Wisconsin Department of Natural Resources
Wastewater Operator Certification

Advanced Anaerobic Digestion Study Guide

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Subclass F

Wisconsin Department of Natural Resources Bureau of Science Services
Operation Certification Program
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http://dnr.wi.gov

Preface

This operator's study guide represents the results of an ambitious program. Operators of wastewater facilities, regulators, educators and local officials, jointly prepared the objectives and exam questions for this subclass.

How to use this study guide with references

In preparation for the exams you should:

1. Read all of the key knowledges for each objective.

2. Use the resources listed at the end of the study guide for additional information.

3. Review all key knowledges until you fully understand them and know them by memory.

It is advisable that the operator take classroom or online training in this process before attempting the certification exam.

Choosing A Test Date

Before you choose a test date, consider the training opportunities available in your area. A listing of training opportunities and exam dates is available on the internet at http://dnr.wi.gov, keyword search "operator certification". It can also be found in the annual DNR "Certified Operator" or by contacting your DNR regional operator certification coordinator.

Acknowledgements

Special appreciation is extended to the many individuals who contributed to this effort.

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Chapter 1 - Principle, Structure and Function

Section 1.1 - Principle of Anaerobic Digestion

1.1.1 Contrast the environmental sensitivity of acid forming bacteria to that of methane forming bacteria.

The acid forming bacteria are not very sensitive as compared to the methane forming bacteria. The methane forming bacteria are very sensitive to slight changes in organic loading, pH, and temperature (a temperature change greater than 2 degrees F./day will affect the methane formers). The methane formers are strictly anaerobic bacteria and are also extremely sensitive to oxygen. Good digester operations requires ensuring that conditions are kept favorable for the methane formers. If the acid former population grows too rapidly (excess volatile acids) a digester upset will occur.

1.1.2 Describe the meaning of "digester buffering capacity" as it relates to digester control.

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.

1.1.3 List the typical values for volatile acids and alkalinity in a well operating digester.

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.

1.1.4 Compare thermophilic bacteria digester operation to mesophile bacteria digester operation.

Temperature control is important for methane forming bacteria. They function in the range of 85 degrees - 100 degrees F. which is known as the mesophilic range. Another temperature range is 120 degrees - 135 degrees F. and is known as the thermophilic range.

Methane forming bacteria's activity outside these two ranges is severely reduced. When operating in the thermophilic range the digestion time is reduced (less than half of mesophilic) but higher operating and maintenance costs would be expected. Most anaerobic digestion in Wisconsin is operated in the mesophilic range normally operating between 90 degrees - 98 degrees F.

1.1.5 State the expected reduction in volatile solids from a well operated digester.

The expected reduction of volatile solids of a properly operating digester is 40-60% of the total volatile solids present in raw sludge feed. The volatile solids in the feed sludge would be about 70% to 75% while the digested sludge would be 45% to 50% volatile solids.

Note: Land disposal regulations are being promulgated at the federal level (503). When these regulations are finalized state codes will have to be modified. An anaerobic objective will need to be added to incorporate this information.

Section 1.2 - Structure and Function

1.2.1 List three types of digester mixing systems.

1. Draft tube and other mechanical impellers/mixers
2. Compressed digester gas mixing
3. Sludge recirculation

1.2.2 Describe the function of gas compressors and explain why they are used.

A gas compressor takes low pressure digester gas after cleaning (scrubbing) and compresses it to a higher pressure. This increase in pressure reduces the volume of gas storage required. This compressed gas has historically been used for such things as it is burned in boilers to provide heat for the digester, it is burned in natural gas internal combustion engines for power generation (pumping sewage, running compressors, and generating electricity, etc.), running automobiles, and it is used for gas mixing in digesters.

1.2.3 Describe the two methods of storing digester gas.

The two methods of storing digester gas are:

A. Gas holding cover: this is a digester cover very similar to a floating cover except it has a much longer skirt; the gas holding cover may be able to rise more than 6 feet above the minimum cover height; this type of cover provides much more volume for gas storage but has similar operating problems as a normal floating cover such as free movement up and down without binding and pressure/vacuum relief valve

B. Separate gas storage tank: digester gas is often stored in a separate tank that is not a part of the digester; normally digester gas is cleaned and is 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

1.2.4 Describe a floating cover position indicator and an alarm system.

A cover position indicator is a dial, staff gauge, or other device that allows an operator to determine the location of the cover within its limits of travel. This will provide a quick indication of cover level to prevent sludge overflow (at high level) or possible structural damage if the cover is resting on corbels (low level). An alarm system is normally provided to prevent the problems with either a high or low level cover position.

