HOW TO GET THE MOST BANG FOR YOUR BUCK: IMPROVING OPERATION AND OPTIMIZATION OF DIGESTION SYSTEMS

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AGENDA

• Why Digest?
• What do we need for good anaerobic digestion?
• Common digestion problems
• How can we ensure good digester operation?
• Improving digestion
WHY DIGEST?
WHY DIGEST?

- Reduce solids quantity for dispersal
- Produce stabilized biosolids
- Meet regulations for land application
  - Vector attraction reduction requires >38% VSR
  - Class B requires 15 days SRT
- Produce biogas to convert to electricity or renewable natural gas
- Reduce product odor
Digestion stabilizes biosolids. Land based use is a sustainable means of recycling the valuable nutrients present in biosolids.
MORE CARBON (BOD) Higher Aeration Costs

Less energy produced.

INFLUENT

PRIMARY CLARIFIER

ANAEROBIC

ANOXIC

AEROBIC

SECONDARY CLARIFIER

EFFLUENT

PRIMARY SLUDGE

WAS

FILTRATE

 PRIMARY SLUDGE

ANAEROBIC DIGESTER

DEWATERING

DEWATERED SOLIDS

CHP
OPTIMIZING USE OF CARBON

Lower aeration costs

MORE CARBON (BOD)

More energy produced.

More biogas

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DEWATERING

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FILTRATE

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ANAEROBIC DIGESTER

INFLUENT

PRIMARY CLARIFIER

MORE CARBON (BOD)
REQUIREMENTS FOR EFFECTIVE DIGESTION
ANAEROBIC DIGESTION

Hydrolysis

Acidogenesis

Acetogenesis + Hydrogen Production

Methanogenesis

Complex Organics

Simple Organics

Long Chain Fatty Acids

\[ \text{CO}_2 + \text{H}_2 \]

\[ \text{Acetic Acid} \]

\[ \text{CH}_4 \]
pH BUFFERING IN DIGESTERS

Complex Organics

Simple Organics

Long Chain Fatty Acids

Acetic Acid

CO$_2$ + H$_2$

CH$_4$

Nitrogen

Ammonium bicarbonate
WHAT DO WE NEED FOR DIGESTION TO WORK?

Feed

Bacteria

Good Mixing

Heat

Time (SRT)

Alkalinity
SOME COMMON DIGESTER PROBLEMS
COMMON DIGESTER PROBLEMS

Causes
- Insufficient SRT
- Lack of acclimatization of bacteria
- Insufficient alkalinity (not enough pH buffering)
- Lack of mixing
- Overloading / excessive increase in organic loading
- Struvite Formation

Symptoms
- Drop in pH
- Drop in methane production
- Foaming
- Increase in CO2 content of biogas
- Poor VS conversion
- Blocked Pipework & Equipment Problems
FOAMING - REASONS FOR DIGESTER FOAM

- Filamentous bacteria / nocardia
- Grease and oils
- Change in feed characteristics
- Unstable digester organic loading rate

So what?

- Blocked digester gas pipelines
- Blocked or clogged pressure relief valves and flame arrestors
- Extreme cases - a mess to clean up
ANOTHER EXAMPLE OF SEVERE FOAMING
Cleansing Up The Mess
INCONSISTENT FEEDING OF THE DIGESTER
STRUVITE
WHAT IS STRUVITE?

Magnesium

$\text{Mg}^{2+}$

Ammonium

$\text{NH}_4^+$

Phosphate

$\text{PO}_4^{3-}$

Mg$\text{NH}_4\text{PO}_4$

(Struvite)
WHEN WILL STRUVITE FORM?

- At equilibrium......
- \([\text{Mg}^{2+}] [\text{NH}_4^+] [\text{PO}_4^{3-}] = K_{sp}\)
- Ksp = solubility product constant
WHEN WILL STRUVITE FORM?

