Current Trends in Digester Mixing Technologies

Becky Daugherty
Brian Hemphill
Outline

- Importance of Digester Mixing
- Digester Mixing Technologies
- Current Trends
- Case Studies
- Design Considerations
- Q & A
Digester without Mixing

- Short Circuiting
- Stratification
- Scum Mat Buildup
- Grit Accumulation
Importance of Good and Reliable Mixing in Digesters

- Provides uniform environment for microbes
- Maintains contact between active biomass and incoming feed sludge
- Enhances biological reaction rates
  - Improves VSS reduction efficiency
- Increases gas production
  - more pronounced at lower HRTs
- Reduces short-circuiting – optimizes HRT
- Reduces process upsets
- Improves operating safety margin
- Minimizes grit accumulation
Mixing Design Parameters

- Digester volume turnover time (DVTT) = (tank volume/pump capacity)

  *Does not consider velocity (→ power); or viscosity*

- Unit power (UP)
  = (pump horsepower/tank volume/1000)

  *Inconsistent HP calculation; ignores viscosity*

- RMS velocity gradient (VGT or G)
  = (pump power/tank volume/sludge viscosity)

  *Better but good viscosity info hard to come by*
Mixing Design Parameters

- Best approach is probably CFD modeling
- This is expensive and not definitive

Complications:
- Inlet feed and outlet hydraulics likely play a big role
- There is natural mixing that occurs due to gas production and by inlet hydraulics
- Nearly impossible to get real world side-by-side realistic comparisons
Digester Mixing Technologies

- Gas Mixing
- Mechanical Mixing
- Pump Mixing
Gas Mixing

- Compressed Digester Gas Recirculated through the Digester

- “Unconfined” Mixing
  - Sequential discharge to individual lances

- “Confined” Mixing
  - Eductor tube acts as gas lift pump to recirculate digester contents
  - Bubble gun generates large bubbles that act as a gas lift pump
Gas Mixing – Unconfined System

- Compressed digester gas recirculated through gas lances
- Sequential discharge to individual lances using rotary valve
- Gas/liquid mixing plume increases in diameter as it rises to the surface

 Courtesy of US Filter
Gas Mixing – Unconfined System

- Rotary Valve
- Housing Heater
- Low Pressure Regulator

Courtesy of US Filter
Gas Mixing – Unconfined System

- Gas discharge lance
- Removable while digester is in service

Courtesy of US Filter
Gas Mixing – Confined System

- **Eductor Tubes** Release compressed gas inside digester
- Eductor tube acts as a gas lift pump
- Creates upward mixing pattern
Gas Mixing – Confined System

- **Bubble Gun** Generation every 3 to 4 seconds per Mixer
- Turbulence created at surface prevents scum buildup

Courtesy of Infilco
Mechanical Mixing

- Non-clog, Axial Flow Propellers
- Often Located Inside Vertical Draft Tubes (a.k.a. Draft Tube Mixing)
- Provides Tangential Mixing Pattern inside Digester
- Reversible Mixing Pattern
- Roof Mounted Equipment
- Optional Heat Exchanger Jacket

Courtesy of US Filter
Mechanical Mixing – Draft Tubes

- **Internal**
  - Roof Mounted

- **External**
  - Platform Mounted
Mechanical Mixing – Draft Tubes

Optional Heat Exchanger Jacket (in lieu of External Heat Exchangers)

Axial Flow Propeller

Courtesy of OTI
Mechanical Mixing Installations

Internally Mounted

Externally Mounted

Courtesy of Westech
Vertical Linear Mixers (VLM)
Gresham LMM Installation

Linear Motion Mixer
Floating Cover Digester

HydroDisk Diameter 8 feet
Travel (up and down) 20 inches
30 cycles/minute
Pump Mixing

- Axial Flow, Screw Centrifugal, or Chopper Type Pumps
- Draw Sludge from Bottom or Top of Digester
- High-velocity Discharge through Nozzles
  - Perimeter Nozzles
  - Internal Nozzles
- Continuous or Intermittent Operation

Courtesy of Vaughan/Rotamix
Pump Mixing Nozzle Design Alternatives

Perimeter-Mounted Nozzles

Internal Floor-Mounted Nozzles
Pump Mixing – Perimeter Nozzles
Pump Mixing – Internal Nozzles

