Wisconsin Department of Natural Resources
Wastewater Operator Certification

Anaerobic Treatment of Liquid Waste

A5

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Preface

The Anaerobic Treatment of Liquid Waste Study Guide is an important resource for preparing for the certification exam and is arranged by chapters and sections. Each section consists of key knowledges with important informational concepts you need to know for the certification exam. This study guide also serves as a wastewater treatment plant operations primer that can be used as a reference on the subject.

In preparing for the exams:
1. Study the material! Read every key knowledge until the concept is fully understood and known to memory.

2. Learn with others! Take classes in this type of wastewater operations to improve your understanding and knowledge of the subject.

3. Learn even more! For an even greater understanding and knowledge of the subjects, read and review the references listed at the end of the study guide.

Knowledge of the study guide material will be tested using a multiple choice format. Every test question and answer comes directly from one of the key knowledges.

Choosing a test date:
Before choosing a test date, consider the time you have to thoroughly study the guides and any other training opportunities available. A listing of wastewater training opportunities and exam dates is available at http://.dnr.wi.gov by searching for the keywords “Operator Certification”.

Acknowledgements

The Anaerobic Treatment of Liquid Waste Study Guide was the result of a collaborative effort of yearlong monthly meetings of wastewater operators, trainers, consultants, the Wisconsin Wastewater Operator Association (WWOA), and the Wisconsin Department of Natural Resources (WDNR). This study guide was developed as the result of the knowledge and collective work of following workgroup members:

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Chapter 1 - Theory & Principles

Section 1.1 - Definitions

1.1.1 Define alkalinity.

Alkalinity is the capacity of the wastewater to buffer against acid and resist fluctuations in pH. It is measured as the calcium carbonate equivalent in mg/L.

1.1.2 Define anaerobic digestion.

At its most basic level, anaerobic digestion is the biochemical decomposition of organic matter into methane gas and carbon dioxide by microorganisms in the absence of oxygen.

1.1.3 Define mesophiles.

Mesophilic microorganisms grow and thrive in a temperature range of 85°F to 104°F (30°C to 39°C).

1.1.4 Describe what is meant by a sour anaerobic reactor.

A sour anaerobic reactor is a reactor that has become upset and is performing poorly. It is characterized by low methane production, high volatile acids to alkalinity (VA/ALK) ratio, and often a low pH. Common causes include: excessive organic loading, inadequate micronutrient supply, inadequate mixing, toxic or inhibitory conditions for the methane-forming microorganisms, or non-optimal temperatures.

1.1.5 Define thermophiles.

Thermophilic microorganisms grow and thrive in a temperature range of 120°F to 135°F (49°C to 57°C).

1.1.6 Define total solids.

Total solids are the sum of dissolved and suspended solid constituents in water or wastewater. For more information, see Standard Methods (method number 2540 B).

1.1.7 Define volatile solids.

Volatile solids are primarily organic compounds, that can be driven off from a dried sample at 550°C; nonvolatile inorganic solids (ash or inert solids) remain. For more information, see Standard Methods (method number 2540 G).

1.1.8 Define chemical oxygen demand.

Chemical oxygen demand (COD) is a measure of how much of a standard oxidant will react with a sample and is expressed as the oxygen equivalent. For more information, see Standards Methods (method number 5220).

Section 1.2 - Benefits of Anaerobic Treatment

1.2.1 List the benefits associated with anaerobic treatment.

A. Economic method to treat waste versus aerobic treatment
B. Production of methane gas for energy recovery
C. Reduces waste biomass by destruction of volatile solids

D. Digested sludge has less odor
E. Reduces pathogens

Section 1.3 - Microbiological Principles

1.3.1 Describe how anaerobic reactors work.

Anaerobic reactors utilize microorganisms without oxygen to convert organic material to methane, carbon dioxide, a small amount of biomass, and some other products.

1.3.2 Describe the environmental factors that influence the health and growth of anaerobic microorganisms.

A. Food
The acid-forming microorganisms require organic compounds found in the influent as a food source to produce volatile acids, which the methane-forming microorganisms use as a food source. In a stable reactor, the volatile acids are used by the methane-forming microorganisms at the same rate they are produced by the acid-forming microorganisms.

B. Temperature
Methane-forming microorganisms are more sensitive to temperature changes than acid-forming microorganisms and do not generally do well with sudden significant temperature changes. Maintaining a mesophilic or thermophilic temperature without fluctuation is important to keep the methane formers stable, especially in colder temperatures.

C. pH
The pH of an anaerobic reactor will not fluctuate when running in good condition and will stay in the range of approximately 6.8 to 8.2.

D. Volatile Acid
The volatile acids in a well-operating reactor will remain steady and will not fluctuate as long as the methane-forming microorganisms are kept in a stable environment.

E. Alkalinity
The alkalinity is an indication of the reactor's buffering capacity and, in a well-operating reactor, will be steady.

F. Toxicity
Some toxic compounds of concern in an anaerobic reactor are heavy metals, chlorides, cleaning chemicals, sulfides, and quaternary amines. Although the microorganisms can handle small concentrations of these toxic substances, any substantial loading of such substances will require action. Keeping the reactor well mixed will eliminate small concentrated areas of toxins.

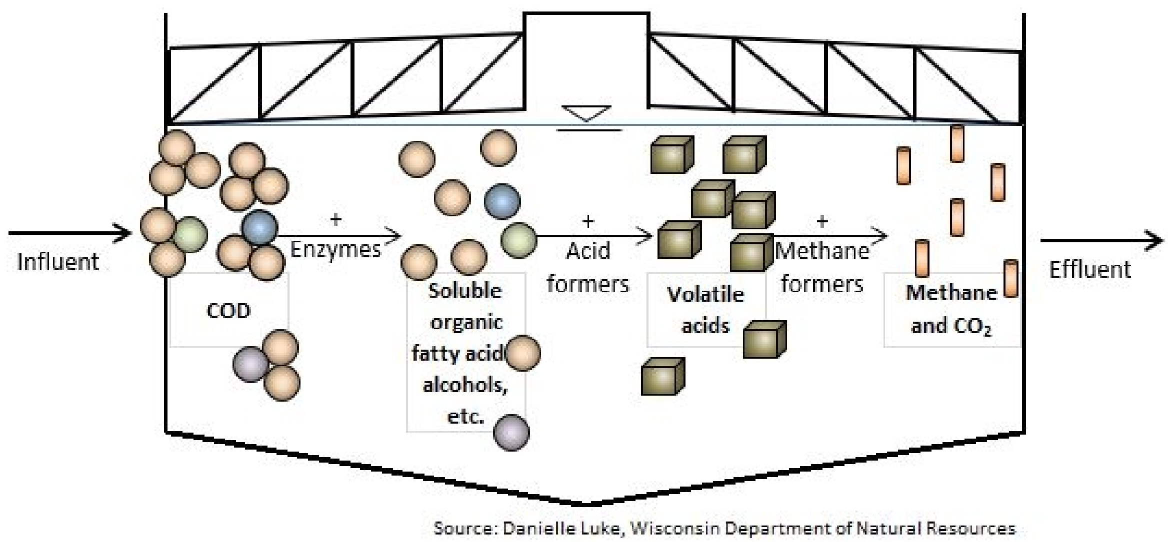
G. COD
COD is a measure of the food source to the reactor. COD is measured before and after treatment and can be used as a measure of efficiency of the reactor. It is desirable to feed a steady level of COD to a reactor. Overloading a reactor with COD can cause process upsets.

H. TSS
Total Suspended Solids (TSS) is used as a measure of the biomass concentration in the reactor. It is used to calculate the food to mass ratio. It is important to maintain the optimal level of TSS in the reactor.

1.3.3 Explain the process through which waste entering an anaerobic reactor is converted to methane, sludge, and water.

The organic matter commonly referred to as COD is used as food by the microorganisms in the reactor. Microorganisms release extracellular enzymes (enzymes located outside of the microorganism's cell) to break down solid complex compounds, carbohydrates, proteins, etc. into soluble organic fatty acids, alcohols, carbon dioxide, and ammonia.
Acid-forming microorganisms convert the products of the first stage into acetic acid, propionic acid, other volatile acids, hydrogen, carbon dioxide, and other compounds.
Methane-forming microorganisms convert the acetate and other volatile acids into methane and carbon dioxide.

