A Neighborhood Fecal Sludge Treatment System Using Supercritical Water Oxidation

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“INSTITUTIONAL” OPEN DEFECATION
Untreated sludge ends in the environment (Dhaka, Bangladesh)

Source: WSP analysis, using BMGF funded research
This is a 87 kWh dump!!!

...a 15 L hot shower ~ 0.4 kWh
Our Vision: Omni Processor for Fecal Waste

Sanitation for the urban poor using supercritical water oxidation (SCWO)

Pit Latrine Collection & Transport Businesses

Community

Ablution Blocks

Public Toilets

Supercritical treatment facility, 20 ft. container for ~1000 people

1000 users equivalent ~450-530 kWh/d
In supercritical water, organics are rapidly oxidized (in seconds) resulting in heat, and CO$_2$

**Benefits**
- Very fast reaction (sec.)
- High conversion to CO$_2$ + clean water
- No SOx, NOx or odor
- No need to dry waste
- Can co-treat haz. wastes

**Technical risks**
- Corrosion
- Salts deposition/plugging

**Diagram**

**Fecal slurry + Air**

<table>
<thead>
<tr>
<th>T &gt; 375 °C</th>
<th>P &gt; 240 bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO$_2$ + H$_2$O + N$_2$ + ashes + heat</td>
<td></td>
</tr>
<tr>
<td>100 m$^3$</td>
<td>~1 m$^3$</td>
</tr>
</tbody>
</table>

1 m$^3$ 600 m$^3$
100 kg solids 160 kg O$_2$ 180 kg
Pilot unit at Duke: 1000 p/d

- Heat and energy recovery
- Metallurgy and corrosion
- Process control
- Slurry pumping
System Characteristics

Basic characteristics
- 100-150 kg dry/day
- 1-2 m³/day
- Feed ~7-20% solids
- Reactor ID: 19 mm
- Reactor length: 4.0 m
- Heat exchanger: 39 m
- Reaction time = 2.5 to 4.5 s

Anti corrosion and plugging measures
- High Re number, slight down slope
- Minimize transition zones
- Stainless steel and special alloys
- Continuous operation with periodic maintenance

Other
- Startup with isopropyl alcohol (IPA) but any other liquid fuel will work
- Air is used as oxidant
Pilot unit construction
Process flowsheet

- **SCWO Reactor**
  - Temperature: $T = 540 - 573 \, ^{\circ}C$ (556 \, ^{\circ}C)

- **Furnace**
  - Temperature: $T = 661 \, ^{\circ}C$
  - $T = 550 \, ^{\circ}C$
  - $T = 540 - 573 \, ^{\circ}C$ (556 \, ^{\circ}C)

- **Water/Air Preheat**
  - Temperature: $T = 356 - 365 \, ^{\circ}C$

- **Sludge preheat**
  - Temperature: $T = 22 \, ^{\circ}C$
  - $T = 200 \, ^{\circ}C$

- **Clean Water**
  - Temperature: $22 \, ^{\circ}C$

- **Gases**
  - $CO_2+N_2$

- **Water Pump**
- **Water Tank**
  - Temperature: $275 \, ^{\circ}C$

- **Water recycle loop**

- **Effluent**

- **Separation / Expansion**
  - $T = 540 - 573 \, ^{\circ}C$ (556 \, ^{\circ}C)

- **Heat Exchangers**

- **Slurry Pump**
  - $T = 540 - 573 \, ^{\circ}C$ (556 \, ^{\circ}C)

- **Slurry Tank**

- **Air Compressor**
Secondary sludge
Dry solids-content ~16%
Ash content: 20-24%
HHV: 15 MJ/kg$_{\text{dry}}$

Dog feces
Dry solids-content 20-30%
Ash content: 27%
HHV: 15.7 MJ/kg$_{\text{dry}}$

- Used as surrogates for human fecal waste (diluted to 4-10% solids)
- Mixed with IPA because of pumping issues
Secondary Sludge Treatment

Biosolids (14 MJ/kg dry)

Feed

Effluent

Effluent After settling

Slurry feed: 4.3% biosolids 9% IPA
Temperatures During a Typical Run

- **Heating up**
- **Steady state** IPA
- **Steady state dog feces**
- **Cooling down**

**Reactor**

**Pre-heated slurry**

**Effluent**

**Temperature, C**

**Time**

- 6:00
- 7:12
- 8:24
- 9:36
- 10:48
- 12:00
- 13:12
- 14:24
- 15:36
- 16:48
- 18:00
- 19:12
- 20:24
# Secondary Sludge Treatment Summary

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Influent (3% sludge + 9% IPA)</th>
<th>Effluent Steady State</th>
<th>Removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/L)</td>
<td>214,000</td>
<td>70</td>
<td>99.97</td>
</tr>
<tr>
<td>Total N (mg/L)</td>
<td>10,875</td>
<td>200</td>
<td>98.12</td>
</tr>
<tr>
<td>NH₃ (mg/L)</td>
<td>443</td>
<td>17.6</td>
<td></td>
</tr>
<tr>
<td>NO₃⁻ (mg/L)</td>
<td>183</td>
<td>15.9</td>
<td></td>
</tr>
<tr>
<td>NO₂⁻ (mg/L)</td>
<td>14.9</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>PO₄³⁻ (mg/L)</td>
<td>4930</td>
<td>67.9</td>
<td>98.60</td>
</tr>
<tr>
<td>pH</td>
<td>6.8</td>
<td>7.02</td>
<td></td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>2560</td>
<td>659</td>
<td></td>
</tr>
</tbody>
</table>
Dog Feces Treatment