Chapter 2 - Operation and Maintenance

Section 2.1 - Operation

2.1.1 List the start-up procedures of a digester using seed sludge.

1. Add well buffered seed sludge; add enough seed so that the seed sludge volatile solids will be about 20 times the expected daily volatile solids in the raw sludge

2. Fill the rest of the digester by continuous pumping of preliminary treated sewage to the normal operating level

3. Begin heating and bring the temperature up to the normal operating level (95 degrees F.) as quickly as possible

4. Begin mixing and/or recirculation at the maximum rate; begin adding raw sludge at a uniform rate pumping small amounts often over a 24 hour period

5. Monitor temperature, pH, alkalinity, and volatile acids

6. Control pH with chemical additions

7. Continue monitoring including gas production and carbon dioxide content of the gas

8. Adjust raw sludge feed rate when necessary

2.1.2 List the start-up procedures of a digester without seed sludge.

1. Fill the digester with preliminary treated sewage with continuous pumping to the normal operating level

2. Begin heating and bring the temperature up to the normal operating level (95 degrees F.) as quickly as possible

3. Begin mixing and/or recirculation at the maximum rate

4. Begin adding raw sludge at a uniform rate pumping small amounts often over a 24 hour period

5. Monitor temperature, pH, alkalinity, and volatile acids

6. Control pH with chemical additions

7. Continue monitoring including gas production and carbon dioxide content of the gas

8. Adjust raw sludge feed rate when necessary

2.1.3 Define the organic loading rates for a conventional and a high rate digester.

Conventional digesters would have a loading rate of 0.03 to 0.10 pounds of volatile solids per cubic foot per day. This includes single stage unheated and unmixed, single stage heated and unmixed, and two stage digesters.

A high rate digester would have a loading rate of 0.10 to 0.40 pounds of volatile solids per cubic foot per day. The high rate units have higher loading rates because their design includes uniform temperature, greater mixing capacity, often times are deeper, and they will be fed on a nearly continuous basis.

The organic loading rate is determined by dividing the daily pounds of volatile solids in the digester by the volume of the digester space in cubic feet.

2.1.4 Explain the impact on the following if a digester is hydraulically overloaded due to pumping thin sludge:

A. Heating
B. Supernatant
C. Gas production

A. Heating: the excess water being pumped will increase heating costs; it could also lower the temperature in the digester if the heating equipment can not keep up with the excess pumpage; any significant temperature change could affect the methane formers and a possible digester upset

B. Supernatant: hydraulic overloading will increase the amount of supernatant volume that must be returned to the head of the treatment plant; this could cause an organic overload to the secondary process reducing overall treatment efficiency because it has a high oxygen demand, high ammonia, and is anaerobic

C. Gas production: gas production (methane) would be reduced as the hydraulic overload could lower temperatures reducing the effectiveness of the methane formers

2.1.5 Compare digestion time when operating at 85 degrees F. and at 95 degrees F.

The mesophilic bacteria used in digestion can function at a range of 85 degrees F. to 100 degrees F. with the optimum range for normal digestion at 90 degrees F. to 98 degrees F. The difference between 85 degrees F. and 95 degrees F. is the length of time required to achieve a given level of digestion. If digestion occurs at 85 degrees F. it will take about 40% longer than at 95 degrees F. This means that digester capacity must be larger to provide the additional detention time at the lower temperature or the raw sludge loading rate must be reduced.

2.1.6 Discuss methods of improving a digester's ability to hold its temperature during winter months.

Methods to improve a digesters ability to hold temperature would include: maintenance of the heating system, adding additional insulation, further concentrate sludge, feed smaller quantities of sludge more frequently, and increase sludge mixing time.