Figure 1.2.3.1: Anaeorbic Reactor Biologic Process



Section 1.4 - Process Understanding

1.4.1 Describe other variations of the anaerobic digestion process.

A. Thermophilic digestion
In thermophilic digestion, the reactor is operated to promote the type of microorganisms that grow and thrive in the temperature range of 120°F to 135°F (49°C to 57°C). The primary goals of this process are pathogen destruction, increased volatile solids destruction, and reduced reactor detention time. Thermophilic systems may have problems with odor and dewaterability of the final sludge. The additional heating requirements typically rely on sludge heat exchangers to preheat the recycle stream of sludge. Thermophilic treatment is particularly beneficial when processing mixed or complex wastes. EPA class A biosolid requirements can be met at this temperature range.
B. Temperature-phased anaerobic digestion (TPAD)
TPAD is a treatment process that involves multiple stages of treatment including at least one thermophilic and one mesophilic stage. The thermophilic stage effectively reduces pathogens and volatile solids and is then followed by a mesophilic-polishing stage, which

helps eliminate the odor and dewatering issues associated with thermophilic digestion. The additional heating requirements typically rely on the return sludge to pass through sludge heat exchangers.

C. Separate acid-phased and gas-phased digestion

Separate acid-phased and gas-phased digestion is carried out in a two-reactor system to provide separate environments for the acid-forming and methane-forming microorganisms. In the first (acid) phase, the feed substrates are hydrolyzed to produce volatile fatty acids (VFA). In the second (gas) phase, the VFAs are converted to methane and carbon dioxide. This process has been used to process difficult to digest organic wastes, such as those with high concentrations of waste activated sludge (WAS), with less foaming.

1.4.2 Describe how buffering works in an anaerobic reactor.

In a reactor, optimum acid to alkalinity ratio is between 0.1 and 0.5; buffers work to keep the acid/alkalinity ratio in this range. This is done by adding various chemicals, like caustic or magnesium hydroxide, to keep the alkalinity high enough to offset the microbial community’s acid production. Alkalinity is related to pH such that if the pH is going down the alkalinity also drops. If buffering does not achieve the proper ratio, reduction of feed source temporarily should be considered to reduce acid production.

1.4.3 Discuss the three types of anaerobic reactor systems commonly found in Wisconsin.

A. Lagoon

Lagoon systems are the simplest type of anaerobic reactors to construct. They are designed for low rate operations with a high efficiency of COD removal. These are typically long basins that can be used to settle solids and remove COD. To recover the biogas produced, impermeable covers are installed over the lagoons. When process temperatures are high enough to support mesophilic microbial activity, volatile solids and COD can be broken down and biogas can be produced. When temperatures change too quickly the lagoon can become overloaded and can become a source of odors because the methane-forming microorganisms are more sensitive to temperature changes than the acid-forming microorganism and so the amount of volatile acids builds up.

B. Membrane

Anaerobic membrane bioreactors (AnMBRs)are designed for a medium rate operation and are very efficient at removing COD.They commonly use microfiltration or ultrafiltration. The filtered effluent is typically pulled through the membrane, which keeps the anaerobic microbes and other solids in the anaerobic reactor longer. Consequently, AnMBRs can maintain very high anaerobic microbial biomass levels, which can therefore treat higher loads of substrate COD. However, membrane fouling and buildup of other solids can lead to problems. The challenges with preventing fouling in anaerobic systems is greater than that of aerobic systems. Therefore, AnMBRs are best suited for systems with well-defined, low-solids, high-strength wastes.

C. UASB/ EGSB

Upflow anaerobic sludge blanket (UASB) reactors are designed for high rate operation. The anaerobic feed source is circulated upwards through a bed of anaerobic sludge, which contains the microbes responsible for COD breakdown and biogas production. Expanded granular sludge bed (EGSB) reactors are similar to UASB reactors, except that the upflow velocity is higher. The higher upflow velocities enable EGSB reactors to treat wastes with higher levels of nonvolatile solids. Both UASB and EGSB reactors can be operated at mesophilic or thermophilic temperatures, and biogas recovery is similar for both systems. The specific upflow velocity selected is designed to maintain a desired solids retention time in the sludge bed. Both UASB and EGSB reactors benefit from the use of anaerobic granular sludge, which can sustain active anaerobic microbes.

Figure 1.4.3.1: Lagoon

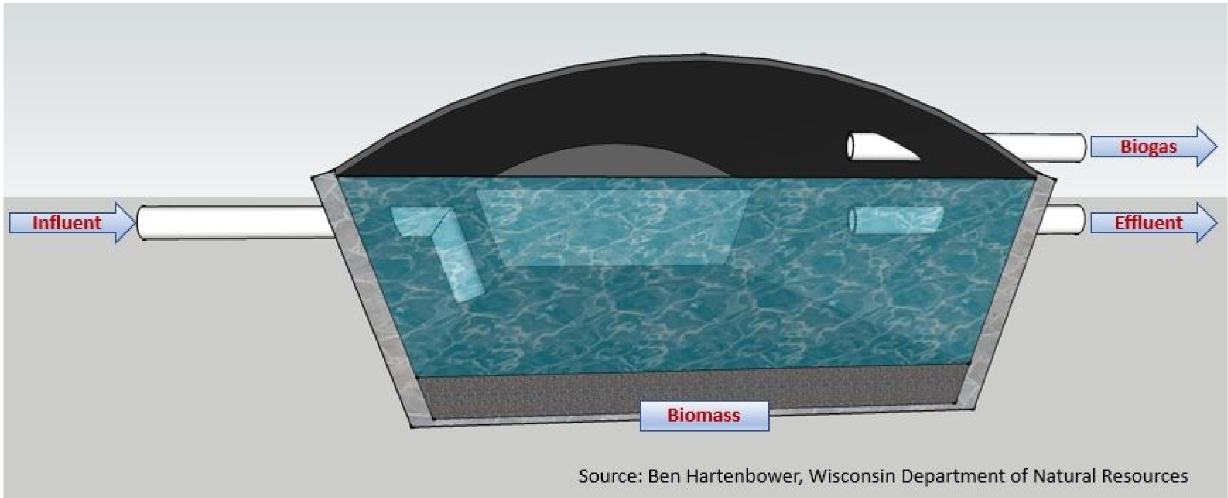
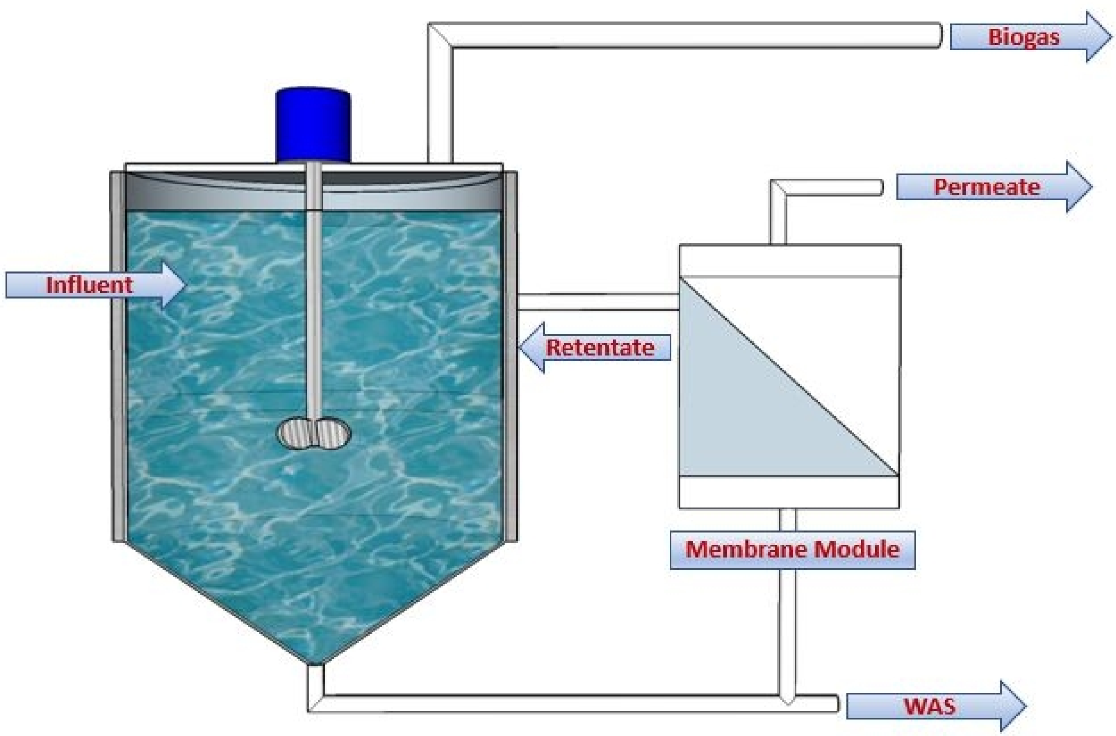


