Outline

• Anaerobic Digestion Process Basics
• Anaerobic Digester Sizing
• Anaerobic Digester Component Parts
• Anaerobic Digester Process Control
Anaerobic Digester Process Basics
Benefits of Anaerobic Digestion

• Mass and volume reduction
• Reduction of pathogens and stabilization of organics
• Production of energy containing biogas
• Class B product quality
Anaerobic digestion is a process with several “steps” converting solid material into a gas.
Hydrolysis is the first step in converting solids into soluble organic molecules.
Soluble organics are fermented into simple and complex volatile fatty acids (VFAs).
Complex VFA are converted to acetic acid (simplest form of VFA) in acetogenesis.
Acetic acid and hydrogen can be converted biologically to methane via methanogenesis.
Operating conditions for a mesophilic anaerobic digestion process:

<table>
<thead>
<tr>
<th>Operating Condition</th>
<th>Typical Range</th>
<th>Extreme Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (std. units)</td>
<td>7.0 to 7.2</td>
<td>6.8 to 7.4</td>
</tr>
<tr>
<td>ORP (mV)</td>
<td>-520 to -530</td>
<td>-490 to -550</td>
</tr>
<tr>
<td>VFA (mg/L as acetic acid)</td>
<td>50 to 500</td>
<td>&gt; 2,000</td>
</tr>
<tr>
<td>ALK (mg/L as CaCO₃)</td>
<td>1,500 to 3,000</td>
<td>1,000 to 5,000</td>
</tr>
<tr>
<td>Hydraulic Retention Time, days</td>
<td>10-15</td>
<td>7-30</td>
</tr>
<tr>
<td>Biogas (%CH₄ by volume)</td>
<td>65% to 70%</td>
<td>60% to 75%</td>
</tr>
</tbody>
</table>

Some elements can be both stimulatory and inhibitory to methanogenesis.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Stimulatory (mg/L)</th>
<th>Moderate Inhibition (mg/L)</th>
<th>Strong Inhibition (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>100 to 200</td>
<td>3,500 to 5,500</td>
<td>&gt; 8,000</td>
</tr>
<tr>
<td>Potassium</td>
<td>200 to 400</td>
<td>2,500 to 4,500</td>
<td>&gt; 12,000</td>
</tr>
<tr>
<td>Calcium</td>
<td>100 to 200</td>
<td>2,500 to 4,500</td>
<td>&gt; 8,000</td>
</tr>
<tr>
<td>Magnesium</td>
<td>75 to 150</td>
<td>1,000 to 1,500</td>
<td>&gt; 3,000</td>
</tr>
<tr>
<td>Ammonia (as N)</td>
<td>50 to 200</td>
<td>1,500 to 3,000</td>
<td>&gt; 3,000</td>
</tr>
<tr>
<td>Sulfide</td>
<td>N/A</td>
<td>200</td>
<td>200</td>
</tr>
</tbody>
</table>

Ref:
Residence time, $VSR_{\text{max}}$ and degradation rate determine observed VSR

$$VSR_{\text{SRT}} = VSR_{\text{MAX}} \times (1 - e^{-R \times SRT})$$

Where:

$VSR_{\text{SRT}}$ = Volatile Solids Reduction at SRT

$VSR_{\text{MAX}}$ = Maximum Volatile Solids Reduction

SRT = Solids Retention Time, days

R = Rate Constant, days$^{-1}$
Degradation potential among common streams to digesters can vary significantly. The graph shows the volatile solids reduction (%VSR) at selected degradation rate constants for different streams:

- GIW - Low Range
- GIW - High Range
- PS - Low Range
- PS - High Range
- WAS - Low Range
- WAS - High Range

The y-axis represents the Volatile Solids Reduction (%VSR), ranging from 0.0% to 100.0%. The x-axis represents the Digester Residence Time (days), ranging from 0.0 to 50.0. The data points are color-coded to distinguish between the different streams and their low and high range conditions.
Digester Sizing Considerations
Hydraulic retention time is an important factor in digester sizing.

\[ HRT = \frac{\text{Digester Tank Volume}}{\text{Volumetric Feed to Digester}} \]

Where:
- Volumetric Feed to the Digester = gallons/day
- Digester Tank Volume = gallons
- HRT = Hydraulic Retention Time, days
**Typical hydraulic retention time sizing and evaluation criteria for mesophilic digesters.**