2.1.7 Discuss operational alternatives when it is difficult to hold constant digester temperature in very cold weather.

The methane forming bacteria are affected by changes in temperatures of as little as 1 degree F. per day and methane former activity will be reduced with changes greater than 2 degrees F. If all operational controls and the adding of insulation still cause temperature fluctuations during very cold weather it is better to slowly reduce the temperature (at a rate not to exceed 1 degree F. per day) and hold it at this lower constant level than to allow fluctuations that will affect the methane formers. It would be better to operate at a constant 90 degrees F. than to bounce between 92 degrees F. and 95 degrees F. as weather conditions vary.

2.1.8 Explain the impact on the following if a digester is being organically overloaded.

A. Gas composition
B. Volatile acids concentration
C. Total alkalinity
D. pH
E. Gas production

A. Gas composition: a digester that is being overloaded will have an increase in carbon dioxide production and a decrease in methane production

B. Volatile acids concentration: will increase; this will be the first indication of an organic overload

C. Total alkalinity: will drop

D. pH: will remain constant until the volatile acids exceed the alkalinity at which time the pH will drop sharply

E. Gas production: will decrease

2.1.9 Explain why the ratio of volatile acid to total alkalinity is more sensitive to digester changes than is the pH test.

The volatile acids to alkalinity ratio will show changes occuring while the pH level will remain constant because the buffering affect of the alkalinity must be used-up before the pH will change.

2.1.10 Identify the volatile acid to alkalinity ratios for the following:

A. A continuously underfed digester
B. A continuously overfed digester
C. The point at which operator should take action
D. The point at which pH will start dropping

A. A continuously underfed digester: a rate of less than 0.1

B. A coninuously overfed digester: a ratio of greater than 0.5

C. The point at which operator should take action: any change in the normal ratio for good operations should be watched; any time the ratio reaches 0.5 corrective actions must be initiated

D. The point at which pH will start dropping: a ratio of 0.8. to 1.0

2.1.11 State the gas pressure manometer reading in inches of water for a typical digester.

A typical digester has a gas pressure manometer reading of 8-9 inches of water.

2.1.12 State the methane concentration level in digester gas when combustion can occur.

Methane concentrations in digester gas will burn when the level reaches 56% but is not usable as a fuel until the methane level reaches 62%. When gas is mixed with air and methane is in the 5% to 20% range it is explosive.

2.1.13 Explain why digester gas has an approximate fuel value of 600 BTU's compared to 1,000 BTU's of pure methane.

Digester gas is not pure methane as it has approximately 30% carbon dioxide and other gases left from the digestion process.

2.1.14 Discuss why hydrogen sulfide and moisture is removed from digester gas.

Digester gas is normally cleaned before being compressed and stored. The cleaning (scrubbing) of gas involves removal of moisture and hydrogen sulfide. This is done to reduce downstream corrosion of other gas handling equipment, piping, and parts.

2.1.15 Describe how to select the level for supernatant withdrawal.

Draw-off supernatant from several different levels to visually find the best supernatant quality.

2.1.16 Discuss the supernatant removal strategies for the following mixed and heated digesters:

A. Single fixed cover
B. Single floating cover
C. Two-stage with at least one floating cover

A. Single fixed cover: shut-off mixing and allow settling (8-12 hours); withdraw at the level with the best supernatant; do not withdraw supernatant in a volume that will cause a vacuum in the digester

B. Single floating cover: shut-off mixing and allow settling (8-12 hours); withdraw at the level of best supernatant; do not lower the liquid operating level below the corbels

C. Two-stage digester with at least one floating cover: withdraw from the level with the best supernatant in the secondary digester; do not lower the liquid operating level below the corbels

Section 2.2 - Maintenance

2.2.1 Develop a maintenance schedule for weekly, monthly, quarterly, and semi-annual activities.

In general consult the O&M manual and manufacturers recommendations for preventive maintenance schedules.

A. Weekly:

1. Inspect all pumps (raw feed sludge and recirculation)
2. Operate and inspect variable speed drives

3. Check floating cover for evenness
4. Check for gas leaks
5. Inspect all safety equipment
6. Check mechanical mixer equipment

B. Monthly:

1. Inspect and clean all drive motors (raw sludge, recirculation, and compressors)
2. Inspect and lubricate raw sludge pumps (piston type and belt driven)
3. Inspect piping and exercise valves
4. Inspect and check sludge flow metering devices
5. Lubrication as needed

C. Quarterly:

1. Lubricate all equipment as needed (including mechanical mixer gear reducers)
2. Check spare parts inventory

Semi-annually:

1. Clean and fill gas manometers
2. Disassemble and clean drip (condensate) traps
3. Disassemble and clean flame arrestors
4. Inspect and clean gas compressor
5. Clean heat exchanger
6. Disassemble and clean pressure/vacuum relief valves

2.2.2 Discuss procedures for complete digester cleaning.

The first consideration for complete digester 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 (single versus multiple tanks) it will be necessary to determine how to handle raw sludge while the unit is down, the equipment necessary to accomplish the job, and how and where to dispose of digested sludge. Other advance planning would include accurate information and a supplier for all internal parts that may have to be replaced during the cleaning process.

