Anaerobic Digestion
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AS Water/Wastewater Technology Solano College
Sludge Digestion

- Need for Sludge Digestion
  - In the Primary Sedimentation Process
    - Settled solids (Primary Sludge)
    - Floating solids (Scum-FOG)
  - In the Secondary Treatment Processes
    - Trickling filter sloughing
    - Activated Sludge WAS

Bacteria decompose the solids to simpler forms that are stable for final disposal.
Sludge Digestion

Sludge digesters can be ANAEROBIC or AEROBIC

- ANAEROBIC - The breakdown of wastes by microorganisms in the absence of dissolved oxygen
- AEROBIC – The breakdown of wastes by microorganisms in the presence of dissolved oxygen
Sludge Digestion

• ANAEROBIC DIGESTION
  • Organic solids are decomposed by anaerobic microorganisms producing methane gas
  • 2 different bacteria in the anaerobic digestion process
    • SAPROPHYTIC ORGANISMS (Acid Formers) break down organic solids into “volatile acids”
    • METHANE FERMENTERS – convert the “volatile acids” to “methane gas”. The Methane Fermenters are sensitive to pH and reproduce in a pH range of 6.6 to 7.6
Sludge Digestion

• ANAEROBIC DIGESTION
  • The object of good anaerobic digester operation is to maintain a suitable environment to sustain a growing population of both Saprophytic (acid formers) and methane fermenters.
  • A properly operating anaerobic digester:
    • Reduces the raw feed volatile (organic) solids by 40-60%
    • Most anaerobic digesters require a minimum of 15-days to reach this reduction
Sludge Digestion

• 40 CFR Part 503, Appendix B: **Process to Significantly Reduce Pathogens (PSRP)**
  
  3. ANAROBIC DIGESTION
  
  • *Biosolids are treated in the absence of air for a specific mean cell residence time at a specific temperature. Values for the mean cell residence time and temperature shall be between 15 days at 35°C to 55°C and 60 days at 20°C.*
Anaerobic Digester Buffering Capacity

- Digester buffering capacity is a digester's ability to resist a change in pH and it is directly measured by the amount of alkalinity present.
- Volatile acids that are formed as part of the first stage of digestion can reduce alkalinity. The volatile acids to alkalinity ratio is used as a measure of these two important operating factors.
Volatile Acid / Alkalinity Ratio

- In a well operating digester the volatile acids expressed as acetic acid would be in the range of 50 to 500 mg/L and the alkalinity expressed as calcium carbonate would be in the range of 2,000 to 3,000 mg/L. In a healthy digester the volatile acids are used as food by the methane formers at about the same rate as they are produced. In general keeping the volatile acids to alkalinity ratio at 0.25 or less is desirable for good operations.
Sludge Digestion

- Anaerobic Digestion Process

Complex Organics → Organic Acids and \( H_2 \) → \( \text{CH}_4 \) and \( \text{CO}_2 \)

- Acid Producing Bacteria (Acidogens)
- Methane Producing Bacteria (Methanogenics)
Microbial Conversion of Organics
Volatile Acid Formation

Particle Disintegration → Hydrolysis → Fermentation (acidogenesis)

Organic Particles (floc) → Complex Polymers, Proteins, Carbohydrates and Lipids → Amino Acids, Sugars, Fatty Acids → Volatile Fatty Acids and Hydrogen Gas (H₂)
Microbial Conversion of Organics
Methane Gas Formation

\[ \text{Acetate} \rightarrow \text{CH}_3\text{COOH} \rightarrow \text{CO}_2 + \text{CH}_4 \]

\[ \text{Propionate} \rightarrow \text{CH}_3\text{COOH} \rightarrow \text{CO}_2 + \text{CH}_4 \]

\[ \text{Butyrate} \rightarrow \text{CH}_3\text{COOH} \rightarrow \text{CO}_2 + \text{CH}_4 \]

\[ \text{Valerate} \rightarrow \text{CH}_3\text{COOH} \rightarrow \text{CO}_2 + \text{CH}_4 \]

\[ \text{H}_2 \rightarrow 4\text{H}_2 + \text{CO}_2 \rightarrow 2\text{H}_2\text{O} + \text{CH}_4 \]

