CAUSES, PREVENTION AND CONTROL OF FOAMING IN ANAEROBIC DIGESTERS

Bhargavi (Gavi) Subramanian, PhD
Staff Scientist, Applied Research Group
BhargaviSubramanian@kennedyjenks.com
Presentation Outline

1. Background
2. Problem Identification and Objectives
3. General Research Methods
4. Results and Discussion
   - Influent and Digester Content Quality Evaluation
   - Digester Performance Evaluation
   - Filament Presence Evaluation
5. Conclusions and Further Research
1. Background
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Anaerobic Digestion in WWTPs

Biochemical Process
1. Primary energy generation method
2. Anaerobic decomposition of volatile solids (VS)
3. Produces biogas
   \((\text{CH}_4 + \text{CO}_2 + \text{Other Gases})\)

Process Requirements
1. Anaerobic conditions
2. Optimal pH
3. Optimal temperature
4. Mixing/homogeneity
5. Sufficient retention time

Desired Product
1. Methane gas production
2. Volatile solids reduction
3. Pathogen destruction

Undesirable Product
1. Process upsets
2. FOAMING

Undesirable Product
1. Process upsets
2. FOAMING
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AD Foam Fundamentals

AD foam is a three-phase foam: liquid-solids-gas
- Bubbles stabilized by filaments, surfactants and solids
- Dissolved/dispersed flotation effects of biogas
- Sludge particles accumulated in foam

Foaming episodes are economic, safety and compliance issues for utilities
- Foam overflow at Marquette City, MI WWTP shown below
Understanding AD Foam – Current Gaps

Current gaps in AD foam knowledge:

• Composition of AD foam:
  o What is the distribution of solids-liquid-gas volume in foam?

• Surface active material
  o What are the thresholds of surfactants and solids in foam?

• Types of digester foams
  o What are the different types of digester foams?

• Mechanism of foam formation
  • What are the factors conducive for foam formation?
Understanding AD Foam – Types

Conventional Foaming
Foam with particles and gas bubbles are relatively of the same size order

Rapid Expansion Foaming
Foams created by growth of bubbles, with increasing size of bubbles rather than new bubbles being formed
Understanding AD Foam - Mechanisms

Formation Steps

Foam in digester
surface/overflowing foam

Bubbles in foam

Bubble
detachment

Controlled factors/
Contributors

Foam stability

Foaming episode
possibility

Bubble
formation

Heterogeneous
nucleation; entrapment; gas
release

Sinking bubbles/gas
nuclei/microbubbles(?)

Release of CO₂
and CH₄

Gas generation

All through digester depth (?)

Causes

Uncontrolled factors
Understanding AD Foam - Mechanisms

Factors / Relationships

- Foam Properties
  - Bubble Size Distribution
  - Stability
  - Bubble sizes

- Bubble Nucleation and Stability
  - Stability
  - Bubble sizes

- Interfacial Physico-chemical Properties
  - Surface Tension
  - Critical Micelle Concentration
  - Particle Size
  - Viscosity

- Operational Parameters
  - Mixing
  - Temperature/Pressure
  - Digester Physical Features

- Process Characteristics
  - Stability
  - Rheology
  - Water
  - Sludge
  - Particulates
  - Lipids
  - Surfactants

- Sludge Feed Characteristics
  - Filaments
  - Proteins
  - Extra Cellular Polymeric Substances (EPS)

- Structure
  - Interactions
  - Rheology

- Gas Bubble
  - Methane and CO₂
## Understanding AD Foam - Causes

<table>
<thead>
<tr>
<th>Classification</th>
<th>Causes</th>
<th>Contributors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge feed characteristics</td>
<td>▪ Surface active agents in feed sludge</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Foam causing filaments in feed sludge</td>
<td></td>
</tr>
<tr>
<td>Digestion process-related characteristic</td>
<td>▪ Organic loading aspects – overload and inconsistent loading</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ PS:WAS solids feed ratio to digester</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ VFA production - Imbalances between the successive hydrolysis, acidogenesis and methanogenesis, upstream fermentation in the WWTP</td>
<td></td>
</tr>
<tr>
<td>Digester operating conditions</td>
<td></td>
<td>▪ Gas production rate/withdrawal variations;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Temperature and pressure changes;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Mixing intensity and patterns</td>
</tr>
<tr>
<td>Digester configuration, shape and physical features</td>
<td></td>
<td>▪ Digester shape and configuration;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Sludge withdrawal and gas piping</td>
</tr>
</tbody>
</table>
Current Research Objectives