Basic requirements for cleaning:

1. Advance planning for all phases of cleaning

2. All sludge piping and valves must be operable

3. Temporary sludge lines for emptying digester

4. Adequate access to the inside of digester (for washdown water & entry for final cleaning and repair of internal parts)

5. All spark proof/explosion proof equipment (ventilation fans, tools, ladders, and lights, etc.)

6. All other safety items (explosion meter, tri-gas meter, self-contained breathing apparatus, safety harness and tripod, hardhats, protective clothing, and personal hygiene, etc.)

7. Adequate source of clean-up water (this could include the use of final effluent if local potable source is inadequate); this would be an inexpensive source just requiring pumping

8. Washdown water hose with nozzles for high pressure application

9. Sludge pumps (fixed and portable)

10. Hoist for installing and removing equipment

11. Tank truck to haul digested sludge to point of ultimate disposal; this may require renting units to ensure a quick take-down and start-up

12. Crane - this unit should be available if the digester cover is expected to be removed and on-call in case the digester cover might have to be removed

The actual sequence of emptying and washing down the inside of the digester is dependent on the type of digester and the types of mixing/recirculation/ heating that the unit has. Refer to the plant O&M manual and the manufacturer for specifics on a given type of digester. In smaller communities it is advantageous to give consideration to using a contractor for digester cleaning as digester cleaning is not a routine operational activity. Depending on the type of wastewater treated, amount of grease, and the efficiency of grit removal complete digester cleaning would be done on a 3-5 year interval.

Chapter 3 - Monitoring and Troubleshooting

Section 3.1 - Monitoring

3.1.1 Explain how to use the quantity of gas production as an indicator of digestor performance.

Gas produced should range between 7 and 12 cubic feet per pound of volatile matter destroyed.

Low gas production indicates problems - toxicity, temperature, volatile acid to alkalinity ratio, mixing, or feed rates.

3.1.2 Describe a method of analysis of digester gas composition.

The use of a carbon dioxide gas analyzer will provide an indication of gas quality. Good digester gas will have a carbon dioxide content of 30% to 35%. If the carbon dioxide reaches 42%, the digester is in poor condition and the gas is close to the burnable limit of 44% to 45%.

3.1.3 Outline procedure for finding percent solids concentration of sludge and percent volatile solids.

1. Collect a representative sludge sample
2. Weigh empty dry crucible
3. Add sample to crucible and weigh
4. Dry sample by heating in an oven at 103 degrees C. to 105 degress C.
5. Cool in desiccator
6. Repeat drying until a constant weight is achieved
7. Weigh sample - dry weight ÷ wet weight x 100% = % solids (by weight)
8. Heat sample in muffle furnace at 550 degrees C.
9. Cool sample in desiccator and weigh (ash weight)
10. dry weight - ash weight ÷ dry weight x 100% = % volatile solids (by weight)

Example:

Empty crucible = 110.3642 gms
Crucible with wet sludge = 466.6742 gms
Crucible with dry sludge = 136.8726 gms
Crucible with ash = 122.4672 gms

% solids = (dry weight - crucible weight) ÷ (wet weight - crucible weight) x 100

(136.8726 - 110.3642) ÷ (466.4642 - 110.3642) x 100 = 7.4%

% volatile solids = dry weight - ash weight ÷ dry weight x 100

% volatile solids= (136.8726 - 110.3642) - (122.4672 - 110.3642) ÷ (136.8726 - 110.3642) x 100

