Anaerobic Digestion 101
Process Description and Process Control

Presented at Anaerobic Digestion and Energy Generation Workshop and Open House
Lewiston Auburn Water Pollution Control Authority

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September 10, 2013

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Overview

1. Process Description
2. Process Control

PROCESS DESCRIPTION

What is Anaerobic Digestion?

Anaerobic digestion is a biological process that uses bacteria that live and reproduce in an environment containing no "free" or dissolved oxygen to treat sludge that is a by-product of the wastewater treatment process.

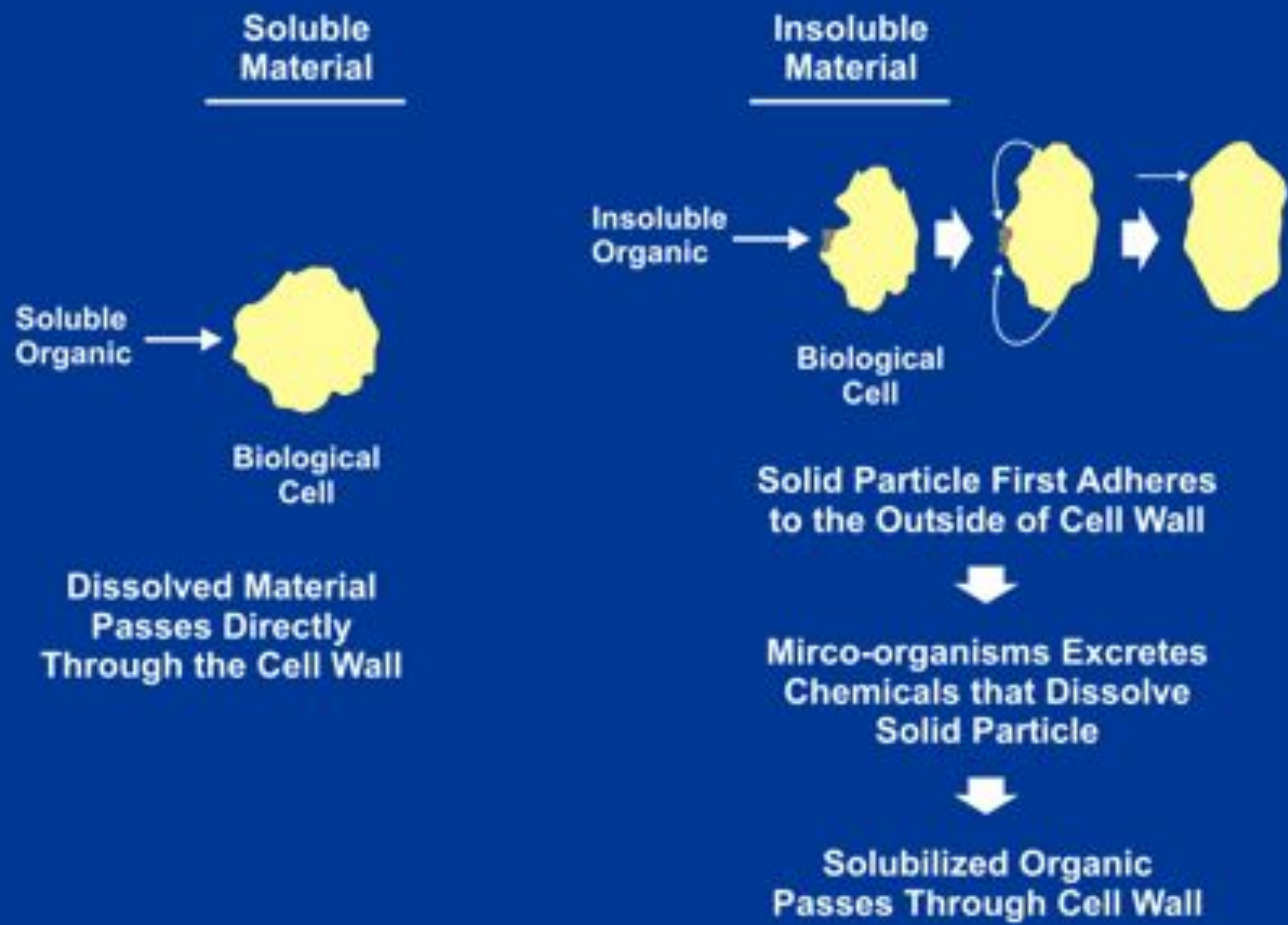
Anaerobic digestion accomplishes several functions