- Evaluate AD foaming in full-scale digesters.
- Relate full-scale AD foam with process and operational factors, namely:
  - Filaments Presence in Feed
  - PS:WAS Solids Ratio Effects
  - Organic Loading Rate (OLR) and OLR_{variation} Effects
  - Effects of Mixing on Foaming and Performance
  - Feed Sludge Holding Effects
  - Specific Full-Scale Foam Detection (Study 4)
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   - Influent and Digester Content Quality Evaluation
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   - Filament Presence Evaluation

5. Conclusions and Further Research
## Full-Scale Case Studies

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Study 1</th>
<th>Study 2</th>
<th>Study 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of digesters</td>
<td>Nos.</td>
<td>2</td>
<td>3; 2 – primary. 1 – secondary methane storage.</td>
<td>1</td>
</tr>
<tr>
<td>Operational HRT</td>
<td>Days</td>
<td>30-32</td>
<td>60-70</td>
<td>30</td>
</tr>
<tr>
<td>Cover type</td>
<td>Nos.</td>
<td>SD - gas holder cover</td>
<td>Primary digesters: fixed cover</td>
<td>Fixed Dystor cover</td>
</tr>
<tr>
<td>Mixing type</td>
<td>Nos.</td>
<td>ND - confined gas mixing system with an eductor tube SD – Pearth gas mixer</td>
<td>Jetmixers (currently not in use). Foam suppression mixing</td>
<td>Jet mixers</td>
</tr>
</tbody>
</table>
### Full-Scale Case Studies

#### Study 1 – OLR and Mixing – Cause Unknown

<table>
<thead>
<tr>
<th>Timeline</th>
<th>North Digester</th>
<th>South Digester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before mixing modification</td>
<td>Continuously mixed</td>
<td>Continuously mixed</td>
</tr>
<tr>
<td>Phase 1</td>
<td>7/1/2011 to 12/31/2011</td>
<td>Mixing only a total of three hours a day – one hour each in the morning, noon and evening</td>
</tr>
<tr>
<td></td>
<td>Mixing only a total of three hours a day – one hour each in the morning, noon and evening</td>
<td>Mixing only a total of three hours a day – one hour each in the morning, noon and evening</td>
</tr>
<tr>
<td>Phase 2 A</td>
<td>9/1/2011 to 12/31/2011</td>
<td>Baseline OLR estimation while maintaining reduced mixing</td>
</tr>
<tr>
<td></td>
<td>Baseline OLR estimation while maintaining reduced mixing</td>
<td>Baseline OLR estimation while maintaining reduced mixing</td>
</tr>
<tr>
<td>Phase 2B</td>
<td>1/1/2012 to 4/30/2012</td>
<td>Increase OLR to ND to twice that of SD while maintaining reduced mixing</td>
</tr>
<tr>
<td></td>
<td>Increase OLR to ND to twice that of SD while maintaining reduced mixing</td>
<td>Baseline OLR while maintaining reduced mixing</td>
</tr>
</tbody>
</table>
## Full-Scale Case Studies