Aceticlastic Methanogenesis
Hydrogenotrophic Methanogenesis
## Sludge Digestion

### Anaerobic Digestion Standard Design Parameters

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<td></td>
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</tr>
<tr>
<td></td>
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<td></td>
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<td>0.1 – 0.5</td>
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</tbody>
</table>
Sludge Digestion

• ANAEROBIC DIGESTION
  • Mixing is the most important factor in the high-rate digestion process:
    • Uses most of the digester volume
    • Quickly distributes food throughout the volume
    • Puts microorganisms in contact with food
    • Achieves good pH control by distributing the BUFFERING ALKALINITY
    • Distributes heat throughout the tank volume
    • Minimizes the separation of heavy grit and floatables
Sludge Digestion

• ANAEROBIC DIGESTION
• Three (3) Anaerobic Digestion Process

Operating Temperatures:

1. **PSYCHROPHILIC** – lowest temperature, unheated digester. Dependent on ambient temperature. No bacterial activity at temperatures below 50°F

2. **MESOPHYLIC** – Medium temperature (most popular), 80°F to 113°F. The optimum range is 85°F to 100°F. Most popular set-point 95°F

3. **THERMOPHILIC** – hot temperature, above 113°F. Optimum range 120°F to 135°F.
Sludge Digestion

- **ANAEROBIC DIGESTION**
- **Secondary Digesters**
  - No mixing
  - Allows solids/liquid (SUPERNATE) to separate
  - Gas storage
  - Floating cover
  - Seed Sludge
Sludge Digestion

• ANAEROBIC DIGESTER GAS SYSTEM
  • Digester Gas has a heat value = 500 to 600 BTU
  • Natural Gas has a heat value = 900 to 1200 BTU
  • Biogas will burn at 55% methane
  • Biogas with at least 62% methane can be used as a fuel source

• Digester Gas is used for:
  • Co-generation Internal Combustion (I/C) Engines
  • Export/Inject back into the PG&E natural gas system
  • Boilers to heat digesters and buildings
  • I/C Engines to operate blower for aeration
  • Biosolids drying
  • Natural gas for vehicles
  • Production of Biodegradable Plastics
Sludge Digestion

Electricity Co-Generation

Boilers for digester heating

Biodegradable Plastic

Natural Gas Vehicles

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Sludge Digestion

• ANAEROBIC DIGESTER GAS SYSTEM
• Digester Dome for Gas Storage
  • Must be kept at positive pressure, <11 in Water
  • Higher than 11 inches of water column pressure could result in gas escaping from the dome water seals
  • Must be kept out of a vacuum situation
    • Withdrawing solids too quickly
    • can collapse dome
    • Could draw in air and cause an explosive atmosphere
• Pressure/Vacuum Relief Valves
  • Pressure Relief generally have a flame arrestor attached to them
Sludge Digestion

- **DIGESTER GAS** + **OXYGEN** = **EXPLOSIVE**

[Image of explosion]

Anaerobic Digester Explosions

[Image of damaged facility]
Sludge Digestion

• ANAEROBIC DIGESTER GAS SYSTEM
• Digester Dome for Gas Storage (Safety Devices)
Sludge Digestion

- **ANAEROBIC DIGESTER GAS SYSTEM**
- Excess gas produced that cannot be utilized is prohibited from discharge to the atmosphere (GHG)
- Removed via a WASTE GAS BURNER
Sludge Digestion