- Breaking down organic matter into simple compounds.
- Minimizing further biological activity.
- Transforming portions of solids into liquid and gas.
- Reducing the sludge solids to be dewatered.
- Producing methane gas (CH_4) for fuel.
- Eliminating some pathogenic bacteria
- Reducing sludge odors

Anaerobic Sludge Digestion Steps

- First, complex organic compounds are converted to soluble forms.
- Second, complex soluble organic matter is changed to volatile (organic) acids.
- Third, organic acids are broken down by a different type of microorganism to form methane gas, but at a much slower rate.

Soluble and Insoluble Material



Microbes Summary

Acid formers:

- Convert soluble organic solids to organic acid
    - Enzymes break down insoluble organics to soluble organics
- High energy, rapid growing
- Not as sensitive to environmental changes

Microbes Summary

Methane formers:

- In a balanced system, organic acids are consumed at the same rate as produced.
- Get little energy from the organic acids
- Grow slowly compared to acid formers
- Susceptible to pH and temperature changes
- Do the work of stabilization

How Does the Transfer Work?

Acid Forming Bacteria +
Organic (Soluble & Insoluble) Matter

↓

Methane Forming Bacteria + Organic (Volatile) Acids

↓

Carbon Dioxide (CO_2) + Methane (CH_4) Gases

Byproducts of Digestion

- Digested sludge
  - Consisting of inorganic solids and volatile solids that are not easily digested
- Gas
  - Methane (65-70%) for fuel, carbon dioxide (30-35%) & lesser gases (hydrogen sulfide, etc).
- Scum
  - Foam: filamentous and from high mixing

PROCESS CONTROL

Process Controls: Fixed and Variable

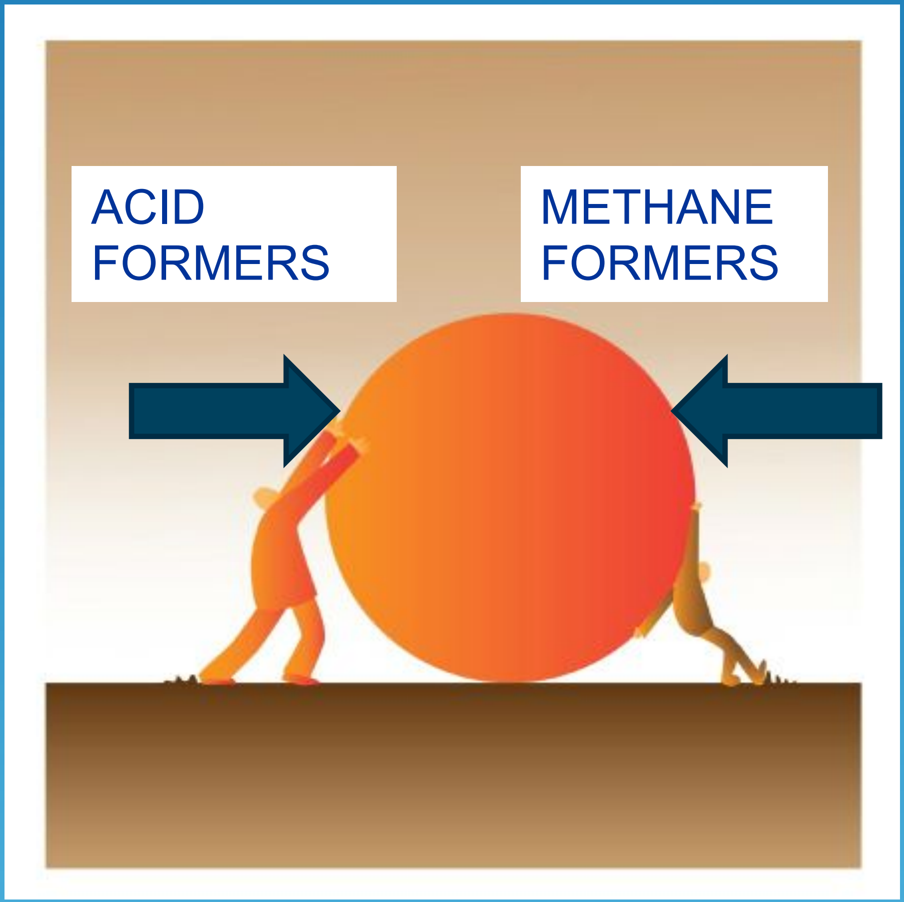
- Fixed (not an operator control, has been designed to handle anticipated sludge volumes)
  - Size and number of digesters
  - Size and number of biogas/digested sludge storage tank
  - Digester feed system
  - Digester mixing system
  - Digester recirculation and heating system

