Analysis and Troubleshooting to put a Digester back on Track

BioCycle
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Overview

The Conundrum of digester Operation
General terms and definitions
The 5 points of Sound Operation
Potential problems with Substrates
Monitoring and Tracking Trends; if you don’t know where you are going.....
Case Evaluation
Summary
The Conundrum:

The anaerobic digestion system is designed to operate with little maintenance and minimal biological problems. Conversely, digesters are complex living organisms that require knowledgeable, trained, and motivated operators if they are to operate successfully.

Ref: Dr. Dana Kirk, PE, PHD, ADREC and Michelle, Crook, PE MDA
Glossary for today

Total solids (TS) – solid concentration of biomass
Volatile solids (VS) – organic fraction of total solids
Fixed solids (FS) – inorganic fraction of total solids
Alkalinity – ability of a solution to neutralize acids
Volatile fatty acids (VFA) – organic acids created during the fermentation process
Chemical oxygen demand (COD) – measure of organic concentration of water
Hydraulic retention time (HRT) – theoretical liquid storage duration
Solid retention time (SRT) – theoretical solids holding period

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The key to good operation and control of a digester is ...

**BALANCE!**

- The rate of acid formation and methane production must be approximately equal – otherwise, the reaction will be **out of balance**.
- Never shock system; a change in any parameter more than 10% in one day. This is important for:
  - Maintaining the proper balance between the acid-forming and the methane-producing microorganisms requires maintaining definite ranges and ratios of solids loading, alkalinity, VFA’s, temperature, pH and mixing.
  - When the methanogens fail to keep pace with the fermenting bacteria, the digester goes acidic and is referred to as being “sour”.

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What factors are necessary for optimal digestion?

Five factors affect digestion:

- Microbial population
- Availability and accessibility of food
- Loading the digester
- Microbial contact with food (mixing)
- Environmental factors

Each of these factors can be monitored and controlled by the operator.
1st Factor – Microbial Population

The key is to maintain adequate quantities of fermenting bacteria and methanogens.
Feed <7% fresh material each day or recycle a portion of the liquid digestate (i.e. seed feedstock), “Friendly Bacteria with Knowledge”
2nd Factor – Microbial Food

Volatile Solids\(\xrightarrow{\text{fermenting bacteria}}\)Organic Acids + Hydrogen

A list of organic acids are as follows:

- **Volatile Acids**: Formic acid, n-Valeric acid, *Acetic acid*, Isovaleric acid, *Propionic acid*, Caproic acid, *n-Butyric acid*, Heptanoic acid, Isobutyric acid, Octanoic acid

- **Non-Volatile Acids**: Lactic acid, Pyruvic acid, and Succinic acid

Digesters should receive feedstocks high in volatile solids for maximum biogas production.

Feedstocks vary in their potential to produce biogas.

Fats, which are high in volatile solids, generate the greatest biogas while manures, by comparison, generate the lowest.
**3rd Factor – Digester Loading**

Loading the digester refers to the amount and type of feedstocks added to the digester. Feedstocks are introduced at such a rate as to maintain microorganism populations. Feeding must be monitored and controlled by the operator.

The operator must consider the:

- Energy concentration and chemical composition of in the incoming feedstocks.
- Amount of volatile solids in the feedstock, which tells how much of the material can be used as food by the fermenting bacteria and indirectly the amount of grit (i.e. material that will not contribute to biogas production).
- Ratio of volatile solids per unit to digester volume, which is used as a loading factor (i.e. mass of VS per gallon of digester capacity).
- Hydraulic loading (hydraulic retention time) which is related to microbial growth and washout.

Monitoring and control of these are described in detail in “Operation and Control of the Anaerobic Digestion Process” (Chapter 7).

Remember: the quantity and characteristics of the feedstocks will affect the efficiency of the digestion process.
Factor #3 – Digester Loading

Frequent, regular loadings (feedings) is recommended
- Continuous
- Intermittent

AD loading can be based on volume or solids
- Volumetric loading
  - Maintain design HRT
  - AD systems have fixed volume, feedstock volumes typically vary
  - Reducing HRT may impact biogas production and treatment
- Solids loading (organic loading rate)
  - Typically based on VS, COD is an alternate
  - Relationship between mass of VS and the system volume
  - Normal range 0.03 to 0.30 lb VS/ft³/d

Avoid excess water whenever possible
- Heating issues
- Reduce retention time
- Impact on alkalinity
Digester Loading

Important digester loading data

• System volume
• Daily flow rate
• TS, VS & COD

Performance values (tracking)