- ANAEROBIC DIGESTER HEATING SYSTEM
Sludge Digestion

- ANAEROBIC DIGESTER HEATING SYSTEM

Spiral Heat Exchanger

Boiler Hot Water Box with Heat Exchanger
Sludge Digestion

• ANAEROBIC DIGESTER MIXING SYSTEM
  • Mechanical Mixing
    • Prop mixing
    • Pump Mixing
  • Gas Mixing
    • Pump digester gas back into bottom of digester to provide gas lift mixing
Sludge Digestion

• **ANAEROBIC DIGESTER MIXING SYSTEM**

  ![Mechanical Mixing](image1)
  ![Pump Mixing](image2)
  ![Digester Gas Mixing](image3)
Sludge Digestion

• ANAEROBIC DIGESTER OPERATION
  • Three main operation controls of an Anaerobic Digester:
    1. Temperature (Heating)
    2. Feeding (Volatile organic feed)
    3. Mixing (Maintaining good contact with food and microorganisms)

1. TEMPERATURE
  • Maintain optimum temperature for operating range to properly reduce volatile organic solids and generate methane gas
Sludge Digestion

• ANAEROBIC DIGESTER OPERATION

2. FEEDING

• Maintain proper balance of Volatile Acids and Methane Fermentation
• Maintain optimal % solids of feed solids of approximately 3.5%
• Thinner solids contain higher concentrations of water
  • Water requires additional heat to maintain optimal temperature
  • Water reduces the working volume and influences the detention time
  • Water can dilute the Alkalinity or buffering
  • Water will increase the digester supernate going back into the plant
Sludge Digestion

• ANAEROBIC DIGESTER OPERATION

3. MIXING

• Maintain optimum contact between food and microorganisms
• Provide good heat distribution of heated sludge
• Provides suspension of heavy solids that would settle without mixing
• Can break up the scum layer that floats on top of the digester volume
Sludge Digestion

• DIGESTED SOLIDS DEWATERING
  • Process and equipment that removes water from the stable digested solids
  • Generally uses a cationic polymer for solids conditioning and floc formation prior to dewatering
    • Mechanical dewatering
    • Heat dewatering
    • Solar dewatering
COAGULATION

- Coagulants tend to be positively charged.
- Due to their positive charge, they are attracted to the negative particles in the water.
- The combination of positive and negative charge results in a neutral, or lack, of charge.
- Van der Waal's forces refer to the tendency of particles in nature to attract each other weakly if they have no charge.
Sludge Digestion

OPERATION

• Coagulation
  • Requires the addition of a coagulant chemical
  • Requires a rapid or FLASH MIX to thoroughly mix the coagulant and charged particles to neutralize the charges

• Flocculation
  • The clumping of particles as the result of coagulation
  • Requires slow mixing to allow particles to softly collide and stick together (AGGLOMERATION)
  • Rapid mixing during the flocculation process would cause the floc particles to fall apart or SHEAR due to the mixing energy
Sludge Digestion

COAGULATION

Van der Waal's forces

Coagulation
- Repeal each other
- Attract each other
- Neutral particles

Coagulation Flocculation/Sedimentation
Polymers

- Water soluble, high molecular weight organic compounds that carry electrical charge along a chain of carbon atoms
- Polymers help build large floc prior to sedimentation

Types of Polymers

- Non-ionic: no electrical charge
- Cationic: net positive (+) electrical charge
- Anionic: net negative (-) electrical charge
Sludge Digestion

ANAEROBIC DIGESTER MATH

Anaerobic Digester Loading

• During a 24-hour period, 2,800 gallons of 6.5% total sludge solids with a volatile content of 68% was pumped to an anaerobic digester.
  • How many pounds of dry solids were fed to the digester?
  • What portion of the solids are volatile organic that can be readily digested?
Sludge Digestion