Process Controls: Fixed and Variable

- Variable (under operator control)
  - Rate, timing, concentration, and quantities of the sludge pumped to the digesters.
  - Quantity of digested sludge withdrawn from the biogas/digested sludge storage tank.
  - Sludge digestion temperature and pH.
  - Control of the amount of sludge recirculated and the amount of mixing.

Process Control Objective

- Control food supply, temperature, pH, and digested sludge feed rate to maintain a proper balance between the acid-forming and the methane-forming bacteria.



Operator Responsibility

- Limit temperature changes to **less than 1°F per day**.
- Feed sludge as near continuous as possible
- Maintain continuous mixing
- Maintain the following operating parameters…

Operating Parameters

Parameter	Approximate Value
• Alkalinity	2000 to 5000 mg/L (as $CaCO_3$)
• Volatile Acids	50 to 300 ppm, (<500 ppm)
• VA/Alk Ratio	0.1 to 0.35 (0.50 is a sour digester)
• pH	6.6 to 7.2
• Temperature	93^oF - 100^oF
• Carbon Dioxide in gas	30 to 35% by volume
• Methane in gas	65 to 70% by volume

Feeding of Sludge

- Nearly continuous basis to reduce or eliminate sudden flow rate and organic loading changes.
  - **WHY?:** Non-continuous , infrequent , or slug feeding causes variations in organism growth, solids decomposition rates, gas production, methane concentration, alkalinity, volatile acids, pH, etc.
- Small additions at frequent intervals assure a more constant food supply to the organisms and a more uniform digestion rate.

Feeding of Sludge

- Feeding outside wastes, septage and FOG require additional care since their strength and composition can vary, thus requiring characterization of the waste.
- Steady consistent feed.
- DO NOT slug load the digesters!!!

Temperature Control

- Ideal digestion temperature of 95°F (range: 93°F to 100°F), supports mesophilic microorganisms.
- Digestion can proceed at lower temperatures (85°F to 90°F) with fairly good effectiveness
  - Requires additional digestion time to allow for the slower breakdown of organics.
- Methane forming bacteria are adversely affected by rapid temperature changes of 2°F
  - <u>Limit and control to 1°F per day</u>

Monitoring and Control: Alkalinity, Volatile Acids, pH, and Carbon Dioxide/Methane

- Factors which indicate proper digester operation.
- Routine measurement of each parameter's concentration is required.
- Operator should know the appropriate range of values for each parameter
- Operator should know what changes in digester conditions are indicated by changes in these values.

Frequency of Measurements

Parameter	Frequency during Startup	Frequency during Stable Operations
Alkalinity	Daily	3-5 days/week
Volatile Acids	Daily	3-5 days/week
pH	Daily	Daily
Carbon Dioxide and Methane	Daily	3-5 days/week
Feed VSS	Daily	Daily
Temperature	Continuous	Continuous

pH; What is it and Why does it Matter?

