Biogas Recovery
from Domestic Wastewater
with Anaerobic Membrane Bioreactor

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Inha WCU research team
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II Anaerobic Treatment
III Pilot Results
IV Summary and Future Directions
I. Wastewater as Resources

- Wastewater’s Resource Potential
  - Water
    - Industry, Agriculture, Domestic Use
  - Fertilizing nutrients (N&P)
  - Energy: Organic & Latent Heat
I. Wastewater as Resources

- Water

Wastewater Reuse for Drinking
Newater - Singapore
I. Wastewater as a Resource

- Nitrogen

Nitrogen Removal or Recovery?

- Biological N removal
- Urban wastewater
- Concentration dependent!
- Irrigation water
- NH$_4^+$
- Stripping 90 kJ/gN 8.00 €/kgN

- NO$_2^-$
- Oxygen $\text{O}_2$
- $\text{N}_2$
- Sharon/Anammox 16 kJ/gN 0.85 €/kgN
- Haber/Bosch 37 kJ/gN 0.15 €/kgN
- Chemical N fixation

- fert.
- Evaporation 34 kJ/gN ？€/kgN
- Separation at the source
- urine (contains 80% of N in toilet water)

Physical-chemical N recovery

Mulder (2003), Maurer et al. (2003), Wilsenach et al. (2003)

(van Lier, 2011)
I. Wastewater as Resources

- What is Best Reuse Option for Capturing All of Wastewater’s Resource Potential?
  - Irrigation is an energy consumptive use
  - Irrigation is major consumer of water
  - Quality requirements less than for domestic reuse
  - Wastewater nutrients (N&P) are useful fertilizers

- Wastewater energy potential can be recovered through anaerobic treatment
II. Anaerobic Treatment

● Paradigm Shift for WW Treatment

Problems with Present WWTP

- Energy: Aeration Energy (50% of STP consumption)
- Sludge: 50% of organic into sludge, non-biodegradable
- Resource: N and P
II. Anaerobic Treatment

- Sewage: BOD = 200, VSS = 192 mg/L

Aerobic vs Anaerobic Treatment

- Methane
- Energy
- Sludge
II. Anaerobic Treatment

- New Paradigm: Resource Recovery from WW

Future STP

- Energy positive STP: saving and production of Energy
- Sludge reduction
- N and P recovery

- Water reuse
  - disinfection
  - membrane

Diagram:
- Drum screen
- Anaerobic Reactors
- Methane recovery
- Thickener
- Digester
- Power Generator
II. Anaerobic Treatment

- Common Fallacies on Anaerobic Treatment

  - Can only treat highly concentrated wastewaters such as sewage sludge
  - High Temp: Must operate at temperature of 35°C to be efficient
  - Long HRT: Retention time of 15 days or more is needed
  - Poor effluent quality: Cannot degrade organic compounds as efficiently as aerobic systems
II. Anaerobic Treatment

● Question

Can we treat DWW anaerobically to achieve net energy production and sludge reduction while meeting normal effluent quality standards at short hydraulic retention time and ambient temperature?
III. Pilot Results

Proposed SAF-MBR system

Staged Anaerobic Fluidized Membrane Bioreactor (SAF-MBR)

(Kim et al., Env. Sci. Tech. 45:576, 2011)
III. Pilot Results

- **Anaerobic fluidized bed reactor (AFBR)**
  - **Advantages**
    - Short HRT
    - Good mass transfer
    - Good sorption capacity (GAC)
  - **Disadvantages**
    - Cost for media

- **Anaerobic fluidized MBR (AFMBR)**
  - **Advantages**
    - High quality (SS free) effluent
  - **Disadvantages**
    - Membrane fouling
III. Pilot Results

Fouling control with GAC fluidization in the AFMBR
III. Pilot Results

10 m³/day SAF-MBR Pilot Plant at Bucheon, South Korea
III. Pilot Results

- Hollow fiber membrane in AFMBR
III. Pilot Results

- Operational Conditions
  - AFBR
    - GAC = 25%
    - HRT = 1.9 h
  - AFMBR
    - GAC = 50%
    - HRT = 3.1 to 3.5 h
    - Hollow Fiber Membranes (PVDF, 0.03 μm)
    - Membrane Flux = 7.4 to 6.5 L/m²/h
  - Total HRT = 5 to 5.4 h
  - 2 mm-screened primary clarifier effluent
### III. Pilot Results

#### COD Removals

<table>
<thead>
<tr>
<th>Day</th>
<th>Season</th>
<th>Temp. (°C)</th>
<th>Inf. (mg/L)</th>
<th>AFBR Eff. (mg/L)</th>
<th>AFMBR Eff. (mg/L)</th>
<th>Rem. (%)</th>
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<tbody>
<tr>
<td>0–64</td>
<td>Fall</td>
<td>20 – 15</td>
<td>273</td>
<td>172</td>
<td>39</td>
<td>86</td>
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<td>65 –165</td>
<td>Winter</td>
<td>15 – 8</td>
<td>319</td>
<td>231</td>
<td>58</td>
<td>81</td>
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<tr>
<td>166–273</td>
<td>Spring</td>
<td>15 – 25</td>
<td>371</td>
<td>252</td>
<td>39</td>
<td>90</td>
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<td>274–366</td>
<td>Summer</td>
<td>25 – 30</td>
<td>282</td>
<td>152</td>
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<td>95</td>
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<td>367–383</td>
<td>Fall(II)</td>
<td>25 – 20</td>
<td>226</td>
<td>164</td>
<td>15</td>
<td>93</td>
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</table>
### III. Pilot Results