- Chopper Pump with Internal Mixing Nozzles

Courtesy of Vaughan/Rotamix
Pump Mixing – Internal Nozzles

Courtesy of Vaughan/Rotamix
Current Trends
90 WWTPs from 39 states responded

Active mixing was found to be the most significant factor in reducing volatile solids

- 13 WWTPs reported “Inadequate” Mixing but still reported >50% VSS Reduction
1983 Survey Results

- Pump Mixing: 32%
- Mechanical Mixing: 20%
- Gas Mixing: 48%
2005/06 Carollo Survey

- 55 WWTPs in 6 Western States Responded
- WWTP Capacities Between 3 and 320 mgd
- PS/TWAS was Most Common Feed Sludge
- VSS Reduction Varied Between 44 and 68% (50 to 55% Most Common)
- HRT Varied Between 15 and 45 Days (Median was 20 Days)
2005/06 Survey Results

- Pump Mixing: 45%
- Gas Mixing: 38%
- Mechanical Mixing: 15%
- No Mixing: 2%

Pie chart showing the distribution of mixing methods.
Survey Comparison

1983 Survey
- Pump Mixing: 32%
- Gas Mixing: 48%
- Mechanical Mixing: 20%

2005/06 Survey
- Pump Mixing: 45%
- Gas Mixing: 38%
- Mechanical Mixing: 15%
- No Mixing: 2%
2005/06 Survey – Frequency of Problems

Frequency of Problems, %

- Gas Mixing: 88
- Mechanical Mixing: 42
- Pump Mixing: 35
2005/06 Survey – Reported Problems

† Gas Mixing

- Compressor failure/extensive maintenance
- Pipe leaking
- Pipe plugging
- Digester foaming
- Poor mixing
2005/06 Survey – Reported Problems

♦ Mechanical Mixing
  • Impeller ragging
  • Vibration problems
2005/06 Survey – Reported Problems

- Pump Mixing
  - Foaming
  - Pump Clogs
Digester Mixing Rating

♦ Rating System

- Score of 1 to 5 (1 = worst, 5 = best)

♦ Average Ratings

<table>
<thead>
<tr>
<th>Method</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Mixing</td>
<td>2.8</td>
</tr>
<tr>
<td>Mechanical Mixing</td>
<td>3.7</td>
</tr>
<tr>
<td>Pump Mixing</td>
<td>3.7</td>
</tr>
</tbody>
</table>
Survey Summary

- Increasing Trend in Use of Pump Mixing

- Pump Mixing is Often the Simplest Retrofit Alternative
  - Lowest cost alternative in most cases

- O&M Concerns are Key Drivers for Selection of Mixing Technology
Case Studies
Case Studies

♦ Monterey, CA

- 30 mgd design ADWF
- 4 86-ft diameter digesters
- Unconfined gas mixing system using discharge lances
Concerns with existing system

- Routine and unexpected leaks in digester gas piping
- Significant maintenance requirements on digester gas compressors
- High water requirement on digester gas compressors (50,000 gallons per day)
- Outdated electrical system
  - Replacement parts were difficult to find
- Improper mixing resulted in significant solids accumulation at bottom of digesters
  - Required frequent cleaning
Case Studies

♦ Eugene, OR

- 49 mgd design ADWF
- 3 85-ft diameter digesters
- Unconfined gas mixing system using diffuser rings
Case Studies – Eugene, OR

♦ Concerns with existing system

- Incomplete mixing
  - active volume of digesters only 63% of total volume based on tracer study
- Replacement parts for the compressed digester gas system are difficult to obtain
Case Studies – Economic Comparison

♦ **Installed Cost**
  - Similar for the three systems (±10%)

♦ **Maintenance Cost**
  - Highest for gas mixing system
    - Based on operator input and results from 2005/06 survey
  - Can vary based on plant-specific factors

♦ **Power cost**
  - Lowest for pump mixing system operated intermittently
## Case Studies – Non-Economic Comparison