- Measurement of hydrogen ion concentration of a solution indicating the relative degree of acid or base.
  - Digestion Range: 6.6 to 7.2;
  - Preferred Range: 6.8 to 7.0
  - Above 8.0, un-ionized ammonia is toxic to methane formers.
  - Below 6.0, un-ionized volatile acids are toxic to methane formers
  - Below 4.5, digestion ceases.
- Un-ionized molecules pass through the methane formers cell wall easily causing toxicity.
  - How do you respond: change the pH which changes the un-ionized concentration preventing toxicity
    - (i.e., adding bicarbonate alkalinity)

Digester Upset

- Failure of the digestion process (souring) may result from a number of causes, including:
  - Overloading the Digester
  - Fluctuations in Digester Temperature
  - Toxic Wastes
  - Poor or Over Mixing
  - Air Leakage (detrimental to methane formers)

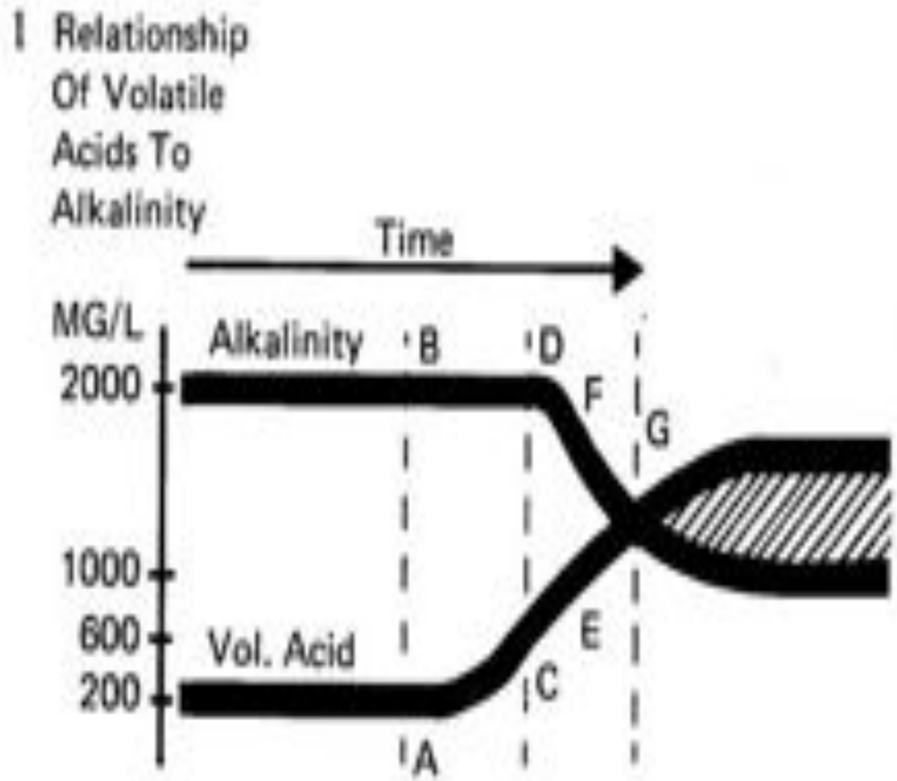
Digester Upset

- Low pH, low alkalinity, and high volatile acids are the result, rather than the cause, of the problem.
- Address the cause(s)
- Add alkalinity

Looking for Trouble

- Important parameters in controlling digestion are:
  - Volatile acids, alkalinity, gas production, percent carbon dioxide in gas, and pH.
- Of these, rate of increase in the volatile acids concentration and rate of gas production will most accurately and reliably forecast digestion failure.
  - Usually a volatile acids concentration above 1000 mg/L and/or a decline in gas production will indicate trouble.

Graph of Change Sequence in a Digester



This graph shows a digester operating with a good buffering capacity (the low volatile acids 200 mg/l compared to an alkalinity of 2,000 mg/l. At Point A, something has happened to cause the volatile acids to increase followed by a decrease in alkalinity at Point D. At Point G, the digester has become sour.