#### BOD$_5$ Removals

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<tr>
<th>Day</th>
<th>Season</th>
<th>Temp. (°C)</th>
<th>Inf. (mg/L)</th>
<th>AFBR Eff. (mg/L)</th>
<th>AFMBR Eff. (mg/L)</th>
<th>Rem. (%)</th>
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<tbody>
<tr>
<td>0 – 64</td>
<td>Fall</td>
<td>20 – 15</td>
<td>169</td>
<td>75</td>
<td>18</td>
<td>89</td>
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<tr>
<td>65 – 165</td>
<td>Winter</td>
<td>15 – 8</td>
<td>233</td>
<td>121</td>
<td>33</td>
<td>86</td>
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<tr>
<td>166 – 273</td>
<td>Spring</td>
<td>15 – 25</td>
<td>187</td>
<td>127</td>
<td>20</td>
<td>89</td>
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<tr>
<td>367 – 383</td>
<td>Fall(II)</td>
<td>25 – 20</td>
<td>148</td>
<td>105</td>
<td>5</td>
<td>97</td>
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III. Pilot Results

- **TMP Variations**

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<tr>
<th></th>
<th>Fall</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Fall (II)</th>
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<tbody>
<tr>
<td>Day</td>
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</tbody>
</table>

- TMP Variations

- **System problem**

- **Idling 36 hr**

**Graph Details**

- **TMP (hollow fiber)**
- **Flux (LMH)**
- **TMP variations**
- **Fall (II)**
## III. Pilot Results

**Energy Balance (kWh/m\(^3\))**

<table>
<thead>
<tr>
<th></th>
<th>Energy requirement</th>
<th>CH(_4) Energy Potential*</th>
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<tbody>
<tr>
<td></td>
<td>GAC</td>
<td>Membrane</td>
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<tr>
<td>AFBR</td>
<td>0.009</td>
<td>-</td>
</tr>
<tr>
<td>AFMBR</td>
<td>0.104</td>
<td>0.003</td>
</tr>
<tr>
<td>total</td>
<td>0.113</td>
<td>0.003</td>
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</table>

* This does not include methane from primary sludge

** Conventional gas purging requires 0.5-1.0 kWh/m\(^3\)**
1. Effluent qualities of the AnMBR treated DWW at a total HRT of < 6 h and ambient temperatures (8 – 30 °C) was comparable to those of the conventional aerobic processes
   - Removals of COD > 85% and BOD$_5$ > 90%
   - Effluent COD < 30 mg/l and BOD$_5$ < 5 mg/L

2. GAC souring was very effective tool for reducing membrane fouling at low operating cost.

3. The AnMBR is a low-biosolids-producing, high-efficiency domestic wastewater treatment system with net energy production and sludge reduction potential.
IV. Future Directions

- Optimization of AFMBR
- Recovery and use of dissolved methane
- Control of \( \text{H}_2\text{S} \) production or its utilization
- N and P recovery
- Nitrogen removal
  - Heterotrophic method is not an option
  - Anammox
  - Short-cut denitrification with sulfide or S
  - Use of dissolved methane
INHA WCU team is Developing the Best Anaerobic Membrane Technology for Domestic Wastewater
COD mass balance

<table>
<thead>
<tr>
<th>Content</th>
<th>Conc. (mgCOD/L)</th>
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<tbody>
<tr>
<td>Influent</td>
<td>227</td>
</tr>
<tr>
<td>Effluent</td>
<td>11</td>
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<tr>
<td>COD removed</td>
<td>216</td>
</tr>
<tr>
<td>Dissolved CH₄</td>
<td>33</td>
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<tr>
<td>Gaseous CH₄</td>
<td>88</td>
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<tr>
<td>SO₄²⁻ reduction</td>
<td>23</td>
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<tr>
<td>Biosolids</td>
<td>30</td>
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<tr>
<td>Unknown</td>
<td>31</td>
</tr>
</tbody>
</table>

III. Pilot Results

- **Dissolved CH₄** 14%
- **Gaseous CH₄** 41%
- **Biosolids** 14%
- **Unknown** 14%
- **Sulfate reduction** 11%
- **Effluent** 5%
## Publications on the SAF-MBRs

1. Domestic Wastewater Treatment as a Net Energy Producer – Can This be Achieved? *Env. Sci. Tech.*, 2011


I. Wastewater as Resources

● Energy: Contents and Treatment Requirements

Energy footprint of the water treatment processes
Thank you