organic digestion (2. step)**
- **R1**
- **R2**

**Nitrogen removal (3. step)**
- **R3**

**Biogas**

**Activated carbon**

**Buffer tank**

**Effluent**
Concept of process control

Basic automation and process monitoring

<table>
<thead>
<tr>
<th>analytics</th>
<th>R 1</th>
<th>R 2</th>
<th>R 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Online:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>pH</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>conductivity</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Offline:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>NH4-N</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>TN</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Methods for guaranteeing process stability

**Proportional Integral Differential (PID) controller**

→ For pH-control

**Fuzzy Logic (FL)** (expert knowledge)

→ for state detection

**Mathematic models** (differential equations)

→ Protection against overload in anaerobic digestion (Anaerobic Digestion Model No. 1)

**Artificial Neuronal Nets (ANN)**

→ Estimation of NH4 degradation based on ΔpH/Δt
Ordinary differential equations (ODE) model:

**Anaerobic Digestion Model No. 1 (ADM1)**

- Continuous stirred tank reactor configuration
- COD base unit (mg COD/L)
- 24 components: 12 soluble components \( S_i | i = 1 - 12 \)
  
  12 particulate components \( X_i | i = 13 - 24 \)
  
  (7 groups of microorganisms)

- 19 biochemical processes
- 5 physico-chemical processes
- 4 inhibition functions

**Plant specific Modifications:**

- Two-stage system
  
  (hydrolysis + acidogenesis → R1
  
  acetogenesis + methanogenesis → R2)

- **Batch operation** with different reactors (mass balance + initial condition equations)

---

Transformation method for domestic wastewater

Chemical measurements:
1) COD → \*0.5X_{ch} + 0.4X_{pr} + 0.1X_{li}
2) TIC† → S_{HCO3}
3) TAN‡ → S_{NH4}

†Total inorganic carbon ‡Total ammonia-nitrogen

Easy to use
### Economic Feasibility Study

#### Wastewater Costs of Central Wastewater Treatment in Germany

<table>
<thead>
<tr>
<th></th>
<th>20 PE plant</th>
<th>200 PE plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>730 m³/a</td>
<td>7,300 m³/a</td>
</tr>
<tr>
<td>Useful Life</td>
<td>30 Jahre</td>
<td>30 Jahre</td>
</tr>
<tr>
<td>Required Rate of Return</td>
<td>7 %</td>
<td>7 %</td>
</tr>
<tr>
<td>Fixed Costs</td>
<td>7,251 €/a</td>
<td>8,967 €/a</td>
</tr>
<tr>
<td>Investment Costs</td>
<td>103,185 €</td>
<td>128,300 €</td>
</tr>
<tr>
<td>Amortisation Costs</td>
<td>3,439 €/a</td>
<td>4,277 €/a</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>200 €/a</td>
<td>200 €/a</td>
</tr>
<tr>
<td>Average Interest</td>
<td>3,611 €/a</td>
<td>4,491 €/a</td>
</tr>
<tr>
<td>Variable Costs</td>
<td>6,733 €/a</td>
<td>24,511 €/a</td>
</tr>
<tr>
<td>Total Average Costs</td>
<td>13,983 €/a</td>
<td>33,478 €/a</td>
</tr>
<tr>
<td>Wastewater Costs</td>
<td>19,16 €/m³</td>
<td>4,59 €/m³</td>
</tr>
</tbody>
</table>

**Wastewater Costs of Central Wastewater Treatment in Germany**

**Middle Franconia:** 2,25 €/m³  
**Brandenburg:** 3,35 €/m³