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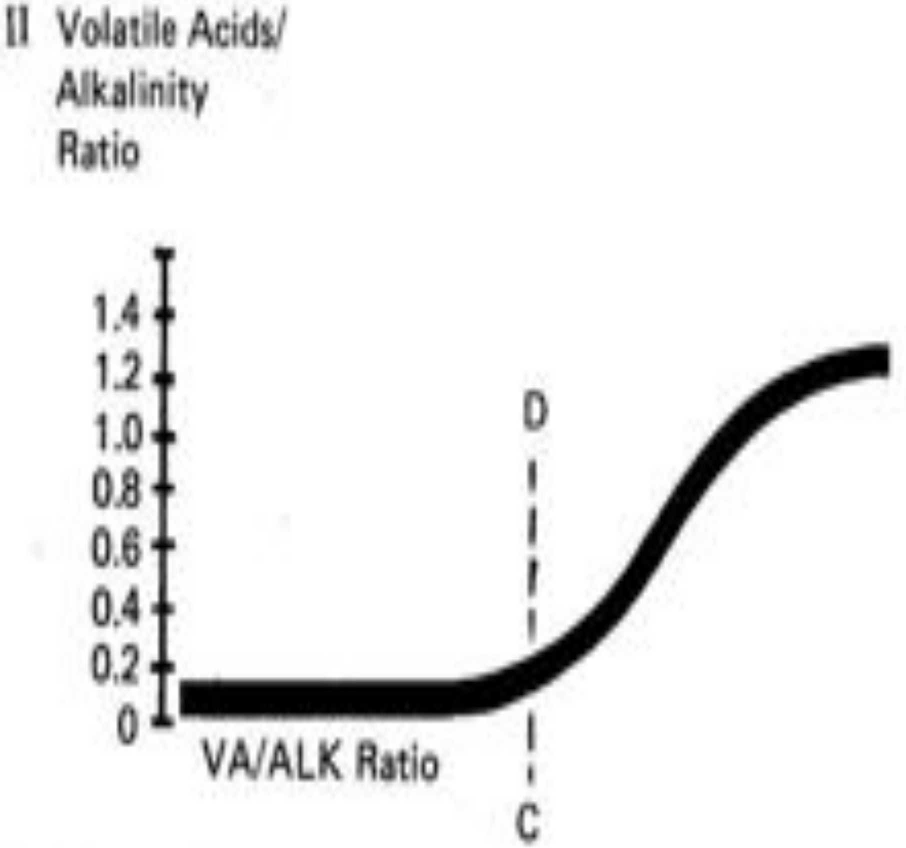
Graph of Change Sequence in a Digester



This graph continues the same digester performance by showing the volatile acids/alkalinity ratio. Notice that at Points CD, the increase in volatile acids produces an increase in the ratio from 0.1 to 0.3.

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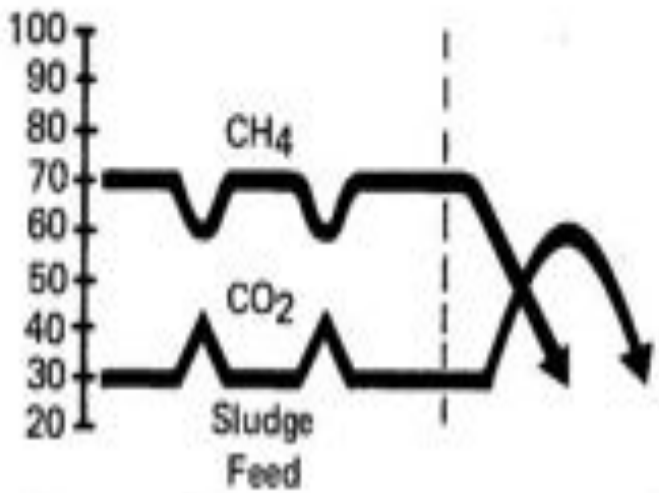
Graph of Change Sequence in a Digester

III Relationship Of The Change In Ratio Of CO_2 To Methane (CH_4) As A Result Of "I"



By comparing this graph with Graph II, methane production begins to drop with a corresponding increase in CO_2 when the ratio in Graph II reaches about 0.5.