Slurry feed pre-processing:
14% solids (15.7 MJ/kg dry)

Feed
10% solids
+ 4% IPA

Effluent
# Fresh Dog Feces Treatment Summary

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Influent (10% feces + 4% IPA)</th>
<th>Effluent Steady State</th>
<th>Removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/L)</td>
<td>192,000</td>
<td>65-280</td>
<td>99.97-99.85</td>
</tr>
<tr>
<td>Total N (mg/L)</td>
<td>4704</td>
<td>220-420</td>
<td>95.32-91.70</td>
</tr>
<tr>
<td>NH₃ (mg/L)</td>
<td>627</td>
<td>185-325</td>
<td></td>
</tr>
<tr>
<td>NO₃⁻ (mg/L)</td>
<td>98</td>
<td>0.3-0.8</td>
<td></td>
</tr>
<tr>
<td>NO₂⁻ (mg/L)</td>
<td>22.5</td>
<td>0.04-0.54</td>
<td></td>
</tr>
<tr>
<td>PO₄³⁻ (mg/L)</td>
<td>14,500</td>
<td>13.4-63.9</td>
<td>99.91-99.56</td>
</tr>
<tr>
<td>pH</td>
<td>5.95</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Conductivity (µS/cm)</td>
<td>4500</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
## Fate of Metals and Other Elements

### Dog Feces Run

<table>
<thead>
<tr>
<th>Element</th>
<th>Conc. dry feces (mg/kg dry)</th>
<th>Conc. liquid feed (mg/L)</th>
<th>Conc. liq. effluent (mg/L)</th>
<th>Conc. dry ashes (g/kg dry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>75,400</td>
<td>2,932</td>
<td>27.50</td>
<td>298</td>
</tr>
<tr>
<td>S</td>
<td>6,180</td>
<td>240</td>
<td>49.70</td>
<td>1.55</td>
</tr>
<tr>
<td>P</td>
<td>4,040</td>
<td>157</td>
<td>2.92</td>
<td>25.2</td>
</tr>
<tr>
<td>K</td>
<td>2,580</td>
<td>100</td>
<td>28.60</td>
<td>2.26</td>
</tr>
<tr>
<td>Fe</td>
<td>1,820</td>
<td>70.8</td>
<td>&lt; 0.05</td>
<td>10.1</td>
</tr>
<tr>
<td>Zn</td>
<td>1,000</td>
<td>38.9</td>
<td>0.04</td>
<td>4.32</td>
</tr>
<tr>
<td>Al</td>
<td>450</td>
<td>17.5</td>
<td>&lt; 0.05</td>
<td>4.44</td>
</tr>
<tr>
<td>Cu</td>
<td>93.6</td>
<td>3.64</td>
<td>0.16</td>
<td>0.23</td>
</tr>
<tr>
<td>Cr</td>
<td>83.2</td>
<td>3.24</td>
<td>&lt; 0.01</td>
<td>0.32</td>
</tr>
<tr>
<td>Ni</td>
<td>57.2</td>
<td>2.22</td>
<td>0.20</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Influent

[Image of Dog Feces Run]

Effluent

[Image of Effluent]

Ashes

[Image of Ashes]
Treatment of Micro-Pollutants

Experimental Approach
• Spiked trace contaminants during a run
• Used high concentrations of Triclosan, Acetaminophen, and Ibuprofen
• Run with spiked IPA first, then spiked dog feces and IPA

Results
• Ibuprofen and acetaminophen (10 mg/L each) – not analyzed yet

• Triclosan:
  Relevant concentration: 0.5 – 1 µg/L
  Concentration spiked: 100 µg/L
  Concentration in effluent (IPA treatment): ND at < 0.1 µg/L
  Concentration in effluent (dog feces + IPA treatment ): < 0.1 µg/L
  Removal > 99.99%
Energy Balances – 1000 users/day

- Compressor: 9 kW
- Water pump: 1.9 kW
- PLC + other: 1.7 kW
- Furnace: 7 kW
- Heat losses: 10 kW
- Reaction: +21 kW
- Feed calorific value: +21 kW
- Slurry pump: 1.7 kW
- Final cooling: 18-20 kW

- Compressor = biggest draw
- Losses + final cooling → not autothermal

Optimized design:
- Turn of furnace (autothermal)
- Recover energy from gas expansion (3-6 kW)
- Expected draw = 6-10 kW (this is 6-10 W/p)
- Produce 5-10 kW has heat
Current and future activities

• Modify current prototype for greater energy efficiency
• New slurry pump to allow operation with high solids content and larger particles
• Techno-economic analysis, sensitivity of CAPEX and OPEX to size
• Design of an optimized and manufactureable product
Conclusions

• SCWO can turn fecal waste into clean water and heat really fast without odor, SOx, or NOx emissions…
• All pathogens are killed
• SCWO can even co-treat hazardous wastes
• Selling “high value added” by products can be a driver

• But many challenges remain…

Acknowledgments
Gates Foundation for funding

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