- \([\text{Mg}^{2+}] \ [\text{NH}_4^+] \ [\text{PO}_4^{3-}] < K_{sp}\)
  
  Struvite will not precipitate

- \([\text{Mg}^{2+}] \ [\text{NH}_4^+] \ [\text{PO}_4^{3-}] > K_{sp}\)
  
  Struvite will precipitate

i.e. more Mg, NH4 and PO4 = more struvite
EFFECT OF PH ON STRUVITE

- Concentration of ionic species is pH dependent
- For example:

\[
\begin{align*}
\text{NH}_3 + H^+ & \rightleftharpoons \text{NH}_4^+ \\
\text{H}_3\text{PO}_4 & \rightleftharpoons \text{PO}_4^{3-} + 3H^+ \\
\text{High pH} & \rightarrow \text{Low pH} \\
\text{Low PH} & \rightarrow \text{High pH}
\end{align*}
\]

Overall effect is that struvite precipitation increases as pH increases
Lots of CO$_2$ is released when digested sludge is exposed to air

Loss of CO$_2$ $\Rightarrow$ increase in pH $\Rightarrow$ more struvite precipitation

- Lots of CO$_2$ in biogas (30%)
- Lots of dissolved CO$_2$
- Equilibrium

- Not much CO$_2$ in air (0.04%)
- Lots of dissolved CO$_2$
- Imbalance

In the digester

Open to atmosphere

- Implementing THP
- 7/28/2016
MANAGING STRUVITE

- Avoid turbulence / exposure to air in places where struvite formation will cause most problems
- Plan for cleaning / pigging of at risk pipework & structures
- Consider encouraging struvite formation where it won’t cause a problem (e.g. dedicated precipitation tank)
- Turn a problem into an opportunity and consider options for struvite harvesting

Source: Ostara
EVALUATING MIXING EFFICIENCY USING COMPUTATIONAL FLUID DYNAMICS (CFD)

Sludge Rheology → CFD
WHAT HAPPENS WHEN MIXING SYSTEMS FAIL.........
SO HOW DO WE ENSURE GOOD DIGESTER OPERATION?
KEY TO STABLE DIGESTER OPERATION

A stable volatile solids / COD Loading Rate

REMEMBER!

GALLONS  POUNDS
These are typical values for conventional digestion. Important to establish normal ranges for your own system. Higher loading can be achieved with ‘advanced digestion systems’.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solids retention time</td>
<td>days</td>
<td>&gt;12 (min)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;15 (Class B)</td>
</tr>
<tr>
<td>VS loading</td>
<td>lbVS/CF.d</td>
<td>&lt;0.15 (av)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;0.18 (max)</td>
</tr>
<tr>
<td>COD loading&lt;sup&gt;1&lt;/sup&gt;</td>
<td>lbCOD/lbVS in digester.d</td>
<td>&lt;0.25-0.3</td>
</tr>
<tr>
<td>Temperature</td>
<td>oF</td>
<td>95-105</td>
</tr>
<tr>
<td>VS reduction</td>
<td>%</td>
<td>45-60</td>
</tr>
<tr>
<td>Methane in biogas</td>
<td>%</td>
<td>55-65</td>
</tr>
<tr>
<td>pH</td>
<td>-</td>
<td>6.5-7.5</td>
</tr>
<tr>
<td>Biogas production</td>
<td>SCF/lb VSR</td>
<td>12-18</td>
</tr>
<tr>
<td>Ammonia concentration</td>
<td>mg/l</td>
<td>&lt;2000</td>
</tr>
<tr>
<td>VFA to alkalinity ratio</td>
<td>mg/l VFA per mg/l alkalinity as CaCO₃</td>
<td>&lt;0.2</td>
</tr>
</tbody>
</table>

<sup>1</sup>A useful rule of thumb if considering co-digestion of high strength waste / FOG
EXAMPLE – INCREASE IN FEED COMBINED WITH LACK OF ACLIMINATION TO FEED STOCK
# Example Monitoring Protocol During Start Up