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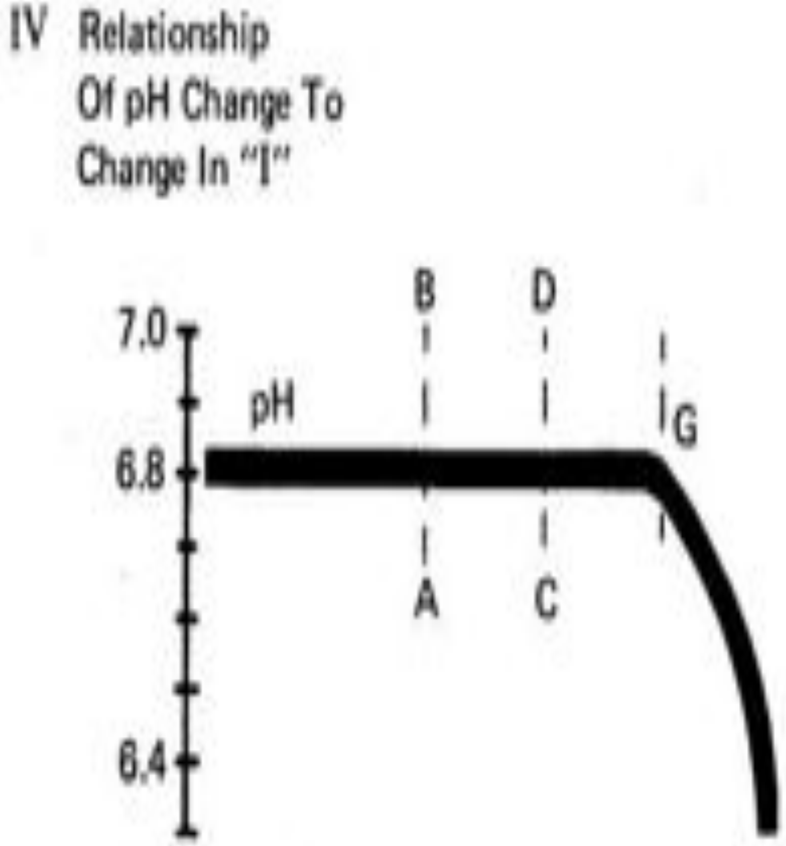
Graph of Change Sequence in a Digester



pH doesn't change in this graph until the digester is becoming sour at Point G.

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Failure Indicator Relationship

Process Indicator	Trend of Indicator	pH *	CH_4	CO_2	Alkalinity	Volatile Acid
pH	Down		Down	Down	Down	Up
CH_4, %	Down	Down		Up	Down	Up
CO_2, %	Up	None	Down		Down	Up
Alkalinity	Down	Down	Down	Up		Up
Volatile Acid	Up	Down	Down	Up	Down	

***pH is a lagging indicator**

How does an operator know when proper digestion is taking place?

1. A variety of field observations and laboratory sampling and analysis can be conducted to ascertain the degree of success of the digestion process.

2. An evaluation of sludge digestion begins by knowing the total and volatile solids content of the sludge.

What are the total and volatile solids?

1. An analysis for total solids identifies the sludge concentration of the blended sludge (primary and activated sludge) entering the digester.

2. The water in the sludge is evaporated in an oven at 103-105°C for an hour, leaving only the residual solids which are expressed as total solids, TS.

3. Volatile solids, VS, represent that portion of the total solids that are organic in nature.

4. These volatile solids represent food matter that is to be stabilized prior to dewatering at the belt filter press.

What are the total and volatile solids?

1. The total solids residue is heated in a furnace to 550°C for two hours, which will ignite the organic material in the solids, leaving only ashes, referred to at fixed solids, FS.

2. Applying these values to a formula.

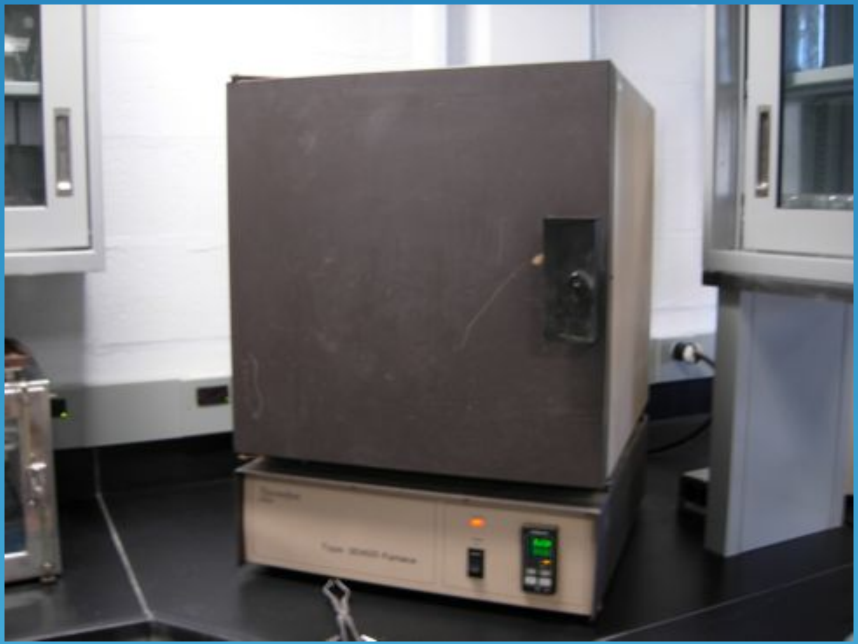
   Total solids (%) – Fixed solids (%) = Volatile solids (%)