Figure 1.4.3.2: Anaerobic Membrane Bioreactor



Source: Ben Hartenbower, Wisconsin Department of Natural Resources

Figure 1.4.3.3: Upflow Anaerobic Sludge Blanket

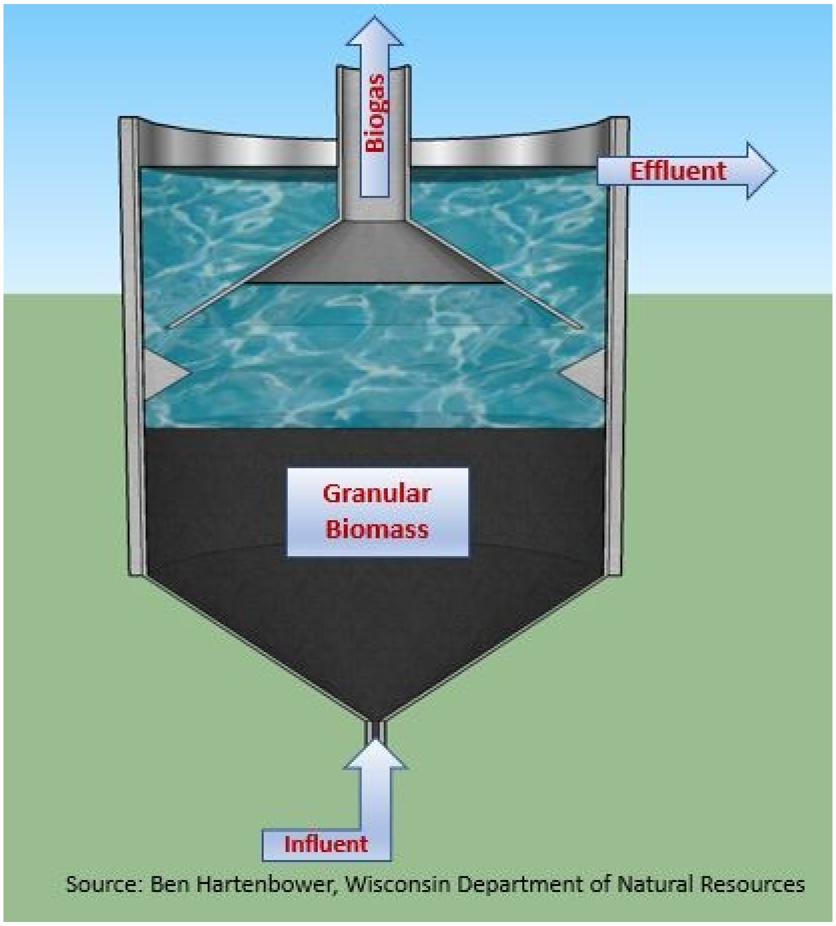


Figure 1.4.3.4: UASB Granular Sludge

Chapter 2 - Operation & Maintenance

Section 2.1 - Definitions

2.1.1 Define volatile acid/alkalinity ratio (VA/ALK).

VA/ALK is the ratio of volatile acid to alkalinity ([mg/L acid] / [mg/L alkalinity]). It is a good indicator of reactor health. A good range for VA/ALK is 0.1 to 0.5. The optimal ratio number is highly dependent on the waste stream and the treatment technology.

2.1.2 Define struvite.

Struvite is an ammonium magnesium phosphate salt. It can form deposits on the piping in treatment systems.

2.1.3 Define hydrogen sulfide.

Hydrogen sulfide (H2S) is a dangerous component of biogas formed under anaerobic conditions when sulfur containing compounds are in the influent. It can be harmful when inhaled and reacts with water to form a corrosive acid. It is characterized by a rotten egg smell.

Section 2.2 - Methods

2.2.1 List some of the key factors related to optimal operation of an anaerobic reactor.

A. Organic loading rate (OLR)
B. Volatile acid/alkalinity ratio (VA/ALK)
C. Temperature
D. Mixing or recirculation
E. Solids retention time (SRT)
F. Methane production
G. pH
H. Micro and macronutrients
I. Grit and scum blanket
J. Toxicity

2.2.2 List four reasons why anaerobic reactor mixing is important.

A. Optimizes contact between the COD and microorganisms
B. Maintains a constant temperature throughout the reactor
C. Reduces scum buildup on the water surface and settled solids on the reactor floor
D. Dilutes localized reactor toxins or inhibitory substances

2.2.3 Describe the temperature ranges commonly maintained in anaerobic reactors and the importance of maintaining stable temperatures.

Most conventional anaerobic reactors in Wisconsin operate at the mesophilic temperature range, normally operating between 90°F and 104°F (32°C and 39°C). The temperature should be changed slowly to allow the methane formers time to adjust. The temperature sensitivity of the reactor's microorganisms is the reason to consider daily temperature logs. Make sure the sludge-heating equipment is maintained to ensure reliable operations and temperature control.

2.2.4 Discuss anaerobic biogas composition and impurity control.

The anaerobic biogas production rate is an indicator of the overall condition of the reactor system. Biogas production rate is a function of the organic loading and the conditions in the reactor that can impact gas production such as temperature, mixing, nutrient/trace metal concentration and bioavailability, toxicity, etc. Methane and carbon dioxide are generally created in a 1:1 ratio and the solubility of carbon dioxide in water drives the difference in biogas ratios.

A. Methane
Methane is typically 60% to 64% of the biogas produced and is the component that impacts the fuel value of biogas. Biogas is combustible fuel at 50% methane. Explosive conditions are created when biogas is mixed with air and the methane concentration is in the 5% to 20% range.

B. Carbon dioxide
Carbon dioxide is typically 35% to 40% of the biogas produced and, when in biogas, dilutes the energy value (British thermal units or btu). This is why the fuel value of anaerobic biogas is approximately 600 btu/ft3 compared to natural gas, which is approximately 1,000 btu/ft3. The removal of carbon dioxide is typically not done, but can be achieved with membrane permeation, chemical scrubbing, or carbon sieves.

C. Water vapor
Water vapor in the biogas condenses, resulting in water accumulation in piping that must be removed. It will also react with hydrogen sulfide, creating a corrosive liquid that affects the equipment. The moisture condensed from cooling biogas can be removed through drip traps. The condensation process can be accelerated with a gas-drying (refrigeration) system.

D. Hydrogen sulfide
Hydrogen sulfide has a smell similar to rotten eggs and is the corrosive component of biogas which reacts with water to form acids and is lethal at concentrations above 700 parts per million (ppm). Removal is commonly necessary to comply with air emission regulations. Hydrogen sulfide removal systems include iron sponge, chemical complexing, and biological systems that produce elemental sulfur.

2.2.5 Explain how to use the quantity of gas produced as an indicator of reactor performance.

Gas production is a function of organic matter fed to the reactor and of the consumption of that material to produce methane. The common range of biogas production is between 7 to 12 ft^3/lb of COD destroyed.
Incremental increases in COD should increase gas production and decreasing COD should decrease gas production. Toxic chemicals, temperature changes, increases in the volatile acid to alkalinity ratio, or pH changes are likely to decrease gas production.

Section 2.3 - Equipment

2.3.1 List and describe the types of anaerobic reactor covers.

Anaerobic reactors are always covered. Four types of covers are used.

A. Fixed cover
In a fixed-cover anaerobic reactor, the cover remains in a fixed position, supported by framework connected to the top of the wall. Fixed-cover reactors require operator attention to liquid levels to maintain the gas seal or avoid overflowing the supernatant into the gas removal piping. It is important to monitor reactor gas pressure to identify a vacuum or over-pressurization condition. The gas is kept in a limited space above the liquid surface and held by the cover. The excess gas not kept under the cover is typically kept in a separate gas storage.

B. Floating covers
A floating cover floats directly on the liquid surface and is supported by a system of roller bearings and guide rails that help prevent the cover from tipping. Like the fixed cover, there is limited space for gas under the cover and the excess gas is kept in separate gas storage.

C. Gas-holder covers
The gas-holder covers are similar to floating covers, but they are designed to accommodate gas storage. As gas pressure in the system rises, the cover will rise to provide additional storage capacity.