• Organic loading rate
• HRT
Change in Manure Mass due to Anaerobic Digestion

Raw Manure
100 lb (MC=90%)

Water = 90 lb

Solids = 10 lb

Solids
10 lb (VS=85%)

FS = 1.5 lb
VS = 8.5 lb

50% Conversion of VS to biogas
= Loss of 4.25 lb of VS
= 4.25% change in mass

Manure mass/volume changes due to anaerobic digestion are insignificant

MC = moisture content
FS = fixed solids = inorganic
VS = volatile solids = organic
4th Factor – Contact (Mixing)

Stabilization cannot occur unless microorganisms are brought into contact with the food. The goals of mixing are to:

- Expose the microorganisms to the maximum amount of food
- Reduce the volume occupied by settled inorganic material, such as grit, and the floating organic material (scum blanket)
- Prevent the formation of a floating crust layer which can slow the percolation of biogas out of the slurry

The benefits of mixing are:

- Speeding up the breakdown of the volatile solids
- Increasing the amount of gas production

Mixing is accomplished in two ways:

- Gas evolution
  - As gas rises to the surface it effectively causes mixing
  - This method is controlled by feeding. In municipal digesters, a loading rate of about 0.4 pounds of volatile solids per cubic foot per day is needed for natural mixing
- By mechanical means
  - Different mixing devices and mechanical impellers
  - The amount and frequency of mixing are controlled by the operator
5th Factor – Environmental Factors

Anaerobic conditions

Temperature
  • Mesophilic
  • Thermophilic

Digester robustness
  • Temperature swings
  • Chemicals
  • Added water

Winter

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5th Factor – Environmental Factors

Buffers

• Process stability largely depends on a digester’s ability to resist a change in pH
• Buffering capacity is measured as alkalinity
• When the pH suddenly starts to change, it means that:
  • The natural alkaline buffer in the digester has been reduced
  • Acids are being made faster than can be buffered
  • Methanogens cannot convert acids into methane fast enough
5th Factor – Environmental Factors

Buffers (cont.)

- Volatile acids and alkalinity are measured to indicate the progress of digestion and to control the digester
  - Volatile acids (VFA) to total alkalinity (TA) ratio (VA:TA)
  - A ratio between 0.1 and 0.4 means that there is between 10 and 2.5 times more alkalinity than volatile acids (meaning the digester will be well buffered to keep the pH from changing)
  - For manure digesters, recent research seems to indicate the highest ratio is 2.0
Summary: Pay Attention to the Data

The best way to avoid a problem is to identify it before it happens

Never change anything more than 10%

Track Critical Indicators and Trend Data

• Microbial population
• Availability and accessibility of food
• Loading the digester
• Mixing
• Environmental factors

Monitoring and controlling these factors will determine digestion success or failure
Common reasons for system failures

Workforce changes
“Overnight” changes
  • Toxic dosages
  • Acclimation is critical to biological systems

Communication failures
Mechanical failures
Holidays
Common inhibitory substances impacting digesters

Heavy metals
  - Copper
Salts
Ammonia
Antibiotics
  - Feed additives
  - Animal health products
  - Cleaning materials
Dilution water
  - Not toxic, but can impact performance
# Heavy metals

<table>
<thead>
<tr>
<th>Metal</th>
<th>Concentration (mg/L)</th>
</tr>
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<tbody>
<tr>
<td>Cadmium</td>
<td>190</td>
</tr>
<tr>
<td>Copper</td>
<td>170</td>
</tr>
<tr>
<td>Zinc</td>
<td>163</td>
</tr>
<tr>
<td>Lead</td>
<td>2</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Micronutrients: Rate Limiting

Nickel
Cobalt
Molybdenum
Calcium
Sulfide
Magnesium
Potassium
Zinc
Others
Salts (Cations)

Required for optimal biological activity

<table>
<thead>
<tr>
<th>Cation</th>
<th>Stimulatory</th>
<th>Moderately inhibitory</th>
<th>Strongly inhibitory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>100-200</td>
<td>3,500-5,500</td>
<td>8,000</td>
</tr>
<tr>
<td>Potassium</td>
<td>200-400</td>
<td>2,500-4,500</td>
<td>12,000</td>
</tr>
<tr>
<td>Calcium</td>
<td>100-200</td>
<td>2,500-4,500</td>
<td>8,000</td>
</tr>
<tr>
<td>Magnesium</td>
<td>75-150</td>
<td>1,000-1,500</td>
<td>3,000</td>
</tr>
</tbody>
</table>