% volatile solids = 26.5084 - 12.1030 ÷ 26.5084 x 100

% volatile solids = 14.4054 ÷ 26.5084 x 100

% volatile solids = 54.6%

3.1.4 Describe the locations for obtaining samples for the following:

A. Feed sludge volatile solids
B. Digester efficiency
C. Volatile acid to alkalinity ratio
D. Digester gas composition

A. Feed sludge volatile solids: collect a composite sample made of grabs at the beginning, middle, and end of the sludge pumping period

B. Digester efficiency: collect representative samples of the feed sludge and draw-off digested sludge for volatility testing and calculate the percent reduction in volatile solids

C. Volatile acid to alkalinity ratio: a representative sample of digesting sludge is obtained from the recirculation sludge pump or a well mixed location within the digester if mechanical or gas mixing is employed; for both volatile acids and alkalinity the samples must be settled or filtered as the test is performed on the liquid portion; the sample should be free of solids; after testing the volatile acid to alkalinity ratio can be calculated; another sample source for this would be to use digester supernatant

D. Digester gas composition: a representative sample of digester gas should be collected from the gas dome on the digester or from digester gas lines where the gas is actively being used (heat exchanger or waste gas burner); a bunsen burner should be connected to the gas outlet, ignited, and allowed to burn for a sufficient length of time to ensure that a representative sample of gas will be collected; the actual analysis of the gas will be for carbon dioxide which will average about 30% carbon dioxide with the remainder being mostly methane

3.1.5 Describe how heat transfer efficiency is determined for internal heating coils.

Heat transfer efficiency can be determined by monitoring the heating coil water temperature in and out of the digester and monitoring the temperature of the digester sludge. Care must be taken to keep the water temperature below 130 degrees F. or sludge will bake on the tubes and cut down on heat transfer efficiency.

3.1.6 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.

Given:
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) = .833 volatile acids (as acetic acid)

1. Find the pounds of volatile acids in the digester

Formula:

pounds = concentration (mg/L) x volume (mg) x 8.34

pounds = 3,000 x .25 x 8.34

pounds = 6,255 pounds (volatile acids)

2. Find pounds of calcium carbonate needed

Formula:

pounds = alkalinity x pounds volatile acids

pounds = .833 x 6,255

pounds = 5,210 pounds (calcium carbonate)

3. Find pounds of 100% sodium bicarbonate needed

Formula:

100% bicarb = equivalent weight of sodium bicarb ÷ equivalent weight of calcium carb x pounds

100% bicarb = 84 ÷ 100 x 5210

100% bicarb = 4,376 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 chemical

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.

Another method for determining chemical amounts would be to obtain a representative sample of digester sludge (about 5 gallons) and add a chemical until a desired pH is reached. Calculate the amount of chemical needed for the entire digester proportional to the amount used in the 5 gallon sample.

A final method would be to use a chart based on the actual pounds of volatile acid per 100 gallons in the digester and the amount of chemical needed to neutralize the volatile acids.

Figure 3.1.6.1

QUANTITIES OF VARIOUS ALKALIES REQUIRED
TO NEUTRALIZE VOLATILE ACIDS

Actual* lbs.of Acid per 100 gals. Soda,lbs.	NH_3 Anydrous Ammonia lbs.	NH_4OH Aqua Ammonia gals.	Na_2CO_3 NaOH Anhydrous Soda Ash lbs.	NaOH Liquid Caustic	Flake Caustic Soda,lbs.
.834	.236	.197	.736	1.11	.555
1.67	.472	.216	1.47	2 22	1.11
2.50	.708	.322	2.21	3.32	1.66
3.34	.944	.429	2.94	4.44	2.22
4.17	1.18	.536	3.68	5.54	2.77
5.00	1.42	.645	4.43	6.68	3.34
5.84	1.65	.750	5.14	7.76	3.88
6.67	1.89	.859	5.89	8.88	4.44
7.51	2.12	.963	6.61	9.96	4.98
8.34	2.36	1.07	7.36	11.10	5.55
16.71	4.73	2.15	14.74	22.24	11.12
25.10	7.11	3.23	22.16	33.42	16.71
33.51	9.49	4.31	29.58	44.60	22.30
41.96	11.88	5.40	36.84	55.84	27.92
50.42	14.27	6.49	44.48	67.06	33.53
84.50	23.92	10.87	74.56	112.42	56.21
171.30	48.50	22.05	151.17	227.96	113.98