ANAEROBIC DIGESTER MATH

Anaerobic Digester Loading

- **Known**
  - Sludge pumped = 2,800 gallons
  - % solids = 6.5%
  - % volatile = 68%

\[
\text{Dry Solids, lbs} = (\text{flow, gal})(\% \text{ solids as decimal})(8.34 \text{ lbs/gal})
\]
\[
= (2,800, \text{ gal})(0.065)(8.34 \text{ lbs/gal})
\]
\[
= (182.0 \text{ gal})(8.34 \text{ lbs/gal})
\]
\[
= 1,518 \text{ lbs dry Solids}
\]
Sludge Digestion

ANAEROBIC DIGESTER MATH

Anaerobic Digester Loading

- Known
  - Sludge pumped = 2,800 gallons
  - % solids = 6.5%
  - % volatile = 68%

Volatile Solids, lbs = (total solids, lbs)(% volatile as decimal)
= (1,518 lbs)(0.68)
= 1,032 lbs of Volatile Solids
Sludge Digestion

ANAEROBIC DIGESTER MATH
Anaerobic Digester Loading Volatile Matter/ft³/day

• A raw sludge volume of 2,800 gallons was pumped in a 24-hour period to an anaerobic digester with a diameter of 40-ft and a 20 ft water depth. The raw sludge with a 6.5% solid and a volatile solids content of 68% contained 1,032 lbs of volatile solids.

• Calculate the digester loading in VM/ft³/day
Sludge Digestion

ANAEROBIC DIGESTER MATH

Anaerobic Digester Loading

- **Known**
  - Sludge pumped = 2,800 gallons
  - % solids = 6.5%
  - % volatile = 68%
  - Lbs volatile solids = 1,032 lbs
  - Digester diameter = 40 ft
  - Digester water depth = 20 ft

Digester Loading, Volatile Matter/ft³/day

\[
= \frac{(VM \text{ added, lbs/day})}{\text{Volume of digester, ft}^3}
\]
Sludge Digestion

ANAEROBIC DIGESTER MATH

Anaerobic Digester Loading

Digester Loading, Volatile Matter/ft³/day

\[ \text{Digester Loading, Volatile Matter/ft}^3/\text{day} = \frac{(\text{VM added, lbs/day})}{\text{Volume of digester, ft}^3} \]

VM added = 1.032 lbs

Volume of digester, ft³ = (diameter ft)² (0.785)(depth ft)

\[ = (40\text{ft})^2 (0.785)(20\text{ft}) \]
\[ = (1,600 \text{ ft}^2)(0.785)(20\text{ft}) \]
\[ = (1,256 \text{ ft}^2)(20\text{ft}) \]
\[ = 25,120 \text{ ft}^3 \]
Sludge Digestion

ANAEROBIC DIGESTER MATH

Anaerobic Digester Loading

Digester Loading, Volatile Matter/ft³/day

\[ \text{Digester Loading} = \frac{\text{VM added, lbs/day}}{\text{Volume of digester, ft}^3} \]

\[ = \frac{1,032 \text{ lbs VM}}{25,120 \text{ ft}^3} \]

\[ = 0.041 \text{ Volatile Matter/ft}^3/\text{day} \]

<table>
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<tr>
<th>Volatile Solids Loading</th>
<th>Standard High Rate</th>
<th>0.03 – 0.1 lbs VS/day ft³</th>
<th>0.1 – 0.4 lbs VS/day/ft³</th>
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Sludge Digestion

ANAEROBIC DIGESTER MATH

Anaerobic Digester Volatile Solids % Reduction

• An anaerobic digester has a feed volatile solid content of 68% and a digested sludge overflow that contains a volatile solids content of 43%.

• Calculate the % volatile solids reduction

\[
\text{in} - \text{out} \times 100\% \\
\text{in} - (\text{in} \times \text{out}) \\
= 0.68 - 0.43 \times 100\% \\
0.68 - (0.68 \times 0.43) \\
= 0.25 \times 100\% \\
0.68 - 0.29 \\
= 0.25 \times 100\% \\
0.39 \\
= 0.64 \times 100\% \\
= 64\% \text{ volatile solids reduction}
\]
Why is this Information Important?