Heavy use of recycle can contribute to accumulation
High concentrations & land application
Carbon : Nitrogen ratio and Ammonia

Carbon

- Carbon (carbohydrates) provide energy
- Nitrogen (protein) functions as building blocks of cell structure
- Optimum C:N ratio between 20:1 and 30:1
- High C:N (50:1) – low gas production
- Low C:N (10:1) – ammonia toxicity
- Feedstock management critical

Ammonia

- High feedstock protein levels
- Swine and poultry manure
- Lowering digester pH will relieve NH\textsubscript{3} toxicity
- Dilution may be needed for extreme NH\textsubscript{3} levels
Indicators of toxic effects/inhibitory conditions

Reduction in CH₄ yield, indicated by two or more consecutive decreases of more than 10% in daily yield at a constant loading rate

Increase in volatile acids concentration, generally occurring when the total volatile acids (expressed as acetic acid) exceed the normal range of about 250 to 500 ppm
Basic monitoring parameters & acceptable ranges

TS – 1 to 20%
VS – 0.03 to 0.30 lb VS/ft³/d
COD – 0.03 to 0.75 lb COD/ft³/d
pH – 6.4 to 8.2
VFA – 50 to 300 mg/L as acetic
Alkalinity – 3,000 to 5,000 mg/L as CaCO₃
Ammonia – 1,500 to 3,000 mg/L
VFA vs. pH

Increasing VFA levels are the main reason for declining pH, alkalinity and biogas production

- In a normal operating systems $H_2$ and acetic acid formed by acidogenic and acetogenic bacteria is immediately converted into methane by methanogens
- Overloaded conditions, unbalanced acidogenic and methanogenic activity or the presence of toxins reduce methanogenic activity
- Identification of declining pH or biogas lags the actual start of the biological failure
Power of Statistics

Graphing operation Data
Look for significant Trends
Graph parameters against each other
Look for dependant relationships
This is the basis of predictability
Methanogenic Activity Test

Samples of effluent from digesters, both the “bad actor” and (if possible) properly operating digester

Bring sample to temperature and feed it a known volume of easily digested food “sugar cube”

Measure gas production versus time

The shape of the curve will indication of what is happening with the “bugs”

Simple, quick, and intuitive test
Tracking system performance

Comparison of Daily Gas Flow Rates (SCFD) and A.D. Input Flow Rate (GPD)

- Engine 1
- Engine 2
- Flare
- A.D. Input
Tracking system performance
Typical Solids Concentrations Example
Case Study

Food residuals and cow manure digester
Poor operation: low gas production

Four Step Process (science and art):
• What is the design basis: how was it intended to operate?
• How was it being operated
• Has there been a failure of a subsystem?
• How are the “bugs doing”?
### Effluent Data

<table>
<thead>
<tr>
<th>pH</th>
<th>EC (mS/cm)</th>
<th>COD (mg/L)</th>
<th>TS (mg/L)</th>
<th>VS (mg/L)</th>
<th>TS %</th>
<th>VS %</th>
<th>% of TS</th>
<th>Total Alkalinity (mg/L)</th>
<th>Volatile Acids as Acetic Acid (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.63</td>
<td>18.14</td>
<td>40,950</td>
<td>34,330</td>
<td>25,485</td>
<td>3.4</td>
<td>2.5</td>
<td>74.2</td>
<td>9,800</td>
<td>2,840</td>
</tr>
</tbody>
</table>
Methane Activity Test results: Good operation versus poor operation

**Graph:**

- **y-axis:** Total Methane Gas Production (mL)
- **x-axis:** Time (days)

**Key Points:**

- **Ph 7.57, TS 3.0%, VS 2.1%:**
  - Gas production: 0.11 m³/kg VS day

- **Ph 7.63, TS 3.4%, VS 2.5%:**
  - Gas production: 0.02 m³/kg VS day

- **Ph 7.60, TS 3.7%, VS 2.7%:**
  - Gas production: 0.03 m³/kg VS day

**Legend:**

- Black line
- Red line
- Purple line
- Blue line
In closing...

Establish a monitoring program that fits the system management and provides sufficient information to operate the system
Review data on regular intervals
Graph and Trend Data
Examine changing conditions
Maintain data collection tools; you will need it at the most inopportune time
Live the 10% Rule
Put your self in the shoes of the bugs
THANK YOU

Special thanks to: Dr. Dana Kirk, PE of ADREC at MSU and Michelle Crook, PE of MDA for taking on the effort to prepare the Operator Training Program.
References and Acknowledgements