D. Membrane covers
Membrane covers vary depending on the technology used. On lagoons, membrane covers usually consist of a single membrane. There is more variation on tanks where either single membrane or dual membranes can be used. Biogas is collected using a slight vacuum assist. It may be insulated for temperature control and there is usually a water collection system on it.
Fixed, floating, and gas-holder covers all contain a skirt for maintaining a water seal.

2.3.2 Describe a floating cover, gas-holder cover, corbel, and the importance of the position indicator.

A free-floating reactor cover provides proper gas pressure. A cover position indicator is a dial, staff gauge, or other device that lets the operator know whether the cover is within its limits of travel. Corbels keep the reactor cover from dropping beyond a certain point, protecting the internal equipment from damage if the effluent is withdrawn below the designed operating range. If the cover position is too low, the cover will be resting on the corbels and gas pressure will be reduced. If the cover position exceeds the upper range of travel, over-pressurization can occur. An alarm system is normally provided to prevent problems with either a high- or low-level cover positions.

2.3.3 Show and explain the parts of an anaerobic reactor gas handling equipment (actual parts and configuration at each treatment plant may vary).

All gas equipment should be maintained per operation and maintenance (O&M) specifications to minimize risk of safety issues.

A. Foam separator
A foam separator immediately downstream of the reactor will prevent foam from entering the biogas stream, where it can clog gas-handling equipment. When foam clogs the flame arresters, it may prevent the pressure and vacuum relief valves from properly

working, causing damage to reactors and the reactor roof. Alternative piping can be used to prevent foam from reaching the gas processing equipment. Internal continuous foam control can be integrated into mixing systems to eliminate the need for foam separators.

B. Sediment and drip trap assembly
Biogas is saturated when it leaves the reactor. To protect downstream equipment and to not impede gas flow, moisture and sediment should be removed. A sediment trap with a drip trap should be located downstream of the reactor. Most systems have a number of traps throughout the system.

C. Pressure vacuum relief valves
These devices relieve excess pressure or vacuum to prevent structural damage to the reactor. Operation of these valves is not desirable because if the pressure relief valve opens, air and gas can mix, creating explosive conditions outside the tank and if the vacuum relief valve opens, it may create an explosive condition inside the tank.

D. Gas pressure regulators
Pressure regulators are installed next to the waste gas burner or at various points in the system to regulate the gas pressure to boilers, heaters, and engines. They maintain a constant pressure at the point of use.

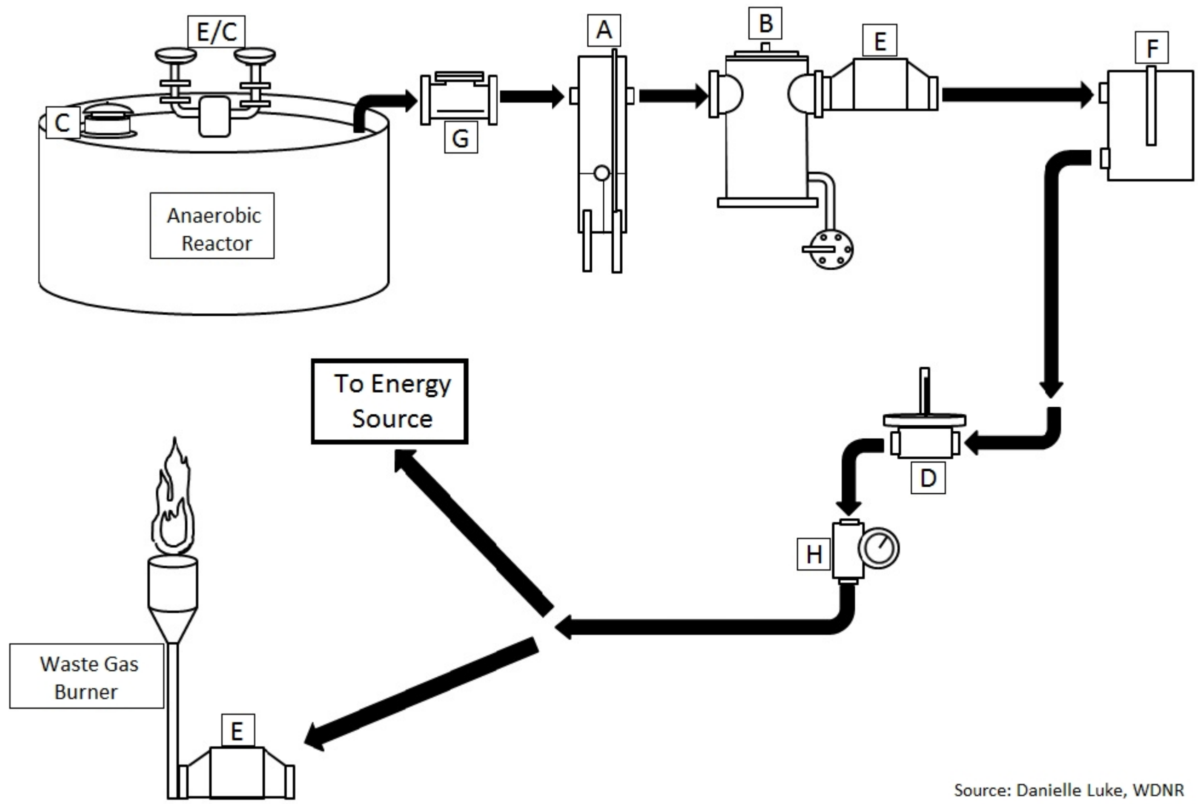
E. Flame trap or arrestor
Flame arrestors prevent a fire from moving backwards through the piping and reaching biogas. Flame arrestors are installed in a line to gas utilization equipment as close as possible to the source of combustion. They typically are a box shape holding a fusible element that would melt if a flame would develop, shutting down the flow.

F. Gas purifier
A gas purifier typically is not necessary if the gas is to be burned in a boiler or high-temperature internal combustion engine. However, if the gas is used as a natural gas substitute, fuel to run electrical turbines, or sell for other uses, then a gas purifier may be necessary beyond sedimentation and condensate drip traps. Gas purifiers are normally installed upstream of the boilers, compressors, or engine generators and often designed to remove highly corrosive hydrogen sulfide. The purifiers are also used to control sulfur emissions and odors.

G. Check valves
Check valves allow flow in one direction only. In anaerobic reactors, these valves are installed to prevent flow of higher pressure gas back to the reactor.

H. Gas meters
Gas meters are used to measure the output of biogas production, which is often an indicator of reactor performance and may alert plant operators to process malfunctions and gas leaks. Types of meters may be positive displacement, thermal-dispersion inserts, pressure-differential orifices, and/or venturis. Some gas meters measure both flow and concentration of gases present.

Figure 2.3.3.1: Anaerobic Gas Handling Equipment



2.3.4 Describe the two methods of storing reactor gas.

A. Gas-holder cover
A gas-holder cover is a reactor cover very similar to a floating cover except with a much longer skirt. The gas-holder cover may be able to rise more than 6 ft above the minimum cover height. This type of cover provides much more volume for biogas storage but has similar operating problems to a normal floating cover such as free movement up and down without binding and pressure or vacuum relief valves.

B. Separate gas storage tank
Reactor gas can be stored in a separate tank separate from the reactor. Normally, biogas is cleaned and compressed to increase pressure and reduce the volume of storage required. Gas storage tanks are often built as spheres, but other tankage configurations can be used.

2.3.5 List three types of reactor mixing systems.

A. Mechanical impellers or mixers
B. Compressed reactor gas mixing
C. Pumped mixing

2.3.6 List the normal types of pumps used in an anaerobic reactor system.

A. Centrifugal
B. Progressive cavity
C. Diaphragm

D. Rotary lobe

For further information about these types of pumps, refer to the Wisconsin Department of Natural Resources (DNR) General Wastewater Study Guide.

2.3.7 Describe how a heat exchanger works.

A heat exchanger works based on a temperature differential between two fluids that are close in proximity to each other. Without mixing the fluids, a warmer fluid can transfer heat through a heat exchanger material to a fluid at a lower temperature. To increase heat transfer rates, one could:

A. Increase the temperature differential between the fluids
B. Increase the surface area of the exchanger material
C. Increase the effective thermal conductivity of the exchanger material

Flow rate is key to optimal performance: too fast and not enough heat is exchanged, too slow and too much heat is exchanged.

2.3.8 List common inline sensors.

A. pH
B. Temperature
C. Liquid flow
D. Gas flow
E. Methane concentration
F. Pressure gauges
G. Hydrogen sulfide concentration
H. Carbon dioxide concentration
I. Oxygen Concentration

Section 2.4 - Preventative Maintenance

2.4.1 Discuss the basic maintenance for equipment used in anaerobic reactors.

Consult the O&M manual for the preventative maintenance tasks and scheduling of all equipment used in anaerobic reactors. Improper maintenance can create more damage than no maintenance.