3. The difference between the two weights represents the volatile or organic portion and the residue after burning represents the ash or inorganic portion.

Total and Volatile Solids

Drying Oven at 103-105°C

Furnace at 550°C



What are other parameters to be monitored in a digester operation?

Once sludge has entered a digester, the major internal control combines two laboratory tests:

1. Volatile Acids and
2. Alkalinity

What are volatile acids and alkalinity?

1. The alkalinity of a digester is important because it represents the ability of a digester to neutralize the acids formed during the digestion process.

2. As a result, the volatile acids should always remain low, when compared to alkalinity.

Volatile Acids (VA)

- Volatile acid production is largely dependent on the volume of sludge fed to the digester.
  - It should be held relatively constant.
- In healthy digesters, acids will be used by the methane formers at the rate they're produced.
  - Severe changes in conc. indicates that acid-producing organisms are multiplying at a rate faster than the methane producing organisms.
  - Staff must monitor the relative change in the proportionality of the VA/Alk ratio.
- Volatile (organic) acids will typically be 50 – 300 mg/l expressed as acetic acid.

Alkalinity (Alk)

- Sufficient alkalinity must be present to "buffer" the volatile acids formed during digestion.
- Alkaline buffers come from two sources:
  - Present and concentrated in the feed sludge.
    - Hard water, alkaline industrial wastes
  - Produced by the methane formers
    - Bicarbonates, carbonate and ammonia
  - Typically 2,000 to 5,000 mg/l expressed as bicarbonate alkalinity (mg/L $CaCO_3$)
- Alkalinity (fed and produced) must be in equilibrium with acid production to prevent upset.

VA/Alk

- Indicates the progress of digestion, its stability, and is used for process control.
- The results of the volatile acids and alkalinity tests are expressed as a ratio. Example:
  - Volatile acids = 300 mg/l
  - Alkalinity = 2,000 mg/l
  - VA/Alk = 300 / 2,000 = 0.15
- The range of VA/Alk ratio is 0.1 to 0.35, 0.1 to 0.25 is ideal.
- VA/Alk ratio of 0.5 indicates a sour digester
- Parameters must be sampled and tested daily at start-up, no less than a minimum of three times per week during stable operation.
  - If unstable conditions are beginning to occur, or are present (trending above 0.25), test daily.

What is the proper ratio of volatile acids to alkalinity?

1. Ideally, the VA/ALK ratio should range between 0.1 and 0.25, once it goes beyond 0.25 the operator is cautioned to back off on the feed and monitor very closely.

2. Within this range, the digester is considered healthy with good digestion taking place.

3. When the ratio begins to change, it is an indication of a potential digester upset. Trending towards 0.35 is entering the danger zone. A ratio of 0.5 indicates a sour digester.