The previous math problem provide the following information:

- 1,032 lbs VS fed to the digester
- Achieved 64% VS Reduction (VSR)

How many Lbs of VSR:

- $1,032 \text{ lbs VS} \times 64\% \text{ VSR} = 660 \text{ lbs VSR}$

- Anaerobic Digesters produces 14-18 $\text{Ft}^3 \text{ Biogas/lbs VSR}$

How many $\text{Ft}^3 \text{ Biogas/lbs VSR}$:

- $660.5 \text{ Lbs VSR} \times 15 \text{ Ft}^3 \text{ Biogas/lbs VSR} = 9,900 \text{ Ft}^3$
Why is this Information Important?

- It requires approximately 19-21 Ft\(^3\) Biogas to produce 1.0 kWh of electric power in an internal combustion engine or Co-Generation Engine.

\[
9,900 \text{ Ft}^3 \text{ Biogas} \div 20 \text{ Ft}^3 \text{ Biogas/kWh Electric Power} = 495 \text{ kWh Electric Power}
\]
SOUR ANAEROBIC DIGESTER

Describe how to determine the amount of alkalinity needed to correct an upset digester including chemical feeding rate.

To determine the amount of chemical needed to achieve a given alkalinity to correct a sour digester would require the determination of the amount of volatile acids present, the amount of alkalinity present, the excess alkalinity desired, and the chemical to be used. Knowledge of the control chemical would include the amount needed (based on equivalent weight [atomic weight]) and the percent availability of the chemical all relative to calcium carbonate.

The equivalent weight of the common chemicals would be:

A. Calcium oxide = 56  
B. Calcium hydroxide = 74  
C. Anhydrous ammonia = 17  
D. Ammonium hydroxide = 35  
E. Sodium carbonate = 106  
F. Sodium bicarbonate = 84  
G. Sodium Hydroxide = 40
Given the following information calculate the amount of chemical needed.

- Digester volume = 250,000 gallons
- Volatile acids = 3,000 mg/L
- Sodium bicarbonate equivalent weight = 84
- Percent availability calcium carbonate = 68%
- Equivalent weight = 100
- Alkalinity (as calcium carbonate) = 0.833 volatile acids (as acetic acid)
1. Find the pounds of volatile acids in the digester
   Formula:
   \[\text{pounds} = \text{concentration (mg/L)} \times \text{volume (mg)} \times 8.34\]
   \[\text{pounds} = 3,000 \times .25 \times 8.34\]
   \[\text{pounds} = 6,255 \text{ pounds (volatile acids)}\]

2. Find pounds of calcium carbonate needed
   Formula:
   \[\text{pounds} = \text{alkalinity} \times \text{pounds volatile acids}\]
   \[\text{pounds} = .833 \times 6,255\]
   \[\text{pounds} = 5,210 \text{ pounds (calcium carbonate)}\]

3. Find pounds of 100\% sodium bicarbonate needed
   Formula:
   \[100\% \text{ bicarb} = \frac{\text{equivalent weight of sodium bicarb}}{\text{equivalent weight of calcium carb}} \times \text{pounds}\]
   \[100\% \text{ bicarb} = \frac{84}{100} \times 5,210\]
   \[100\% \text{ bicarb} = 4,376 \text{ pounds (as 100\% sodium bicarbonate)}\]
4. Find pounds of chemical needed at 68% alkalinity

Formula:
Chemical pounds = 100% ÷ 68% x pounds
Chemical pounds = 100% ÷ 68% x 4,376

Chemical pounds = 6,435 pounds of 68% Sodium bicarbonate

The amount of chemical calculated should not all be added at once but fed in increments spread over a week or longer. Monitoring of volatile acids, alkalinity, and pH in the active zone of the digester will indicate progress towards recovery and would determine when to stop feeding chemicals.