Anaerobic Digestion of Food Waste Through the Operation of a Mesophilic Two-Phase Pilot Scale Digester

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The Overall System

• Vertical aeroponic greenhouse.
• Wood pellet and passive solar boiler.
• Anaerobic digester for food waste.
The Vision
The Motivation

- 35 million tons of food waste is produced out of 250 million tons MSW each year.\(^1\)

- Landfills are third largest human methane source.\(^1\)
- High disposal costs of waste removal.

- Anaerobic digestion is a biological process that converts organic substrates into primarily methane and carbon dioxide in absence of oxygen.
Food Waste Potential

- Food waste has higher biogas potential than other sources like agriculture and wastewater sludge.
Food Waste Success Stories

• East Bay Municipal Utility District, Oakland, CA
  – First wastewater treatment plant in the nation to convert post-consumer food scraps to energy via anaerobic digestion.
  – Methane powers plant and produces natural fertilizer.

• University Wisconsin, Oshkosh
  – Use dry fermentation technology to digest university food waste scraps and city yard waste to produce enough electricity to power up to 15% of institution’s electricity.
Clarkson’s Mixed Food Waste Composition

- Chemical Oxygen Demand (COD) = 268,264 ± 181,549 mg/L
- Total Solids (TS) = 19.66 ± 12.88%
- Volatile Solids (VS) = 18.74 ± 12.60%
Clarkson’s Digester Operation

- Ability to run single stage and two-phase digestion.
- Separate mixing cycles for each stage.
• Material grinding and feeding system
• Three 5 m³ reactors operated as two-stage digester
• Biogas generated in the anaerobic environment
• ENI 20kW co-generation combustion engine → CHP
• Instrumentation for independent operation and remote control
Anaerobic digester
Up to 300 kg food waste/day
Transformed into biogas
Savings - $200/ton food waste diverted from landfill
Given the variable loading what process will be most reliable and efficient?

• Single stage system could result in overloading at high loading conditions, or

• Fermentation stage of 2-stage system may be difficult to maintain during low loading conditions
Approach

• Operate system first as single stage system at higher loading rates
• Followed by 2-stage operation at low loading
Digester Loading Rate

Food Waste Loading [kg/(m³d)]

Digester Operation [d]

1-stage  2-stage
2-phase digestion

Influent → Hydrolysis → Acidogenesis → 1st Stage effluent → Acetogenesis → Methanogenesis → Digested Effluent

H₂ & CO₂ → Bio-gas (CH₄ & CO₂)

Volatile Fatty Acid (VFA)

*K. Venkiteshwaran “Two-Stage Anaerobic Co-Digestion using crude glycerol or cheese whey with dairy manure to improve methane production”*
Food Loading Variation

Average 37 kg/day
Peaking Factor ~ 6
Methane Content

http://greenhouse.wlan.clarkson.edu:8080/mango/login.htm
Methane Production against COD removal

Methane Yield: 488 L-CH₄·kg-COD⁻¹ removed  (Range = 1784 – 15 L-CH₄·kg-COD⁻¹ removed )
Methane Production against VS Added

Methane Yield: 628 L-CH₄·kg-VS⁻¹ Added (Range = 2230 – 13 L-CH₄·kg-VS⁻¹ added)
Chemical Characterization Results

93% Reduction in COD
94% Reduction in VS
Fermentation Stage HRT Affecting pH in Reactor

Acid Reactor 15-day Average HRT
Acid Reactor pH
## Process Comparison

<table>
<thead>
<tr>
<th></th>
<th>One-stage</th>
<th>Two-stage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COD (mg·L⁻¹)</strong></td>
<td>273400</td>
<td>267000±149900</td>
</tr>
<tr>
<td><strong>TS (%)</strong></td>
<td>19.62</td>
<td>23.62±7.85%</td>
</tr>
<tr>
<td><strong>VS (%)</strong></td>
<td>18.69</td>
<td>22.88±8.53%</td>
</tr>
<tr>
<td><strong>Digester operation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VS loading rate (kg·m⁻³ d⁻¹)</strong></td>
<td>3.79</td>
<td>0.78±0.42</td>
</tr>
<tr>
<td><strong>COD loading rate (kg·m⁻³ d⁻¹)</strong></td>
<td>3.87±1.93</td>
<td>0.79±0.16</td>
</tr>
<tr>
<td><strong>Digester characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>7.32</td>
<td>5.2±0.4</td>
</tr>
<tr>
<td><strong>COD (mg·L⁻¹)</strong></td>
<td>19730</td>
<td>162700±60900</td>
</tr>
<tr>
<td><strong>VS (%)</strong></td>
<td>0.84</td>
<td>6.01±3.31%</td>
</tr>
<tr>
<td><strong>TS (%)</strong></td>
<td>1.54</td>
<td>7.32±3.37%</td>
</tr>
<tr>
<td><strong>VFA (mg·L⁻¹ as HAc)</strong></td>
<td>38900±4800</td>
<td>6300±3600</td>
</tr>
<tr>
<td><strong>Digester performances</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temperature (°C)</strong></td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td><strong>VS removal (%)</strong></td>
<td>96</td>
<td>94</td>
</tr>
<tr>
<td><strong>COD removal (%)</strong></td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td><strong>Methane concentration (%)</strong></td>
<td>59</td>
<td>63</td>
</tr>
<tr>
<td><strong>Methane yield (L·CH₄·kg VS⁻¹)</strong></td>
<td>380</td>
<td>628</td>
</tr>
<tr>
<td><strong>Methane yield (L·CH₄·kg COD⁻¹ removed)</strong></td>
<td>359</td>
<td>488</td>
</tr>
</tbody>
</table>
So...

- 2-stage system stable during low loading conditions
- 2-stage system slightly more efficient compared to single system
- System net energy positive at full capacity operation
Inhibitory Effects of Ammonia

![Graph showing the inhibitory effects of ammonia on net methane production rate per COD added. The x-axis represents ammonia concentration (TAN) in g/mL, and the y-axis represents net methane production rate per COD added in mL/hr/g. Two curves are shown: one for food waste only and another for co-digestion. The data points indicate a decrease in net methane production rate with increasing ammonia concentration.]
Literature Comparison

$K_I$ Values

Manure/Animal Waste
- 4 mg/L NH$_3$-N
- 213.3 mg/L NH$_3$-N
- 1600 mg/L NH$_3$-N
- 1450 mg/L NH$_3$-N

OFMSW
- 215 mg/L NH$_3$-N
- 98.7 mg/L NH$_3$-N
- 88.0 mg/L NH$_3$-N
- 180.9 - 230.3 mg/L NH$_3$-N
- 158.4 - 395.4 mg/L NH$_3$-N
- 161.9 - 219.8 mg/L NH$_3$-N
- 237.6 mg/L NH$_3$-N

Clarkson’s Kitchen Waste
- 341 mg/L NH$_3$-N

$K_I$ Value

- Monod Inhibition Coefficient. $K_I$

The 95th percentile of $K_I$ is between 206 mg/L and 993 mg/L
Membrane Assisted TAN Removal

- Nafion cation exchange membrane
- Batch TAN removal

TAN flux of 140 g/(m²d)

Come see the poster for more information
In Conclusion

- System is very stable despite high peaking factors and low loading conditions
- Two stage operation generates more biogas than single stage system
- Ammonia recovery will maintain fertilizer value of effluent AND increase biogas yield