Volatile Acids/Alkalinity Ratio

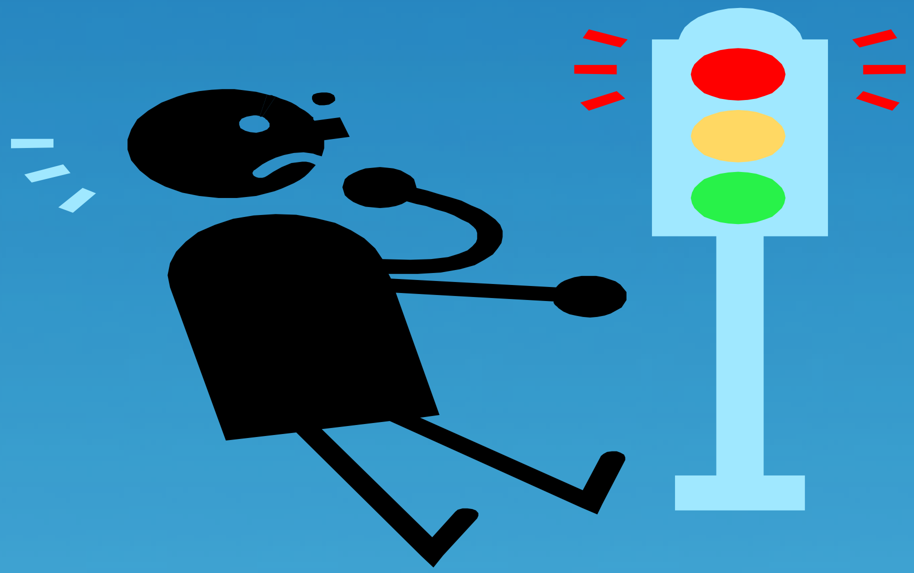
0.1 – 0.25 green light

0.25 + **yellow caution light**

0.35 + **red warning danger light**

0.5 **FLASHING RED LIGHT!**

SOUR DIGESTER !!!



Since the VA/ALK ratio is the first indicator of potential digester upset, what are some other signs which follow?

1. The process of sludge digestion generates methane and carbon dioxide gas and other trace gases.

2. Under normal circumstances, the production of methane represents 65 to 70 percent of the digester gas; carbon dioxide being 30 percent and the remaining 1 or 2 percent various trace gases.

3. Since an increase in the VA/ALK ratio is the first sign of digester trouble, an increase in this ratio will ultimately lead to an increase in carbon dioxide and a decrease in methane.

Since the VA/ALK ratio is the first indicator of potential digester upset, what are some other signs which follow?

4. Methane production will represent less than 65 percent of the contents of the digester gas and carbon dioxide will exceed 30 percent.

5. Finally, the pH of the digester sludge will begin to drop.

6. Temperature also affects the work of the methane bacteria.

Since the VA/ALK ratio is the first indicator of potential digester upset, what are some other signs which follow?

7. The best temperature range for the digester contents should be between 93° - 100°F and variations in temperature should **not exceed 1°F per day.**

8. In general, the detention time needed to obtain complete digestion decreases with increasing temperature since organism activity increases as temperature increases.

Wouldn't monitoring pH be the easiest method of controlling digester process control?

1. pH is one of the simplest tests that can be conducted to indicate process control and should be done at least once per shift.

2. However, there is a danger in solely relying on pH for process control because the pH changes very slowly and the digester may be completely upset before the pH changes.

pH as a Performance Parameter

- pH is a "lagging" indicator. Why?
  - When a digester is upset, volatile acids concentration will increase neutralizing the alkalinity.
  - Once exhausted, volatile acids concentration continues unchecked and the pH drops rapidly.
  - Alkalinity masks volatile acid build-up, when the pH does drop, the digester has been sour for a long time.

- Therefore, pH is the poorest indicator of performance.

Now that the process control parameters are known, how does an operator begin the monitoring process?

1. In order for the operations staff to effectively control the digestion process, an operator must be aware of the various sampling points and required tests.

2. A good sampling and testing program will consist of samples being collected from the same location at regular intervals.

3. Analysis of these samples will assist in informing the operations staff of digester performance and can be used to adjust the process operation

What process streams of the digester should be sampled and what analysis should be performed?

1. The digesters should have the following process streams sampled:
   - Blended sludge (digester feed)
   - Recirculated sludge
   - Digester Gas
   - Digested sludge (sludge from the digester to the sludge dewatering facilities.
2. The blended sludge or the influent sludge to the digester, should be analyzed for total solids and total volatile solids.
3. During the recirculation of the sludge, a sample should be taken and tested for volatile acids, alkalinity, pH and temperature.

Importance of Accurate Data

- You must be able to trust the numbers that you get
- Test results are only as good as the representativeness of the sample
- Do not underestimate the importance of proper sampling technique
- Duplicate samples on solids analyses take very little extra effort, in order to ensure that you know what you are feeding
- Trend results
- Record events and establish operational history

Questions?