### Study 2 – Foam Suppression Mixing – Possible Rapid Rise

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Digester 1</th>
<th>Digester 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal operation</td>
<td>Prior to full-scale study</td>
<td>WAS storage and foam suppression always ON</td>
</tr>
<tr>
<td>Phase 1 (Baseline)</td>
<td>8/2012 to 9/2012</td>
<td>Bypass aerated WAS holding tank (no WAS storage); foam suppression ON</td>
</tr>
<tr>
<td>Phase 1A: No WAS storage</td>
<td>2/1/2012 to 5/1/2012*</td>
<td>Foam suppression OFF</td>
</tr>
<tr>
<td></td>
<td>9/2012 to 10/2012</td>
<td></td>
</tr>
<tr>
<td>Phase 1A: WAS storage</td>
<td>10/2012 to 12/2012</td>
<td>Foam suppression OFF</td>
</tr>
</tbody>
</table>
Full-Scale Case Studies
Full-Scale Case Studies

Study 3 – Modifying PS:WAS Ratio in Feed – Cause Unknown

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Digester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before modification</td>
<td>Widely varying PS:WAS feed solids ratio to digester</td>
</tr>
<tr>
<td>Full-scale modification</td>
<td>5/1/2012 to 11/26/2012</td>
</tr>
<tr>
<td></td>
<td>Increasing the PS feed to the digester gradually until digester is fed all PS and no WAS</td>
</tr>
</tbody>
</table>

Study 4 - Full Scale ESD Mixing Evaluation – Rapid Rise

<table>
<thead>
<tr>
<th>Period</th>
<th>Mixing Frequency (% of the time)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dig. 1</td>
</tr>
<tr>
<td>Since Plant Start-up</td>
<td>100%</td>
</tr>
<tr>
<td>Phase 1</td>
<td>100%</td>
</tr>
<tr>
<td>Phase 2</td>
<td>100%</td>
</tr>
<tr>
<td>Phase 3</td>
<td>25%</td>
</tr>
<tr>
<td>Phase 4</td>
<td>0%</td>
</tr>
<tr>
<td>Phase 5</td>
<td>0%</td>
</tr>
</tbody>
</table>

- Even FOG injection to all three digesters until August 2012
- FOG injection to ONLY digester #1 starting January 2013
Full-Scale Foam Detection (Study 4)

Temperature difference between the recycled W3 water used to shower the gas (55-72°F) in the foam separator and the digested sludge (95°F).

Foam event: Foam probe reading above 75°F for time duration greater than 5 minutes.

Technique does not differentiate between conventional and rapid expansion events in the ESDs.
Influent and Digester Content Quality/ Foam Potential

**Surface Tension**
- De-Nuoy Ring Tensiometer
- Surface activity of feed and digester contents
- Indirect estimate of the foam potential

**Foam Potential**
Conventional aeration method to estimate unstable and stable foam potential ratios

\[
\text{Unstable Foam Ratio} = \frac{\text{Maximum Foam Height (mL)}}{\text{Initial Ht.of Sludge (mL)}}
\]

\[
\text{Stable Foam Ratio} = \frac{\text{Settled Foam Height (mL)}}{\text{Initial Ht.of Sludge (mL)}}
\]

**VA/A Ratio**
Hach esterification technique
Digester Performance Evaluations

- Digester performance - gas production data, mixing run-times, operational temperatures etc usually obtained from the plant data collection systems.

- Detection of presence/ absence of foam by plant-specific methods (Study 4) and/or visual observation.

- Depth profiles – to test mixing efficiency
  - TS and temperature
  - Sampling at different depths using a zone sampler.

Schematic of a Cylindrical Digester Depth Profile (Study 2)
Filament Presence Evaluations