<table>
<thead>
<tr>
<th>Parameter</th>
<th>pH</th>
<th>VFA/Alkalinity Ratio</th>
<th>Observation of digester foaming</th>
<th>Methane of Gas</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status OK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceptable limits</td>
<td>&gt;7.0</td>
<td>&lt;0.3</td>
<td>No digester foaming observed</td>
<td>60-70%</td>
<td></td>
</tr>
<tr>
<td>Actions required</td>
<td>No action required – continue with planned ramp up regime.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 1 alert</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Action limit</td>
<td>&lt;7.0</td>
<td>&gt;0.3</td>
<td>First sign of foaming</td>
<td>55-60%</td>
<td></td>
</tr>
<tr>
<td>Action required</td>
<td>No immediate change in feed regime.</td>
<td>No immediate change in feed regime.</td>
<td>Begin dosing antifoaming agent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 2 alert</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Action limit</td>
<td>&lt;6.8</td>
<td>&gt;0.4</td>
<td>Significant / Severe foaming observed</td>
<td>50-60%</td>
<td></td>
</tr>
<tr>
<td>Action required</td>
<td>Stop increasing feed rate. (If in ramp up phase). Remain at constant feed rate for 3 days.</td>
<td>Stop increasing feed rate. (If in ramp up phase). Remain at constant feed rate for 3 days.</td>
<td>Stop increasing feed rate. (If in ramp up phase). Remain at constant feed rate for 3 days. Continue dosing antifoaming agent.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 3 alert – still out of limits after previous level 2 alert</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Action limit</td>
<td>&lt;6.8</td>
<td>&gt;0.4</td>
<td>Significant / Severe foaming observed</td>
<td>50-60%</td>
<td></td>
</tr>
<tr>
<td>Action required</td>
<td>Reduce feed rate by 10%. Remain at constant feed rate for 3 days.</td>
<td>Reduce feed rate by 10%. Remain at constant feed rate for 3 days.</td>
<td>Reduce feed rate by 10%. Remain at constant feed rate for 3 days. Continue dosing antifoaming agent.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
VERIFYING DIGESTER ACTIVE VOLUME

\[ y = -7 \times 10^{-7}x + 0.1309 \]

\[ R^2 = 0.9921 \]

Cumulative Volume Pumped to Digester, gallons

\[ \ln \left( \frac{C}{C_0} \right) \]

Digester 4
Linear (Digester 4)
IMPROVING DIGESTION
IMPACT OF FEED SOLIDS CONCENTRATION (EXAMPLE FOR A 1 MG DIGESTER)
IMPACT OF SOLIDS RETENTION TIME

Based on data presented by Nges & Liu, Renewable Energy Vol35 issue 10, 2010
Recuperative thickening is one option to increase SRT with a given digester volume.

E.g. ‘Omnivore system’ offered by Anaergia (source: Anaergia.com)
THERMAL HYDROLYYSIS PROCESS (THP)

- Lysis – breaking stuff apart
- Thermal – with heat
- Hydro – with water (solubilization)
TYPICAL CONFIGURATION (WITH CHP)

- **Solids Dewatering**
- **Boiler**
  - Heat: 90 - 95%
  - Steam: 5 – 10%
- **CHP**
- **Thermal Hydrolysis**
- **Digestion**
- **Dewatering**
TYPICAL CONFIGURATION (WITHOUT CHP)

Solids → Dewatering → Thermal Hydrolysis → Digestion → Dewatering

Boiler: 25-35%
Alt Use / Flare: 65-75%

Steam
THERMAL HYDROLYSIS (BASED ON CAMBI SYSTEM)

- **PULPER**
  - Sludge Feed (Continuous)
  - 16% DS

- **Reactors (2 to 4)**
  - 320 °F
  - 90 PSI
  - Hold for 20-30 min

- **Flash Tank**
  - Depressurize to just above atmospheric pressure
  - Sludge Discharge (Continuous)
  - 225 °F
  - 14% DS

- **Recirculation**
# CAMBI MODELS

<table>
<thead>
<tr>
<th></th>
<th>B2</th>
<th>B6</th>
<th>B12</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Single skid system (pre-assembled)</strong></td>
<td><strong>Multiple skid system (pre-assembled)</strong></td>
<td><strong>Shop assembled components, on-site installation</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Up to 24 dtpd capacity</strong></td>
<td><strong>Up to 90 dtpd capacity</strong></td>
<td><strong>Up to 135 dtpd capacity</strong></td>
</tr>
</tbody>
</table>

Similar systems also provided by Veolia / Kruger. A number of other vendors are also now entering the market.
BENEFITS OF THP