1kg = 2.205 lb. & 1L = 0.264 gallons)

$$\frac{\text{POUNDS OF VOLATILE ACIDS}}{\text{DIGESTER VOLUME/100 GAL.}}$$

$$\text{CHEMICAL DOSAGE} = \frac{\text{POUNDS OR GALLONS NEEDED}}{\text{100 GALLONS}} \times \text{DIGESTER VOLUME}$$

(CHART FROM "OPERATIONS MANUAL ANAEROBIC SLUDGE DIGESTION" EPA 430/9-76-001, FEBRUARY, 1976)

Section 3.2 - Troubleshooting

3.2.1 Identify the causes and corrective actions for the following gas system problems:

A. Gas pressure lower than normal
B. Gas pressure higher than normal
C. Waste gas burner problems
D. Gas meter failure

A. Gas pressure lower than normal:

1. Cause: Gas leaking out through pressure/vacuum relief valve
Correction: Service valve to ensure proper seating adding more weights if necessary; install new parts if worn

2. Cause: high gas usage in the plant
Correction: check gas usage in the plant against gas production and adjust usage

3. Cause: gas leaking out of the cover or gas piping
Correction: check for leaks around the cover and repair; check all piping for leaks and repair

4. Cause: poor digester operations
Correction: monitor alkalinity, volatile acids, pH, and gas quality (carbon dioxide concentration); adjust raw sludge feed rate (to prevent organic or hydralic overloading) and add chemicals to restore good digester operations

5. Cause: excessive sludge or supernatant removal
Correction: stop sludge or supernatant removal until the digester gas pressure returns to normal

6. Cause: excessive use of lime
Correction: stop addition of lime and increase mixing to restore normal gas pressure

B. Gas pressure higher than normal:

1. Cause: stuck pressure/vacuum relief valve
Correction: 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 reqularly in very cold weather and vented barrel could be placed over the valve with an explosion proof light bulb inside to reduce freezing temperatures

2. Cause: low gas usage in the plant
Correction: check the waste gas burner and all piping for proper operation so excessive gas will be burned

3. Cause: gas piping blocked or pressure regulating valve not functioning
Correction: 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

4. Cause: supernatant lines are frozen or blocked
Correction: check lines frequently in very cold weather and protect with insulation to reduce freezing problems

C. Waste gas burner problems:

I. Yellow gas flame at the waste gas burner:

1. Cause: poor quality digester gas with a high carbon dioxide content from poor digester operations

Correction: correct digester operations; check raw feed sludge operations to prevent hydraulic or organic overloading, check volatile acids, alkalinity, and pH; adjust with chemicals to improve gas composition

II. Gas flame lower than usual:

2. Cause: high gas usage in the plant
Correction: check gas production against usage

3. Cause: gas leakage in the collection and distribution system
Correction: check for gas leaks, repair piping, and other appurtenances as needed

4. Cause: low gas production due to process problems
Correction: correct digester operations (see above)

III. Waste gas burner not lit:

5. Cause: pilot flame not burning
Correction: check for adequate pressure, service, and relight

6. Cause: obstruction or water in the pilot gas line
Correction: clean with air and check low spots for in-line water

7. Cause: obstruction or water in main gas line
Correction: drain all drip (condensate) traps; check for low spots in piping for water or other blockages; clean and repair as necessary

IV. Pressure control valve:

8. Cause: malfunction of the valve
Correction: clean, service, and repair valve as necessary

D. Gas meter failure:

1. Cause: debris in gas line
Correction: clean by flushing with water

2. Cause: mechanical failure or diaphragm problems
Correction: isolate the meter, disassemble, service, and replace worn or damaged parts

3.2.2 List the methods for testing for digester gas leaks.

1. On-line:
A. Gas detector
B. Soapy water

2. Off-line:
A. Pressure test with air
B. Vacuum test

Note: Always use sparkproof tools and keep any open flames away from all digester equipment and structures to prevent fire or explosion.