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>AVG365</th>
<th>MAX30</th>
<th>MAX07</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Digester Tanks in Service, days</td>
<td>25.0</td>
<td>20.0</td>
<td>15.0</td>
</tr>
<tr>
<td>One (Largest) Digester Tank out of Service, days</td>
<td>20.0</td>
<td>15.0</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Note:
1. Design HEX system to accommodate operation under winter loadings down to at least 12.5-days in digester tank.
2. If evaluating existing confirm HEX system can accommodate loadings down to minimum HRT at winter conditions.
Volatile solids organic loading rate (VSLR) is one measure to track digester loading.

\[
VSLR = \frac{\text{Volatile Solids Feed to Digester}}{\text{Digester Tank Volume}}
\]

Where:
- Volatile Solids Feed to the Digester = lb(VS)/day
- Digester Tank Volume = 1,000 cubic feet
- VSLR = Volatile Solids Loading Rate, lb(VS)/day-1000ft³
Typical and maximum VSLR for well heated and mixed digesters.

<table>
<thead>
<tr>
<th></th>
<th>Metric Units (kg/m³-day)</th>
<th>English Units (lb/1000ft³-day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical VSLR</td>
<td>&lt; 2.4</td>
<td>&lt; 150</td>
</tr>
<tr>
<td>Range VSLR</td>
<td>1.6 to 6.2</td>
<td>100 to 400</td>
</tr>
</tbody>
</table>

Digester Component Parts
The anaerobic digester system has several major supporting systems

- Mixing
- Heating
- Covers
- Gas Handling & Treatment
Digester Mixing Systems

• Draft Tubes
• Pumped Mixing Systems
• Gas Mixing Systems
• Linear Motion Mixer
Effective digester mixing provides several operational benefits:

- Elimination of temperature stratification and maintenance of homogeneous mixture
- Rapid dispersion of raw feed sludge with the active biomass
- Mitigation of formation of excessive floating scum layers or deposition of heavy silt, grit and inert solids
Typical design criteria for digester mixing systems.

<table>
<thead>
<tr>
<th>Mixing Criteria</th>
<th>Type of Mixing System</th>
<th>Process Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Power, HP/1000cft</td>
<td>Mechanical, Pumped</td>
<td>0.2 to 0.3</td>
</tr>
<tr>
<td>Unit Gas Flow, CFM/1000cft</td>
<td>Gas – Unconfined</td>
<td>4.5 to 5.0</td>
</tr>
<tr>
<td>Unit Gas Flow, CFM/1000cft</td>
<td>Gas - Confined</td>
<td>5.0 to 7.0</td>
</tr>
<tr>
<td>Velocity Gradient “G”, 1/sec.</td>
<td>All Types</td>
<td>50 to 80</td>
</tr>
<tr>
<td>Turnover Time, minutes</td>
<td>Confined Gas / Mechanical Systems</td>
<td>20 to 30</td>
</tr>
</tbody>
</table>

Draft tube mixers can be side mounted or cover mounted

Courtesy: Olympus Technologies, Inc.
Pumped mixing systems from Vaughan and Siemens JetMix use nozzles.
“Cannon” are floor mounted inside the digester and gas is recirculated
Linear motion mixers are relatively new to the market for digester mixing
Heating

• Heat Exchangers

• Hot Water Boilers

• Combination Boiler / HEX Systems
Tube-in-Tube heat exchangers are among the most commonly applied HEX units.
Spiral heat exchangers have also been used for digester heating.
Combination hot water boiler / heat exchanger
Covers

• Fixed Covers
• Gas Holder Covers
• Steel Truss Floating Covers
• Membrane
Fixed covers are the least costly but have special operating considerations.

Courtesy: Olympus Technologies, inc.
Floating covers are ballasted and can provide for some gas storage capacity.
Membrane covers can provide high gas storage volume
Different cover types have different advantages and disadvantages.