1. Gram Staining and counting of *G. amarae*

2. Fluorescent in situ Hybridization: identification of specific organisms (EUB, *G. amarae* and *M. parvicella*).

<table>
<thead>
<tr>
<th>Target organism</th>
<th>Probe</th>
<th>Sequence and Flurophore</th>
<th>Pretreatment</th>
<th>Formamide (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mycolata</td>
<td>Myc657</td>
<td>/5Cy3/AGTCTCCCTCTGYAGT A</td>
<td>Acid hydrolysis</td>
<td>30</td>
</tr>
<tr>
<td><em>Gordonia</em> (Nocardia)</td>
<td>Gor596</td>
<td>/56-FAM/TGCAGAATTTCACAGACGACG</td>
<td>Acid hydrolysis</td>
<td>20</td>
</tr>
<tr>
<td><em>Microthrix Parvicella</em></td>
<td>MPA60</td>
<td>/5Cy3/GGATGGCCGCGTTCTAG</td>
<td>Lysozyme+ Achromopeptidase Extended hybridization Time</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>MPA223</td>
<td>/5Cy3/GCCGCGAGACCTCTAG</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MPA645</td>
<td>/5Cy3/CCGGACTCTAG TCGAGACG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All bacteria</td>
<td>EUB338</td>
<td>GCTGCCTCCCGTAGG AGT/3-6FAM/</td>
<td></td>
<td>20-35</td>
</tr>
</tbody>
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Influent and Digester Content Quality/ Foam Potential - Study 2

- Highest values were exhibited by Digester 2 samples. Feed samples have low or negligible values.
- No significant changes in surface tension values between the various scenarios.
Influent and Digester Content Quality/ Foam Potential – Study 3

• All of the WAS samples measured none or negligible foam potential.  
• WAS displayed higher surface tension and low to negligible foam potential.  
• Increasing PS in digester feed did not impact foam potential and surface tension considerably.

Feed PS:WAS ratio  
2010 : 0.65:0.35.  
2011 : 0.76:0.24.  
Full-Scale Study: Increased PS until feed was 100% PS.
Influent and Digester Content Quality/ Foam Potential – Study 4

- The unstable foam ratios were higher than the stable foam ratios
- The stable foam ratios for most samples were less than 1
- Foam potential values were not representative of foaming events in the full-scale ESDs
- No significant changes in surface tension values between the samples from the various mixing scenarios
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## Digester Performance – Study 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Year 2009 Mean ± standard deviation (Max value)</th>
<th>Year 2010 Mean ± standard deviation (Max value)</th>
<th>7/1/2011 to 12/31/2011 Mean ± standard deviation (Max value)</th>
<th>1/1/2012 – 4/30/2012 Mean ± standard deviation (Max value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OLR – ND (lbs VS/ft³/d)</td>
<td>0.02±0.01 (0.07)</td>
<td>0.04±0.03 (0.15)</td>
<td>0.018±0.012 (0.01)</td>
<td>0.03±0.006 (0.05)</td>
</tr>
<tr>
<td>OLR – SD (lbs VS/ft³/d)</td>
<td>0.01±0.006 (0.08)</td>
<td>0.025±0.01 (0.12)</td>
<td>0.3±0.1 (0.09)</td>
<td>0.025±0.003 (0.03)</td>
</tr>
<tr>
<td>Gas production (kcf/d)</td>
<td>N.A.</td>
<td>30±15 (75)</td>
<td>30±11 (51)</td>
<td>25±9.9 (57)</td>
</tr>
<tr>
<td>VA/A Ratio - ND</td>
<td>N.A.</td>
<td>N.A.</td>
<td>0.5±0.006 (0.07)</td>
<td>0.07±0.006 (0.08)</td>
</tr>
<tr>
<td>VA/A Ratio - SD</td>
<td>N.A.</td>
<td>N.A.</td>
<td>0.06±0.006 (0.07)</td>
<td>0.07±0.004 (0.08)</td>
</tr>
</tbody>
</table>
Digester Performance - Study 2

- Overall gas production was not impacted by turning off the foam suppression mixing.
- Bypass of the aerated WAS tank: Improve VS destruction leading to enhanced biogas production.

Zero gas values in 2010 due to foam intruding gas lines.

Additional amounts of VAs were not produced due to extended storage (10 to 13 days HRT) prior to feed to digester.
Feed PS:WAS ratio
2010: 0.65:0.35.
2011: 0.76:0.24.
During the foam episode in 2011, feed was all PS and no TWAS (accompanied by overloading).

Spike in VA/A ratio during foaming event.
Other spikes do not correspond to foaming events.