3.2.3 Identify the causes and corrective actions for the following pump problems:

A. Plugging
B. Motor runs but is not pumping
C. Drive motor stops

A. Plugging: clean impellers on centrifugal pumps; clean ball check valves on piston pumps; clean all piping

B. Motor runs but not pumping: examine shear pin on piston pumps; examine check valve balls for seating on piston pumps; make sure drive belts are not broken on piston pumps (replace if needed); examine coupling on the shaft to make sure impeller is turning on centrifugal pumps; make sure that all proper valves are open

C. Drive motor stops: check circuit breakers or thermal overload switch; check for overheating (clean vents and cooling fins and determine the cause of overheating); check for loose connections or an open circuit; check brush or slip rings for proper operation and replace if necessary

3.2.4 Identify the causes and corrective actions for the following mechanical mixing equipment problems:

A. Shaft seal leaks
B. Gear reducer wear
C. Internal mixing parts

A. Shaft seal leaks:

Cause: packing dried-out or worn causing gas leakage (confirmed by gas odor or bubbles with a soap solution)

Correction: repack shaft seal as needed and anytime the tank is down for cleaning

B. Gear reducer wear:

1. Cause: lack of proper lubrication which would cause noise, vibration, and shaft wear
Correction: use correct type and amount of lubrication as recommended by the manufacturer

2. Cause: poor alignment of equipment
Correction: properly align equipment and correct for any imbalance of internal parts which cause alignment problems

C. Internal mixing parts:

1. Cause: imbalance from debris on moving parts causing vibration, motor overheating, and noisy operations
Correction: make sure preliminary treatment (comminution and screening) is operating properly to prevent debris from getting to the digester; 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 digester will need to be totally drawn-down and cleaned to remove the accumulation of debris

2. Cause: wear on internal parts from grit or misalignment
Correction: make sure preliminary treatment (grit removal) is operating properly to minimize grit getting to the digester; excessive wear will require replacement of the worn internal parts

3.2.5 Discuss problems associated with control of scum blankets.

Thick scum blankets in digesters can have an adverse affect on digestion as they cause a loss of digester capacity, can plug the supernatant line, can leak out at the water seal on floating covers, and could affect the heat exchanger. Thick scum blankets are normally associated with inadequate mixing and high grease content. To keep scum blankets at a minimum will require adequate mixing and the minimizing of greases sources within the sewer collection system by pretreatment using grease traps. If sludge mixing or recirculation is done intermittently the mixing time should be increased or run continuously to reduce scum blanket thickness. If adequate sludge mixing has not been provided as part of the digester construction it may be necessary to reconstruct the digester or provide some form of portable mixer to reduce scum blanket thickness. Other alternatives would be to physically break-up the scum blanket with poles or paddles and use chemicals to soften the scum blanket or contract commercial haulers to remove it.

3.2.6 Discuss the toxicity concerns of the following:

A. Heavy metals
B. Sulfides
C. Ammonia
D. Alkaline salts

A. Heavy metals: heavy metals in solution can act as biocides (will kill the bacteria in the digester); heavy metal sources are often from industrial sources especially metal finishing and metal plating operations; common toxic heavy metals would include: aluminum, copper, chromium, mercury, arsenic, nickel, and zinc

B. Sulfides: sulfides can come from industrial sources as sulfate salts that are reduced to sulfides in the digester; the bacteria can tolerate between 50-100 mg/L of soluble sulfide but concentrations above 200 mg/L are toxic and would require treatment with iron salts to precipitate the sulfides; the source of this waste stream should be eliminated or pretreated

C. Ammonia: ammonia from industrial sources, organic overloading, or from using anhydrous ammonia to correct a digester pH problem can cause a die-off of bacteria; ammonia toxicity begins around 1,500 mg/L and is totally toxic at 3,000 mg/L

D. Alkaline salts: the alkaline salts can cause toxicity and would originate from industrial sources or chemicals used to correct digester pH problems

Salt --- Moderately inhibitory --- Toxic

1. Calcium (mg/L) --- 2,500 to 4,500 --- 8,000
2. Magnesium (mg/L) --- 1,000 to 1,500 --- 3,000
3. Potassium (mg/L) --- 2,500 to 4,500 --- 12,000
4. Sodium (mg/L) --- 3,500 to 5,500 --- 8,000

Chapter 4 - Safety and Calculations

Section 4.1 - Safety

4.1.1 Describe the storage and handling concerns for the following chemicals:

A. Calcium oxide
B. Calcium hydroxide
C. Anhydrous ammonia
D. Ammonia (liquid)
E. Ammonium hydroxide
F. Sodium carbonate
G. Sodium bicarbonate
H. Sodium hydroxide

These chemicals are all used to control pH in digestors. In handling at a minimum an operator should prevent the chemical from touching the skin (wear rubber gloves and full face mask or goggles). In addition to the items listed below the operator should be sure to read all label instructions provided by the manufacturer and store as directed in the original containers.