<table>
<thead>
<tr>
<th></th>
<th>Drawdown</th>
<th>Gas Holding</th>
<th>Odor Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Cover</td>
<td>No</td>
<td>No</td>
<td>Excellent</td>
</tr>
<tr>
<td>Floating Cover</td>
<td>Yes</td>
<td>No</td>
<td>Moderate</td>
</tr>
<tr>
<td>Floating Gas Holder</td>
<td>Yes</td>
<td>Yes</td>
<td>Moderate</td>
</tr>
<tr>
<td>Membrane</td>
<td>Yes</td>
<td>Yes</td>
<td>Excellent</td>
</tr>
</tbody>
</table>
Gas Handling and Treatment

- Condensate and Moisture Removal
- Sulfide Removal
- Siloxane Removal
- Gas Storage
- Waste Gas Flaring
Gas handling equipment for condensate removal
Gas handling equipment for moisture removal
Iron sponge can be used for sulfide removal from digester gas
Activated carbon treatment and be utilized for siloxane removal
Gas storage can be provided in several different ways within the facility.
Waste gas flare for burning excess digester gas
Digester Process Control Monitoring
Process monitoring should be done for each of the feedstock streams

- Daily Volumetric Feed Rate (gallons/day)
- Raw Feed Total Solids (mg TSS/L or %TS)
- Raw Feed Volatile Fraction (VS/TS Ratio)
- Raw Feed Temperature (°F)
Process monitoring recommendations for each digester tank in service

- Blended Volumetric Feed Rate (gallons/day)
- Blended Feed Total Solids (mg TSS/L or %TS)
- Blended Feed Volatile Fraction (VS/TS Ratio)
- Digester Temperature (°F)
- Digester VFA (mg/L as acetic acid)
- Digester Alkalinity (mg/L as CaCO3)
- Digester VFA/ALK Ratio
- Digester Volume (gallons)
Process monitoring parameters for the digester heating system

- Primary Hot Water Loop Temperature
- Secondary Loop Temperature(s)
  - HEX Sludge Inlet Temperature
  - HEX Sludge Outlet Temperature
  - HEX Hot Water Supply (Inlet) Temperature
  - HEX Hot Water Return (Outlet) Temperature
- Digester Gas Consumption to Boilers
- Natural Gas Consumption to Boilers
Process monitoring parameters for the digester gas utilization systems

• Total Digester Gas Production
  – Digester Gas to Hot Water Boilers
  – Digester Gas to Thermal Dryer
  – Digester Gas to Waste Gas Flares

• Digester Gas Pressure
  – Operating pressure under digester cover
Failure indicators to be on the look out for in your process control monitoring

- Volatile fatty acids (VFA) concentration increases rapidly
- Bicarbonate alkalinity decreases rapidly
- Reactor pH declines below 6.8 std. units
- Gas production rate decreases relative to the volatile loading to the reactor
- Carbon dioxide in the digester gas increases significantly
Keep VFA/ALK in the proper balance for good digester “health”

- Typical VFA/ALK = 0.02 to 0.05 (2% to 5%)
- High VFA/ALK = 0.08 to 0.10 (8% to 10%)
- If VFA/ALK gets to high:
  - VFA production exceeds VFA consumption
  - Organic overloading risk
  - Buffering capacity may be compromised
  - pH could drop in the reactor below 6.8
  - pH shift can further compromise methanogenesis
Typical causes of process failure in anaerobic digestion systems

- Mechanical failure
- Hydraulic overload
- Organic overload
- Toxic overload
UNIFORMITY and CONSISTENCY is the Key

• UNIFORMITY
  – Strive for uniform loading rates across time
  – Avoid intermittent slug load feeding
  – Continuous feed or near continuous feed
  – Mixing helps provide uniformity in the reactor

• CONSISTENCY
  – Strive for consistent blend of sludge feedstocks
  – Maintain temperature with minimal variation in reactor.
Two basic types of foaming have been reported in anaerobic digester systems

• “Nuisance” Foaming
  – Low level foaming
  – Transient condition

• “Rapid Rise” Foaming
  – aka Rapid Volume Expansion
  – Rapid increase in gas production rate
  – Gas hold-up in liquid sludge matrix
  – Reduction in sludge bulk density
  – Increase in sludge volume
Foaming can be caused by a number of factors working alone or together...

• **Digester Operational Stress**
  – Temperature fluctuations
  – Loading fluctuations
  – Mixing interruptions

• **Digester Feedstock**
  – Loading fluctuations
  – *Nocardia* (foaming organisms)
  – Fats, Oils, Greases (organic and/or surfactant)
Digester foaming can create a number of operational issues
Questions?

- W. James Gellner, PE
- jgellner@hazenandsawyer.com