• Feeding all PS to the digester during the full scale study did not result in a foam episode.
• The OLR to the digester ranged between 0.07 – 0.09 lbs VS / ft³ day (1.1 - 1.4 kg VS / m³ per day), which is lesser than the OLR during the historical foam event.
# Digester Performance and Foam Presence – Study 4

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dig. 1</th>
<th>Dig. 2</th>
<th>Dig. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior to mixing reduction</td>
<td>(Mixing 100% of time)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas production (x1000cf/d)</td>
<td>140±6</td>
<td>118±19</td>
<td>132±4</td>
</tr>
<tr>
<td>Foam presence (% of time)</td>
<td>8.5</td>
<td>6.7</td>
<td>10.7</td>
</tr>
<tr>
<td>Phase 1 Mixing -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas production (x1000cf/d)</td>
<td>128 ± 3</td>
<td>106± 36</td>
<td>132± 1</td>
</tr>
<tr>
<td>Foam presence (Jan–Apr 2012)</td>
<td>4</td>
<td>61</td>
<td>6.6</td>
</tr>
<tr>
<td>Phase 2 Mixing -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas production (x1000cf/d)</td>
<td>135± 9</td>
<td>139±9</td>
<td>129±11</td>
</tr>
<tr>
<td>Foam presence</td>
<td>14.6</td>
<td>9.3</td>
<td>12.2</td>
</tr>
<tr>
<td>Phase 3 Mixing -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas production (x1000cf/d)</td>
<td>125± 0.4</td>
<td>125± 2</td>
<td>112± 0.25</td>
</tr>
<tr>
<td>Foam presence (10/2/ 2012 to 11/13/2012)</td>
<td>6.5</td>
<td>12.5</td>
<td>8.4</td>
</tr>
<tr>
<td>Foam presence (11/15/ 2012 to 12/1/2012)</td>
<td>9.2</td>
<td>3.8</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Phase 4 Mixing -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas production (x1000cf/d)</td>
<td>103± 21</td>
<td>100± 22</td>
<td>96± 21.9</td>
</tr>
<tr>
<td>Foam presence</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Phase 5 Mixing -</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas production (x1000cf/d)</td>
<td>150 ± 39</td>
<td>127± 14</td>
<td>123± 17</td>
</tr>
<tr>
<td>Foam presence</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Sample Temperature Datalogger Plot

- Digester Gas Line Scum Separator Drainage Temperature (Greater than 75 °F Indicates that Foam / Sludge is Reaching the Digesters Gas Line)
- Digester 4 experiences intermittent foaming and events are relatively fewer than in digester 1
Digester Performance and Homogeneity – Study 1 & 2

**STUDY 1**
- Digester contents are homogeneous after mixing reduction

**STUDY 2**
- Foam suppression: Off in Digester 1 for 70 days and On in control Digester 2.
- Although digester performances are comparable with periods of normal mixing, contents of Digester 2 are not homogeneous.
Digester Performance and Homogeneity – Study 4

- TS profile shows complete homogeneity after interrupting mixing for 50 days.
- Temperature difference between top and bottom was only about 3°F.
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Filament Presence Evaluation

<table>
<thead>
<tr>
<th>Study/Sample Name</th>
<th>G. amarae</th>
<th>M. parvicella</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1* 2* 3*</td>
<td>1* 2* 3*</td>
</tr>
</tbody>
</table>

Study 1<sup>a</sup>

<table>
<thead>
<tr>
<th></th>
<th>WAS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Digester contents</td>
<td>N.D. N.D.</td>
<td>N.D. N.D.</td>
</tr>
</tbody>
</table>

Study 2<sup>b</sup>

<table>
<thead>
<tr>
<th></th>
<th>WAS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerated WAS tank contents</td>
<td>N.D. N.D. N.D.</td>
<td>1 0.5 N.D.</td>
</tr>
<tr>
<td>Digester contents</td>
<td>N.D. N.D. N.D.</td>
<td>1 0.5 N.D.</td>
</tr>
</tbody>
</table>