- Less digester volume required (higher loading rates)
- Higher COD and VS conversion in digesters
  - More biogas
  - Less dry solids for disposal
- Better dewaterability (lower VS)
  - Less volume of wet sludge for disposal
- Pathogen free product for land application
### DIFFERENCES BETWEEN CONVENTIONAL DIGESTERS AND THP DIGESTERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional</th>
<th>THP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed solids, %</td>
<td>5 to 6</td>
<td>10 to 12</td>
</tr>
<tr>
<td>Digestate solids, %</td>
<td>3 to 4</td>
<td>5 to 7</td>
</tr>
<tr>
<td>COD/VS conversion, %</td>
<td>40 to 50</td>
<td>55 to 65</td>
</tr>
<tr>
<td>pH</td>
<td>6.8 to 7.5</td>
<td>7.5 to 8.0</td>
</tr>
<tr>
<td>Ammonia as N, mg/L</td>
<td>1,000 to 2,000</td>
<td>2,500 to 3,200</td>
</tr>
<tr>
<td>Alkalinity as CaCO3, mg/L</td>
<td>4,500 to 7,000</td>
<td>9,000 to 11,000</td>
</tr>
<tr>
<td>% CH4 in biogas</td>
<td>55 to 65</td>
<td>65 to 68</td>
</tr>
<tr>
<td>H2S in biogas</td>
<td>Higher concentration</td>
<td>Lower concentration</td>
</tr>
<tr>
<td>Digester temperature, F</td>
<td>85 to 100</td>
<td>95 to 105</td>
</tr>
</tbody>
</table>
Table 1  Base case example

<table>
<thead>
<tr>
<th></th>
<th>Conventional digestion</th>
<th>Digestion +</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry solids feed to digesters</td>
<td>5% (70% VS)</td>
<td>5% (70% VS)</td>
</tr>
<tr>
<td>Digester volume 22,000 m³</td>
<td>25 d HRT</td>
<td>21 d HRT</td>
</tr>
<tr>
<td>Organics (VS) reduction</td>
<td>40 - 45%</td>
<td>50 – 55 %</td>
</tr>
<tr>
<td>Methane production</td>
<td>10,400 Nm³/d</td>
<td>13,000 Nm³/d</td>
</tr>
<tr>
<td>Dry solids after dewatering</td>
<td>23%</td>
<td>50%</td>
</tr>
<tr>
<td>Sludge cake</td>
<td>56,500 t/y (wet)</td>
<td>25,990 t/y (wet)</td>
</tr>
</tbody>
</table>

54% reduction of sludge volume, 25% more biogas.
All steam for the Cambi SolidStream™ process can be recovered from the gas engine waste heat.
THP INTEGRATION: CONSIDERATIONS

• Sludge screening (<6mm)
• Pre-dewatering not just thickening
• Digester mixing
• Digester gas pipework
• Struvite?
• Integration of existing CHP (need steam not hot water)
• Sludge cooling
• Recycle N & P and rDON
THERMO CHEMICAL HYDROLYSIS (TCHP) - PONDUS

1. Thickened Waste Activated Sludge (TWAS)
2. Caustic Soda
3. Heating of recirculating sludge
4. Lysing Reactor
5. Primary sludge
6. Digester
7. Circulation Digester
8. Digester Heating
SUMMARY

- Maintain stable organic loading
- Monitor key parameters during digester operation
- Optimize feed solids concentration / SRT
- Ensure mixing is operating effectively (consider washout tests if VSR is low and mixing efficiency is unknown)
- Consider pre-treatment to increase achievable digester loading
WHAT DO WE NEED FOR DIGESTION TO WORK?

Feed

Bacteria

Good Mixing

Heat

Time (SRT)

Alkalinity

Feed → Bacteria → Good Mixing

Heat

Time (SRT)

Alkalinity

Feed: [Image of a bowtie]

Bacteria: [Images of bacteria]

Good Mixing: [Images of mixing]

Heat: [Image of a thermometer]

Time (SRT): [Image of a clock]

Alkalinity: [Chemical reactions involving water, carbon dioxide, hydrogen ions, and bicarbonate]
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Together

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