2.4.2 State the approximate time intervals that reactors should be drained, cleaned, inspected, and repaired.

Reactor cleaning schedule is dependent on the type of waste treated, system loading patterns, design, efficiency of grit removal, efficiency of mixing, tank structure and age, and condition of internal equipment and redundancy. Cleaning and structural inspections should be performed on about a 5 to 10 year interval or as needed.

2.4.3 Discuss procedures for complete anaerobic reactor cleaning.

Before beginning, the local DNR representative needs to be notified. The first consideration for complete reactor cleaning is whether the work is to be done with plant personnel, to use an outside contractor specializing in this service, or a combination of

both.
Depending on the type of system, it is necessary to determine how to handle the influent while the unit is down, the equipment necessary to accomplish the job, and how and where to dispose of digested sludge. Other advanced planning would include accurate information and a supplier for all internal parts that may have to be replaced during the cleaning process.
The actual sequence of emptying and washing down the inside of the reactor is dependent upon the type of reactor system and the types of mixing, recirculation, and heating the unit has. Safety is the key; follow all proper safety procedures.

2.4.4 Discuss struvite clogging and how to prevent it.

Struvite is common in the effluent of a reactor. The formation of struvite depends on levels of calcium, magnesium, phosphate, ammonia, pH and temperature. Ideally formation of struvite in the pipes should be prevented. This can be done either by encouraging the formation in a better location when it can be harvested or by preventing the struvite from forming at all. The prevention can be done by eliminating the source of one of the components or by introducing additives that keep one or more key components in solution.

2.4.5 Discuss the importance of changing scrubber material.

Scrubbers remove hydrogen sulfide, which can be corrosive to downstream gas equipment. A sign of scrubber media being “spent” is difficulty drawing gas through the scrubber units. Typically, it is changed at least twice a year but consult the O&M manual as to the proper schedule for a given system. When changing the media, the color will change from brown when new to black/grey when used or spent. Make sure to follow safety procedures when changing scrubbing media.

2.4.6 Discuss the importance of gas system maintenance.

Water traps should be serviced twice a year, this includes checking the o rings, checking for struvite build up, and greasing the handle. Water traps that are not working properly can affect other parts of the gas system by allowing moisture into the gas lines.
Flame arrestors have a filter bank that should be cleaned and serviced at least once a year. If a flame arrestor fails, there can be a flare back flash into the gas line potentially causing a catastrophic explosion. The filter banks should be checked annually or as described in the O&M manual.
Vacuum and pressure relief valves are important to prevent air from getting into the line. If air gets into the line explosive conditions can occur. Determine the functionality and condition of the valves. If the valves fail the pressure inside the reactor can get too high or too low and cause structural damage.
For all parts of the gas system be sure to check the O&M manual for the proper maintenance schedule.

2.4.7 Discuss the importance of calibration for instrumentation.

Calibration is required to make sure that the value the instrument reads is accurate. For example, anaerobic reactors are very pH sensitive, it is important to calibrate pH meters quite often. Follow the O&M manual for each instrument to maintain accuracy of readings.

2.4.8 Discuss the importance of maintaining the methane and gas flow meters.

Methane meters and flow meters are used for monitoring greenhouse gas emissions and also can be used to monitor the health of the reactor system. Maintaining the meters ensures that the instrument reading is accurate. Methane meters measure percent methane and if the measure goes below 50%, there likely is a problem with the reactor. Follow the O&M manual for each instrument to maintain accuracy of readings.

Chapter 3 - Monitoring, Process Control, & Troubleshooting

Section 3.1 - Definitions

3.1.1 Define supernatant.

Supernatant is the liquid part of the reactor mixture after solids have been removed.

Section 3.2 - Sampling & Testing

3.2.1 Describe tests used to monitor anaerobic reactor performance.

Collect representative samples in clean containers.

Figure 3.2.1.1

Parameter:	Sample location:	Why tested:	How often:
Volatile acids/ alkalinity ratio (VA/ALK)	Sampling pipe from the reactor, recirculating sludge line, or thief holes	Increased volatile acids concentrations and decreased alkalinity are the first measurable changes to take place when a reactor begins to sour	3 times per week; daily if a result is abnormal until result is back in normal range.
pH	Sampling pipe from the reactor, recirculating sludge line, or thief holes	pH is strictly measured for record and is not used for plant control; pH changes are an indicator of troubles with reaction processes	Daily
Temperature	Thermometer is usually installed in the recirculated sludge line from the reactor to the heat exchanger	Measured to ensure the proper temperature is maintained for the microorganisms	Daily, Continuous
Total solids and volatile solids	Sampling pipe from the reactor, recirculating sludge line, or thief holes	TSS for maintaining mass levels for treatment, VS as an additional aid in troubleshooting.	Daily for TSS on reactor MLSS, as needed for VS
Ammonia	Reactor supernatant	Can relate to health of reactor, also for ammonia load to aerobic side of plants	3X/week
COD	Influent load to reactor, reactor supernatant out	Determine efficiency of COD removal in reactor, good is 80% or more removal	3X/week Rolling average can be used to determine efficiency
Chlorides	Influent load to reactor, reactor supernatant out	Chlorides may be toxic to reactors at certain levels, 600-800 mg/L or higher may affect reactor or aerobic plant performance	Daily
Micronutrients	Reactor MLSS	To determine health of reactor, troubleshooting unknown issues	As needed
Ortho-Phosphorus	Reactor supernatant	To determine phosphorus speciation and phosphorus balance in the system	As needed
Total Phosphorus	Reactor supernatant	To determine phosphorus load to aerobic plant	3X/week

Section 3.3 - Data Understanding & Interpretation

3.3.1 Describe gas flame color when a reactor is working well and when it is starting to go sour.

The gas flame color of a well-working reactor is blue at the base with a yellow tip. The gas flame color of a sour reactor is mostly yellow. A high BTU value biogas creates a blue flame. A yellow flame indicates a lower methane concentration. Color changes relative to individual reactor performance in the direction of lower methane content could be caused by a sour reactor or a leak (air ingress) diluting the methane content.

Figure 3.3.1.1: Blue Flame at Night

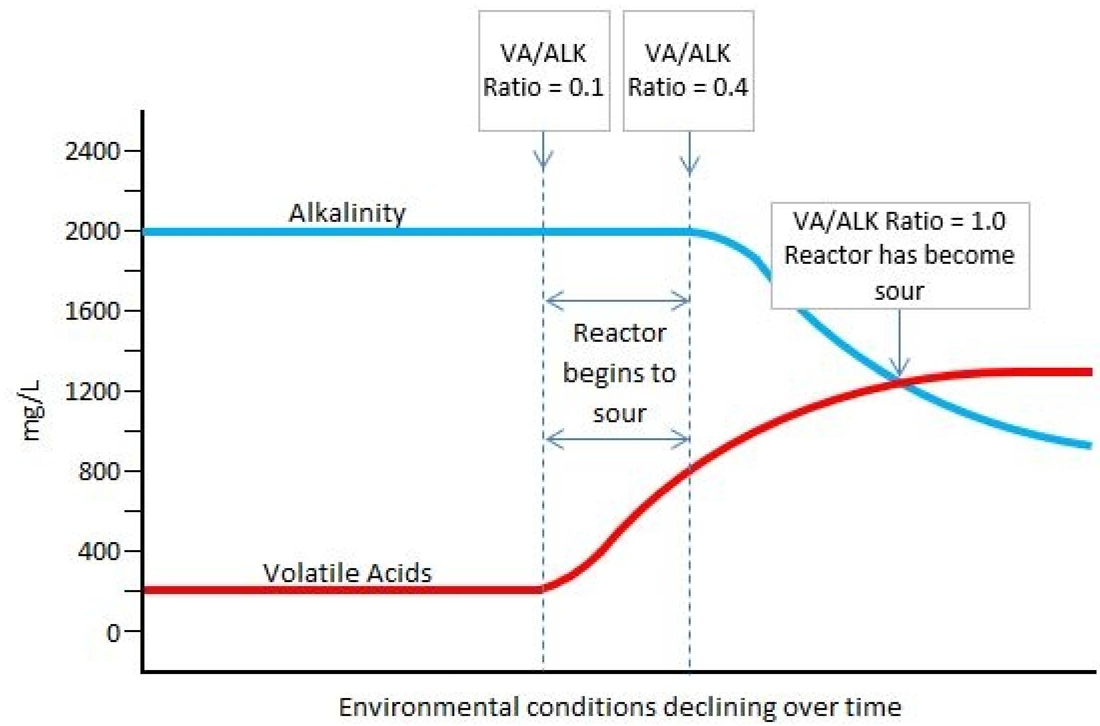
3.3.2 Explain the effect on gas production, volatile acid production, and alkalinity if the feed rate to a reactor is suddenly reduced.