<table>
<thead>
<tr>
<th>Mixing Technology</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Mixing</td>
<td>• No moving equipment submerged</td>
<td>• Explosive gas hazard</td>
</tr>
<tr>
<td></td>
<td>• Mixer can reverse pump flow</td>
<td>• Compressor operation and maintenance</td>
</tr>
<tr>
<td></td>
<td>• Multiple mixers provide added reliability</td>
<td>• Potential for gas leaks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Can contribute to digester foaming</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lower mixing efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Large wall penetrations</td>
</tr>
<tr>
<td>External Pump Mixing</td>
<td>• Low explosive hazard</td>
<td>• Roof mounted motors are more difficult to maintain</td>
</tr>
<tr>
<td></td>
<td>• Easier equipment access</td>
<td>• Prone to clogging with rags</td>
</tr>
<tr>
<td></td>
<td>• Chopper pumps macerate rags and debris</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Lower maintenance</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Piping/nozzles inside digester (difficult to access)</td>
</tr>
</tbody>
</table>
Case Studies – Plant Specific Factors

♦ Struvite (NH₄MgPO₄) build-up
  • Precipitation can lead to clogged pipes
  • Struvite deposits most often occur at locations of local turbulence (pipe fittings, valves, pumps)

♦ Energy Costs
  • Peak demand charges can influence equipment’s life cycle cost
Case Studies

♦ Monterey, CA

- High energy cost shifted economic to favor the use of intermittent pump mixing
- Rotamix system has been installed in one of four digesters

♦ Eugene, OR

- Struvite concerns shifted the analysis to favor the use of external draft tubes
- 3 digesters were converted
Design Considerations
Pump Mixing Design Considerations

- Provide 1 or 2 Pumps per Digester
- Size Pump based on 8 Turnovers per day (or 1 turnover every 3 hours)
- Pump Venting needed for Intermediate Operation
- Provide 1 to 2 Mixing Nozzles per 100,000 cf of Volume
- Size Nozzle for discharge velocity between 20 to 30 fps
- Size Digester Piping between 5 to 8 fps
- Check Pump hp is within 0.2 to 0.3 hp/1,000 cf
Mechanical Mixing (Draft Tubes) Design Considerations

- Provide minimum of 4 External Mixers on Digesters greater than 70 ft in diameter
- Consider Both Upflow and Downflow Mixing in Design of Draft Tubes
- Consider Insulating Exposed External Draft Tubes
- Provide Mixer Motors rated for Class I Div 1 service
- Check Total Mixer hp is within 0.2 to 0.3 hp/1,000 cf
Gas Mixing Design Considerations

- Don’t do it unless you have to!
- Consider Pump Mixing or Mechanical Mixing Systems instead
Q & A
Factors affecting selection of digester mixing technology

- Digester size
- Digester shape
- Sludge type (primary, secondary, or mixed)
- Mixing system reliability
# Digester Mixing Technology Cost Comparison

<table>
<thead>
<tr>
<th></th>
<th>Gas Mixing</th>
<th>Mechanical Mixing</th>
<th>Pump Mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Cost</td>
<td>$97,000</td>
<td>$300,000</td>
<td>$147,000</td>
</tr>
</tbody>
</table>

**Notes:**

1. Based on vendor quotes for an 80-foot diameter digester
2. Includes associated piping costs.
3. Does not include installation costs.
Other Observations

- Use of Mechanical Mixing in Egg-Shaped Digesters
- Difficult to Retrofit Using Draft Tubes
  - Large sidewall penetrations
- Selection of Pump Mixing for Cylindrical Digesters
## Comparison of Digester Pump Mixing Alternatives

<table>
<thead>
<tr>
<th>Perimeter-Mounted Nozzles</th>
<th>Internal Floor-Mounted Nozzles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Features</strong></td>
<td></td>
</tr>
<tr>
<td>• Three nozzles located around each tank perimeter to create spiral mixing pattern</td>
<td>• Four floor-mounted nozzles inside each tank to produce a dual-zone mixing pattern</td>
</tr>
<tr>
<td>• Five side wall penetrations per tank</td>
<td>• Two sidewall penetrations per tank</td>
</tr>
<tr>
<td>• Requires more piping and larger diameter piping</td>
<td>• Requires less piping and smaller diameter piping</td>
</tr>
<tr>
<td>• Proven Carollo design</td>
<td>• Vendor guarantee on mixing</td>
</tr>
<tr>
<td>• $904,000 w/outdoor pumps</td>
<td>• $714,000 w/outdoor pumps</td>
</tr>
</tbody>
</table>
# Mixing Pump Location Evaluation