Study 3<sup>c</sup>

<table>
<thead>
<tr>
<th></th>
<th>WAS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Digester contents</td>
<td>1 1 -</td>
<td>1 1 -</td>
</tr>
</tbody>
</table>

* Indicates sampling events
<sup>a</sup> - Dates of Sampling for Study 1 – 3/2/2012 and 4/20/2012
<sup>b</sup> - Dates of Sampling for Study 2 – 3/2/2012, 8/1/2012 and 8/16/2012
<sup>c</sup> - Dates of Sampling for Study 3 – 3/14/2012 and 8/7/2012
N.D. - Not Detected

- The three plants did not experience any foaming during the duration of the study.
- Filament levels remained very low over the duration of study.
Filament Presence Evaluation – Study 4

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Sample</th>
<th>Gram stain count (Log of Intersections/mg VSS)</th>
<th>Filament Index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>G. amarae</td>
</tr>
<tr>
<td><strong>Before mixing reduction</strong></td>
<td>ML</td>
<td>5.9</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Digester 1</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Digester 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Digester 4</td>
<td>3</td>
<td>N.D.</td>
</tr>
<tr>
<td><strong>After mixing reduction</strong></td>
<td>ML</td>
<td>6.4</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Dig. 1</td>
<td>N/A</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Dig. 2</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Dig. 4 (depth sampling)</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>After mixing reduction</strong></td>
<td>ML</td>
<td>4.4</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Dig.1</td>
<td>N/A</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Dig. 2</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Dig. 4</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Level evaluation</strong></td>
<td>ML</td>
<td>6.3</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Dig. 1 bottom</td>
<td>N/A</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Dig. 2 bottom</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Dig. 4 surface skim</td>
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<td>0.5</td>
</tr>
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</table>

- Though *G. amarae* counts in ML are considered to be significant due to their value being closer to the threshold number, their corresponding incidence in the digester contents remained between low and moderate.
• Seasonal AD foaming: Directly related to *G. amarae; G. amarae* growth related to ML temperature.
Presentation Outline

1. Background
2. Problem Identification and Objectives
3. General Research Methods
4. Results and Discussion
   - Influent and Digester Content Quality Evaluation
   - Digester Performance Evaluation
   - Filament Presence Evaluation
5. Conclusions and Further Research
Conclusions from Full-Scale Studies

• Mixing is a contributor to foaming
  o Over or under mixing are ambiguous terms. Improper mixing, though it cannot be given a universal definition, is a supplementary cause of foaming (exacerbating the foam episode when a primary cause exists), but not necessarily a cause of the foam.
  o Unmixed/intermittently mixed digesters experienced lesser and shorter foam episodes than those mixed continuously, in Study 4.
  o Reduced mixing did not impact performance. In studies 1, 2, and 4 after lower mixing the digesters seem to perform just like the normal conditions and the relative deviations of the gas volume flow stay within the experimental reproducibility.
  o Considerable energy savings with reduced mixing.

• Natural mixing
  o Can be achieved without mixing 24x7, in most cases, due to contribution of the various sources natural mixing in the digesters.
  o Natural mixing source such as gas production, heat convection, heat recirculation pumping and inflow and outflow of sludge seem to be dominant, though not quantifiable.
Conclusions from Full-Scale Studies (contd.)

- The popular opinion that all foaming has to be filamentous seems to be unfounded
  - It is not conclusive if it is the only established primary cause of foaming from the full-scale evaluations.
  - Filament thresholds for AD foaming are much lesser than secondary system
    - The threshold value of *G. amarae* (log #6 intersections/mg VSS) in the ML is not an absolute number and will vary from digester to digester.
    - The qualitative abundance of filament species in all the digesters varied between 0 and 3 in the filament index scale and higher index values did not correspond to foaming.

- OLR values are specific for each digester
  - Case specific OLR thresholds signify that the digestion process is overloaded not by just the absolute quantity of feed but a combination of the digestion process, operational factors (mainly mixing).
  - Relative contribution of PS and WAS solids content was not correlated to AD foaming.
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