The gas and volatile acid production would decrease. The alkalinity would stay the same or slightly increase.

3.3.3 Discuss the volatile acid/alkalinity (VA/ALK) ratio.

In a stable reactor, the volatile acids are used at about the same rate they are produced. If excess organic loading is fed into a reactor, the acid-forming microorganisms population will grow creating an overabundance of acids. The methane-forming microorganisms reproduce much slower than the acid-forming microorganisms and cannot handle the increase in acids, ultimately causing a reactor upset.
A good VA/ALK target ratio for most reactors is generally between 0.1 to 0.5, but this varies widely depending on feedstock. Maintaining the appropriate VA/ALK ratio is the key to proficient operations. VA/ALK should be monitored consistently because it will be the first warning of problems occurring and action should be taken immediately once it begins to rise.

Figure 3.3.3.1: Graph of VA/ALK Ratio



3.3.4 Discuss the importance of pH and when pH adjustments need to be made.

Methanogenic organisms are sensitive to pH. If pH decreases too much, then gas production will decrease. In general, the pH range should be approximately 6.8-8.2. If pH is outside of this range, then adjustments should be made. The exact pH range will be reactor specific so get to know your own reactor. pH change is a possible indicator of a VA/ALK change.

Section 3.4 - Performance Limiting Factors

3.4.1 Discuss common toxicity issues.

A. Chloride: If a high enough level is reached, it can become toxic to the microbiology, generally it should not go above 600-800 mg/L.

B. Quaternary ammonia: try not to allow any quaternary ammonia into the reactor. It can accumulate in the biomass and is highly toxic to the microbiology and can result in system failure.

C. Peracetic acid: over 5 mg/L can be toxic or affect the health of the system. Aerobic systems are more sensitive than anaerobic systems to peracetic acid.

D. Cleaners: Cleaners are designed to kill microbes and are made of many chemicals that can harm the system. Thus, the amount of cleaners going into the system should be minimized.

3.4.2 Discuss the toxicity concerns of heavy metals and sulfides.

A. Heavy metals
Heavy metals in solution can act as biocides, killing the microorganisms in the reactor. Common toxic heavy metals include copper, chromium, mercury, arsenic, nickel, zinc, cadmium, selenium, molybdenum, and lead. The sources of this waste stream should be reduced or eliminated.

B. Sulfides
Microorganisms can tolerate between 50 and 100 mg/L of soluble sulfide. Concentrations above 200 mg/L are toxic and would require treatment with iron salts to precipitate the sulfides. The sources of this waste stream should be reduced or eliminated.

3.4.3 Discuss how size of the reactor changes the reactor performance.

The size of the reactor can affect the amount of microbial mass in the reactor as well as the hydraulic and solids retention times.

3.4.4 Describe how retention time influences reactor performance.

The retention time describes the average duration of a substance (for example liquids or solids in the reactor). Longer retention times provide the reactor more time to react. This can promote the growth of slower growing microbes, including methane formers instead of just the faster growing acid formers. In effect this can change the final product of the reactor.

3.4.5 Describe the effect of the food to mass (F/M) ratio on reactor performance.

The food to mass ratio can affect the biogas production rate. It is critical that F/M be managed according to the system limits and to maintain system balance. When organic conditions are overloaded, excess food is provided beyond what the biomass can process. This can result in process upsets.

3.4.6 Describe how feed rate influences reactor performance.

If the feed rate is too high, the acid formers can be more productive and the VA/ALK can become too high. This could result in low methane content in the biogas and higher COD coming out in the effluent.
If the feed rate is too low for too long, the rate of decay would overtake the growth rate and the biomass would decrease.

Section 3.5 - Corrective Actions

3.5.1 Identify the causes and corrective actions for anaerobic reactor problems.

Figure 3.5.1.1

Problem	Cause	Corrective Action
Supernatant is dark grey, brown, or murky	Pockets of raw influent in the tank	Check and repair or replace mixing system
	Short retention time from grit or scum buildup	Clean out the grit or scum from the reactor
	System could be upset	System needs to be buffered or feed rate decreased.
Supernatant solids are too high	Decanting point is too low	Adjust tank operating level or decanting point
Scum blanket is too thick	Inadequate mixing or the mixing system is off	Adjust mixing or repair/replace system; restart mixing system
Temperature drop inside tank	Heat exchanger is not working properly	Check heat exchanger for fouling, flow, and design capacity
Light grey or brown anaerobic sludge	Short-circuiting or insufficient mixing	Adjust mixing or repair/replace system
Anaerobic sludge or supernatant has a sour odor	Reactor has gone sour or toxic load	Reduce organic loading; find and address source of the toxic loading

3.5.2 Identify the causes and corrective actions for mechanical mixing equipment problems in a reactor.

Figure 3.5.2.1

Problem	Cause	Corrective Action
Shaft seal leaks	Packing old and worn causing gas leakage (confirmed by gas odor or bubbles with a soap solution)	Repack shaft seal as needed or anytime the tank is down for cleaning
Gear reducer wear	Lack of proper lubrication causing noise, vibration and shaft wear	Use correct type and amount of lubrication as recommended by the manufacturer
	Poor equipment alignment	Properly align equipment and correct for any imbalance of internal parts which cause alignment problems
Internal mixing parts	Imbalance from debris on moving parts causing vibration, motor overheating, and noisy operations	Make sure preliminary treatment (comminution and screening) is operating properly to prevent debris from getting to the reactor; if possible reverse direction of the mixer or alternately start and stop the mixer to dislodge the debris; if this does not correct the problem the reactor will need to be totally drawn-down and cleaned to remove accumulation of debris
	Wear on internal parts from grit or misalignment	Check the alignment and replace worn parts

3.5.3 Identify the causes and corrective actions for gas system problems in an anaerobic reactor.

Figure 3.5.3.1

Problem	Cause	Corrective Action
Gas pressure lower than normal	Gas leaking out through pressure/vacuum relief valve	Service valve to ensure proper sealing adding more weights if necessary; install new parts if worn
	High gas usage in the plant	Check gas usage in the plant against gas production and adjust usage
	Gas leaking out of the cover or gas piping	Check for leaks around the cover and repair; check all piping for leaks and repair
	Poor reactor operations	Monitor alkalinity, volatile acids, pH, and gas quality (carbon dioxide concentration); adjust influent feed rate (to prevent organic or hydraulic overloading) and add necessary chemicals to restore good reactor operations
	Excessive sludge or supernatant removal	Stop sludge or supernatant removal until the reactor gas pressure returns to normal
	Excessive use of lime	Stop addition of lime and increase mixing to restore normal gas pressure

Figure 3.5.3.2

Problem	Cause	Corrective Action
Gas pressure higher than normal	Stuck pressure/vacuum relief valve	Service the valve to ensure proper operations and install new parts as necessary; in winter condensation and freezing conditions can cause the valve to freeze; the valve should be inspected regularly in very cold weather and vented barrel could be placed over the valve with an explosion proof light bulb inside to reduce freezing temperatures
	Low gas usage in the plant	Check the waste gas burner and all piping for proper operation so excessive gas will be burned
	Gas piping blocked or pressure regulating valve not functioning	Check all drip (condensate) traps, check all low spots in the piping for water or other blockage, and clean/repair as necessary; isolate pressure regulating valve and service/repair as necessary
	Supernatant lines are frozen or blocked	Check lines frequently in very cold weather and protect with insulation to reduce freezing problems

Figure 3.5.3.3

Problem	Cause	Corrective Action
Yellow gas flame at the waste gas burner	Poor quality reactor gas with high carbon dioxide content from poor reactor operations	Correct reactor operations; check influent feed rate to prevent hydraulic or organic overloading; check volatile acids, alkalinity, and pH; adjust with necessary chemicals to improve gas composition
Gas flame lower than usual	High gas usage in the plant	Check gas production against usage
	Gas leakage in the collection and distribution system	Check for gas leaks, repair piping, and other appurtenances as needed
	Low gas production due to process problems	Correct reactor operations; check influent feed rate to prevent hydraulic or organic overloading; check volatile acids, alkalinity, and pH; adjust with necessary chemicals to improve gas composition
Waste gas burner not lit	Pilot flame not burning	Check for adequate pressure, service and relight
	Obstruction or water in the pilot gas line	Clean with air and check low spots for in-line water
	Obstruction or water in the main gas line	Drain all drip (condensate traps); check for low spots in piping for water or other blockages; clean and repair as necessary
Pressure control valve failure	Malfunction of the valve	Clean, service and repair valve as necessary
Gas meter failure	Debris in gas line	Clean by flushing with water
	Mechanical failure or diaphragm problems	Isolate the meter, disassemble, service, and replace worn or damaged parts

3.5.4 Explain the possible causes and corrective actions for a sudden loss of gas production combined with a low volatile acid concentration in an anaerobic reactor.