<table>
<thead>
<tr>
<th></th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outdoor Installation</strong> (adjacent to each digester)</td>
<td>• Simplifies construction sequencing (shorter construction period)</td>
<td>• Aesthetics and noise concerns</td>
</tr>
<tr>
<td></td>
<td>• Less piping required</td>
<td>• Electrical equipment needs to be Class I, Div 2 minimum when located adjacent w/in 10’ of digester</td>
</tr>
<tr>
<td></td>
<td>• Readily accessible for O&amp;M needs</td>
<td>• More complex construction sequencing (longer construction period)</td>
</tr>
<tr>
<td><strong>Indoor Installation</strong> (w/in digester control building)</td>
<td>• Equipment protected from weather</td>
<td>• More piping required in tunnel areas</td>
</tr>
<tr>
<td></td>
<td>• All pumps centrally located in one area</td>
<td>• Electrical equipment needs to be Class I, Div 2 minimum when located inside building</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• May trigger upgrade of electrical equipment inside building to meet Class I, Div 2 requirements ($50,000 to $250,000)</td>
</tr>
</tbody>
</table>
Pump Mixing

- Axial Flow, Screw Centrifugal, or Chopper Type Pumps
- Draw Sludge from Bottom or Top of Digester
- High-velocity Discharge through Nozzles
  - Perimeter Nozzles
  - Internal Nozzles
- Continuous or Intermittent Operation

Courtesy of Vaughan/Rotamix
# Digester Mixing Cost Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Confined Gas Mixing</th>
<th>Mechanical Mixing</th>
<th>Pump Mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Cost</td>
<td>$880,000</td>
<td>$785,000</td>
<td>$745,000</td>
</tr>
<tr>
<td>Present Worth of O&amp;M Cost</td>
<td>$268,000</td>
<td>$209,000</td>
<td>$89,000</td>
</tr>
<tr>
<td><strong>Total Present Worth Cost</strong></td>
<td><strong>$1,148,000</strong></td>
<td><strong>$994,000</strong></td>
<td><strong>$834,000</strong></td>
</tr>
</tbody>
</table>

**Notes:**

1. Based on vendor quotes for an 85-foot diameter digester.
2. Based on present value of 20 years of annual costs at 6% interest.
3. Based on an estimated O&M labor week of $50/hour depending on complexity of the equipment: 9 hrs/week for gas mixing, 7 hrs/week for mechanical mixing, 3 hrs/week for pump mixing.
Comparison of Surveys – Frequency of Problems

Frequency of Problems, %

- Gas Mixing
- Mechanical Mixing
- Pump Mixing


Bar chart showing the frequency of problems in gas mixing, mechanical mixing, and pump mixing for the years 1983 and 2005/2006.
# Design Criteria Comparison for an 85-ft Diameter Digester with 27-ft SWD

<table>
<thead>
<tr>
<th>Item</th>
<th>Confined Gas Mixing</th>
<th>Mechanical Mixing</th>
<th>Pump Mixing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Infilco</td>
<td>OTI</td>
<td>Vaughan/Rotamix</td>
</tr>
<tr>
<td>Number of Compressors</td>
<td>1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Number of Mixers</td>
<td>N/A</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td>Number of Pumps</td>
<td>N/A</td>
<td>N/A</td>
<td>1</td>
</tr>
<tr>
<td>Energy, hp (total)</td>
<td>32</td>
<td>40(^1)</td>
<td>37.5(^2)</td>
</tr>
<tr>
<td>Energy Input, hp/1,000 cf</td>
<td>0.20</td>
<td>0.26</td>
<td>0.24(^2)</td>
</tr>
<tr>
<td>Turnover Rate, minutes</td>
<td>29</td>
<td>28</td>
<td>30(^3)</td>
</tr>
</tbody>
</table>

**Notes:**

1. Based on equipment manufacturer’s design for continuous operation using four mixers at rated 10 hp.
2. Based on equipment manufacturer’s design for intermittent operation (2 hours on/off cycle), which is equivalent to 50% of the rated 75 hp mixing pump.
3. Adjusted value considering nozzle entrained flow velocity of 40 fps.