The cause is a toxic material is being introduced into the reactor which is causing the microorganisms to be inhibited or killed. The corrective actions would be to dilute and recycle from the secondary reactor or to attempt to identify the toxicity, its source, and eliminate it from the wastewater flow.

3.5.5 Explain the possible causes and corrective actions for a gradual loss of gas production combined with a high volatile acid concentration in an anaerobic reactor.

The cause is the reactor is imbalanced and is tending towards going sour. Assuming that temperature is not a problem, the obvious problem is excessive loading of organics in too short of a time to the reactor. Reduce the loading if possible and/or pump sludge more frequently for shorter durations

3.5.6 Explain the possible causes and corrective actions for intense anaerobic reactor foaming.

Figure 3.5.6.1

Problem	Cause	Corrective Action
Intense anaerobic reactor foaming	Intermittent reactor feeding	Feed reactors continuously
	Separate feeding or inadequate blending of influent and WAS	Blend influent and WAS before feeding
	Insufficient or intermittent gas mixing	Confirm that reactor mixing system is operating well; repair or replace
	Excessive amounts of grease or scum in reactor feed	Limit quantities of grease or scum in the reactor feed

3.5.7 Outline an action plan to use if an anaerobic reactor is starting to become upset or go sour.

A. Monitor volatile acid/alkalinity (VA/ALK) ratio and pH
B. Reduce loading to the reactor by reducing COD loading
C. If needed, increase alkalinity through the addition of lime, sodium bicarbonate, magnesium hydroxide, or sodium hydroxide
D. If upset or sour conditions continues, this would be the occasion to check micronutrient levels, look for toxicity issues, and check volatile solid levels
E. Once the VA/ALK ratio has decreased and pH returns to normal, begin to gradually increase the COD loading rate to normal.
F. Continue monitoring VA/ALK ratio and pH

3.5.8 List the methods for testing for biogas leaks.

A. Online
1. Gas detector
2. Soapy water
B. Offline
1. Pressure test with water or inert gas

2. Vacuum test
NOTE: Always use spark-proof tools and keep any open flames away from all reactor equipment and structures to prevent fire or explosion.

3.5.9 Describe what should be done to a gas handling system after a foaming incident.

After a foaming incident, it will be necessary to clean all gas handling equipment that was affected by the foaming event. This would include the use of water, solvents, and air as specified in the O&M manual or as recommended by the manufacturer.

3.5.10 Describe how odor problems can generally be managed.

Many odors cannot be eliminated, only controlled to an acceptable level. Control measures can include source reduction, good housekeeping, ventilation, air scrubbing, and/or chemical treatment (oxidizing agents).

3.5.11 Discuss the problems associated with hydrogen sulfide gas.

Hydrogen sulfide in the presence of moisture forms weak sulfuric acid which is highly corrosive to a wide variety of materials (most metals, electrical equipment, and concrete). The gas in low concentrations produces a very noticeable odor. The characteristic odor is often described as smelling similar to rotten eggs. At relatively low concentrations, the gas is very toxic and causes a serious problem in confined spaces. Prolonged exposure to hydrogen sulfide desensitizes the sense of smell. If you smell it you need to yell, if you stop smelling it you need to run!

3.5.12 Explain how the generation of hydrogen sulfide gas can be controlled.

Hydrogen sulfide gas is typically associated with low-oxygen conditions. Hydrogen sulfide can be removed from reactor gas with an absorbing agent such as an iron sponge. Decreasing the source of sulfur going into the reactor could also reduce its production. Iron salts can also be used to tie up the sulfur going into the reactor.

Chapter 4 - Safety & Regulation

Section 4.1 - Personal

4.1.1 Describe the applicable safety program and requirements that industrial wastewater treatment plants must follow.

Industrial wastewater treatment plants must follow the Occupational Safety and Health Administration (OSHA) Code CFR 29 part 1910. Also, be sure to follow your plant's safety plan!

4.1.2 Discuss the importance of flotation devices at a wastewater treatment plant.

Sampling from basins, channels, and other treatment processes puts an operator at risk of falling into the wastewater. For this reason, an operator should never extend beyond the protection of the guardrails. The Occupational Safety and Health Administration (OSHA) highly recommends ring buoys with at least 90 ft of line be provided and readily available for emergencies, strategically placed around all process basins. OSHA also recommends any operator working over or near water that presents a risk of drowning be provided with a life jacket or buoyant work vest.

4.1.3 Discuss the safety cautions to be taken before entering an anaerobic reactor.

All confined space procedures should be followed. Personal protective equipment (PPE) should be used. All tools and equipment used should be non-sparking and explosion proof. This type of work is often contracted to a specialty company.
Follow the plant's Safety Management Plan!

Section 4.2 - Chemicals & Gases

4.2.1 List three purposes for ventilation.

A. Safety
Ventilation removes toxic gases and particulates from work areas. Gas detectors should be in place too if this is a concern.
B. Odor control
Ventilation pulls outside air into work areas and reduces odor.
C. Corrosion prevention
Ventilation keeps the humidity and hydrogen sulfide levels down reducing corrosion.

4.2.2 Describe the potential safety hazards of anaerobic reactors and methane gas.

Two reactor gases, methane and hydrogen sulfide, can be explosive if the concentration (percentage) is above the lower explosive limit (LEL) and below the upper explosive limit (UEL). LEL is the lowest concentration of a gas or vapor in air capable of producing a flash of fire in the presence of an ignition source. UEL is highest concentration of a gas or vapor in air capable of producing a flash of fire in the presence of an ignition source. The LEL and UEL for methane gas is 5% and 20%, respectively. For hydrogen sulfide, the LEL is 4% and the UEL is 44%.
Fixed-cover reactors require diligent operator attention during influent addition and effluent withdrawal, because the additional flow must be equal to the withdrawal flow. Influent addition without an accompanying effluent withdrawal over-pressurizes the reactor cover and will cause gas to vent from the reactor to the atmosphere. Air can enter a reactor through the vacuum/pressure relief valve forming a potentially explosive atmosphere in the reactor when a effluent withdrawal occurs without a corresponding influent addition.
A floating cover used in anaerobic reactors eliminates many of the influent addition and effluent withdrawal issues associated with fixed covers. The potential for air entering a floating-cover reactor and forming an explosive mixture exists when the cover is resting on the corbels and the water seal is lost or if the floating cover becomes tilted.
Reactor gas consists of methane, carbon dioxide, and hydrogen sulfide. All of these gases are asphyxiants as they replace oxygen for breathing. Methane and hydrogen sulfide can also form an explosive mixture.

4.2.3 Describe the safety monitoring equipment used to identify hazardous conditions created by biogas.
A quad-gas or tri-gas meter, stationary or portable, can be used to measure the following gases:

A quad-gas or tri-gas meter, stationary or portable, can be used to measure the following gases:
A. Hydrogen sulfide

B. Combustible/LEL
C. Carbon monoxide
D. Oxygen

4.2.4 Discuss the chemicals used to adjust anaerobic reactor pH/alkalinity and safety considerations.

Chemicals may be used to raise the pH of a reactor. Two common chemicals used are lime and sodium bicarbonate. The total amount of chemical needed is calculated and then added in small increments, checking pH after each addition. Specific procedures for addition should be checked in the O&M manual or with a consultant.
The use of calcium oxide (quicklime) or calcium hydroxide (slaked or hydrated lime) can be dangerous when these chemicals are mixed with water. Lime must always be added to water and not water added to lime. When water is added to lime, a violent reaction and splashing can occur, splattering this strong caustic. Strong caustic chemicals can burn the skin or eyes (similar to an acid burn).

4.2.5 Discuss the allowed concentration of hydrogen sulfide.

According to 29 CFR 1910.1000 TABLE Z-2, hydrogen sulfide exposure must not exceed 20 parts per million (ppm) as a ceiling concentration with the following exception; if no other measurable exposure occurs during the 8-hour work shift, exposures may exceed 20 ppm, but not more than 50 ppm as a peak for a single time period of up to 10 minutes.

Section 4.3 - Regulations & Procedures

4.3.1 Discuss air permits in regards to anaerobic reactor emissions.:

Governmental air quality requirements may affect wastewater treatment facilities and, in some cases, require the facility to apply and obtain an air permit. Facilities should inventory their respective air emission sources to determine whether they may need an air permit or determine whether the facility is eligible for a permit exemption. Air emission sources at a wastewater facility may include boilers which burn biogas, engines, turbines, flares, or any other combustion unit. Once air emission sources are inventoried, an operator may want to contact their environmental consultant, use online resources, and/or contact DNR staff to determine what requirements may apply to the facility. While specific air regulations and requirements are beyond the scope of this study guide, it is a key role of the facility owner to evaluate, obtain, and comply with all appropriate permit requirements.

4.3.2 Discuss the importance of having explosion proof equipment in and around an anaerobic reactor.

Anaerobic reactors produce methane which in the right concentrations can be explosive. Thus, it is important to ensure that the equipment in and around the reactor is explosion proof.

4.3.3 Discuss which anaerobic reactors require subclass A5 operator certification.

Facilities with anaerobic reactors that treat industrial liquid waste must have operators with subclass A5 operator certification. This does not include facilities that digest sludge from municipal waste.

Chapter 5 - Calculations

Section 5.1 - Treatment

5.1.1 Given data, calculate the amount of influent (gals) that had been pumped into an anaerobic reactor based on the change in height (ft) of the floating cover.

GIVEN:
Diameter = 30 ft
Initial cover height = 18.7 ft
After pumping height = 20.7 ft
1 ft^3 = 7.5 gals-
FORMULAS AND SOLUTION:
Volume (ft^3) = area (ft^2) × height (ft)
Change in height (ft) = height at pump stop (ft) - height at pump start (ft)
= 20.7 ft – 18.7 ft
= 2.0 ft
Volume of influent pumped (ft^3) = 3.14 × (radius (ft))^2 × change in height (ft)
= 3.14 × (15 ft)^2 × 2.0 ft
= 3.14 × 225 ft^2 × 2.0 ft
= 1413 ft^3
Volume of influent pumped (gals) = volume of influent (ft^3) × 7.48 gals/ ft^3
= 1413 ft^3 × 7.48 gals/ ft^3
= 10,569 gals

5.1.2 Given data, calculate the hydraulic retention time (HRT) (days) in an anaerobic reactor.

GIVEN:
[gpd = gallons per day]
Anaerobic reactor diameter = 50 ft
Anaerobic reactor height = 24 ft
Influent pumped to anaerobic reactor = 14,092 gpd
1 ft^3 = 7.48 gals/ft^3
FORMULAS AND SOLUTION:
Reactor volume (ft^3) = 3.14 × [radius (ft)]^2 × height (ft)
= 3.14 × (25 ft)^2 × 24 ft
= 47,100 ft^3
Reactor volume (gals) = volume (ft^3) × 7.48 gals/ft^3
= 47,100 ft^3 × 7.48 gals/ft^3
= 352,300 gals
HRT (days) = reactor volume (gals) ÷ influent pumped (gpd)
= 352,300 gals ÷ 14,092 gpd
= 25 days

5.1.3 Given the volume of feed, influent chemical oxygen demand (COD) concentration, and volume of a reactor, calculate the organic loading rate (OLR) (lbs/day/ft^3).

GIVEN:
Reactor volume = 76,000 ft^3

Influent rate= 1.05 MGD
COD concentration = 4,100 mg/L
FORMULAS AND SOLUTION:
COD (lbs/day) = influent rate (MGD) × COD conc. (mg/L) × 8.34
= (1.05 MGD) × 4,100 mg/L × 8.34
= 35,900 lbs of COD/day
OLR (lbs/day/ft^3) = COD (lbs/day) ÷ reactor volume (ft^3)
= 35,900 lbs of COD/day ÷ 76,000 ft^3
= 0.47 lbs of COD/day/ft^3

5.1.4 Given data, determine the chemical oxygen demand (COD) (lbs of COD/day/ft^3) loading to an anaerobic reactor.

GIVEN:
Reactor volume = 80,000 ft^3
Feed rate = 56,000 lbs of COD/day
FORMULA AND SOLUTION:
COD loading (lbs of COD/day/ft^3) = feed rate (lbs of COD/day) ÷ reactor volume (ft^3)
= 56,000 lbs of COD/day ÷ 80,000 ft^3
= 0.7 lbs of COD/day/ft^3

5.1.5 Given data, calculate the reactor efficiency (% chemical oxygen demand (COD) reduction)

GIVEN:
Influent COD = 5,600 mg/L
Effluent COD = 840 mg/L
FORMULA AND SOLUTION:
Efficiency (%) = [(COD in – COD out) ÷ (CODin)] × 100
= [(5,600 in - 840 out) ÷ (5,600)] × 100
= [4,760 ÷ 5,600] × 100
= 0.85 × 100
= 85%

5.1.6 Given data, calculate the amount of biogas produced per amount COD removed in one day.

GIVEN:
COD in= 6,200 mg/L
COD out = 800 mg/L
Flow =1.3 MGD
Biogas produced (ft^3) = COD removed (lbs) × 9 ft^3/ lb removed
FORMULA AND SOLUTION:
COD removed (lbs) = (COD in (mg/L) –COD out (mg/L)) × Flow (MGD) x 8.34
COD removed = (6,200– 800) × 1.34 x 8.34
COD removed = (5,400) × 11.18
COD removed = 60,348 lbs
Biogas produced = 60,348 lbs × 9ft^3/ lb removed
Biogas produced = 543,134 ft^3

5.1.7 Given data, calculate the volatile acids/alkalinity (VA/ALK) ratio.

GIVEN:
Volatile acids = 400 mg/L
Alkalinity = 2,500 mg/L
FORMULA AND SOLUTION:
VA/ALK ratio = volatile acids (mg/L) ÷ alkalinity (mg/L)
= 400 mg/L ÷ 2,500 mg/L
= 0.16

References and Resources

1. **UW WATER LIBRARY**

   Most of the resources listed on this page can be borrowed through the UW Water Library as part of a partnership between the UW Water Library, the Wisconsin Wastewater Operator Association (WWOA), Central States Water Environmental Association (CSWEA), and the Wisconsin Department of Natural Resources. Instructions for borrowing materials from the UW Water Library can be found by visiting the website provided below, clicking on 'WISCONSIN RESIDENTS', and then clicking on 'HOW TO BORROW MATERIALS'.
   www.aqua.wisc.edu/waterlibrary

2. **OPERATION OF MUNICIPAL WASTEWATER TREATMENT PLANTS: MANUAL OF PRACTICE NO. 11**

   Water Environmental Federation (WEF). (2008). Operation of Municipal Wastewater Treatment Plants: Manual of Practice No. 11 (6th ed., Vols. I, II, III). New York, New York: McGraw-Hill.
   www.wef.

3. **OPERATION OF WASTEWATER TREATMENT PLANTS**

   Office of Water Programs, California State University, Sacramento. (2008). Operation of Wastewater Treatment Plants (7th ed.). Sacramento, CA: University Enterprises, Inc., California State University.
   www.owp.csus.edu

4. **STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER**

   American Public Health Association, American Waterworks Association, and Water Environment Federation (WEF) (22nd ed.)
   www.standardmethods.org

5. **BIOLOGICAL SOLIDIS AND SLUDGES – HANDLING, PROCESSING, and REUSE STUDY GUIDE**

   Wisconsin Department of Natural Resources, Bureau of Water Quality. (2016). Madison, Wisconsin.
   https://dnr.wi.gov/regulations/opcert/wastewater.html

6. **NR 114 CERTIFICATION REQUIREMENTS FOR WATERWORKS, WASTEWATER TREATMENT PLANT, SEPTAGE SERVICING AND WATER SYSTEM OPERATORS**

   Wisconsin Administrative Code NR 114 Certification Requirements for Waterworks, Wastewater Treatment Plant, Septage Servicing, and Water System Operators
   http://docs.legis.wisconsin.gov/

7. **OSHA CFR 29 PART 1910**

   Occupational Safety & Health Administration (OSHA). (2012). Regulations (Standards-29 CFR 1920.100)
   www.osha.gov