A. Calcium oxide: this chemical comes in 50 pound bags (quicklime) in powder form; normally water must be used (slaked) to form a slurry before using; always add quicklime to water to prevent a violent reaction which can cause splattering; it is very caustic and can cause severe burns; it is difficult to wash off as it is a very slimy material when slaked; the powder is dusty and can cause nasal irritations; this powder is hygroscopic absorbing moisture from the air so needs to be stored in a dry area

B. Calcium hydroxide: this chemical comes as a powder and (slaked or hydrated lime) keeps better in storage than calcium oxide; it is similar to calcium oxide and all the same precautions (as noted above) should be taken; storage bin agitation must be provided

C. Anhydrous ammonia: this chemical is commonly used as an agricultural fertilizer and comes in cylinders or tanks as a gas; it should be stored at temperatures below 70 degrees F. in a well ventilated room; the gas should not come in contact with chloride solutions as free chlorine gas can be liberated

D. Ammonia (liquid): is an irritating alkali that can cause severe skin burns and is corrosive to copper and brass; when using it to raise digestor pH care must be exercised to prevent ammonia toxicity which occurs at concentrations of 1,500-1,600 mg/L as nitrogen

E. Ammonium hydroxide: this chemical is available in liquid (liquid ammonia) form from farm supply dealers; as with the other caustics it can cause skin burns and is an eye irritant

F. Sodium carbonate: this chemical is usually supplied in (soda ash) 50 pound bags in powder form; it is highly soluble in water, is caustic, can cause skin burns, and is an eye irritant

G. Sodium bicarbonate: this chemical is supplied as a powder (baking soda or in 50 pound bags and should be treated bicarbonate of soda) the same as sodium carbonate

H. Sodium hydroxide: this chemical is supplied in steel (caustic soda) drums or in bags; it is available as a flake, crystals, or a liquid; normally it is purchased as a flake or a crystal form; the common name is "lye" and has all the problems of the other caustics previously mentioned

4.1.2 Discuss the relative safety of the chemicals used to adjust digester pH.

All chemicals used to adjust digester pH have handling and safety problems. At larger treatment plants chemical handling equipment is usually available which reduces handling and feeding problems. At smaller plants lack of chemical handling equipment and experience would favor certain chemicals. The use of sodium bicarbonate (baking soda) is probably the least hazardous of the chemicals followed by sodium carbonate. Sodium bicarbonate can be applied as a powder or as a premixed solution with water.

The use of calcium oxide (quicklime) or calcium hydroxide (slaked or hydrated lime) is probably the most dangerous when these chemicals are mixed with water prior to feeding. They must always be added to water and not the water added to the chemical. This can cause a violent reaction and splattering of this strong caustic. Sodium hydroxide would be the next most dangerous followed by ammonium hydroxide (which is supplied as a liquid eliminating the mixing problem). The use of anhydrous ammonia should be limited to facilities that have the equipment to handle gas cylinders and that have feed connections or the ability to make the necessary feed connections. Do not use copper or brass fittings as they will be affected by ammonia. The feeding of lime can only raise the digester pH to about 6.8. When lime is added it reacts with carbon dioxide to form calcium bicarbonate. Excessive feeding of lime causes insoluble calcium carbonate to form. In addition excessive lime may remove too much carbon dioxide which could lower gas pressures or even the formation of a vacuum. This could cause air to be drawn into the digester and cause an explosive gas mixture.

Section 4.2 - Calculations

4.2.1 Given data find how much seed sludge is needed for a particular digester.

The amount of seed required is about 20 times the anticipated volatile solids in the daily raw feed sludge.

Given:
If raw sludge is 1,000 GPD at 4% solid and 80% volatile, seed sludge is 5% solid and 50% volatile.

Formula:

pounds = % solids x volume (gallons) x % volatile x 8.34

gallons = pounds ÷ (% solids x % volatile x 8.34)

Note: percent expressed as a decimal

pounds = .04 x 1,000 x .8 x 8.34 = 270 pounds

270 x 20 = 5,400 # of volatile solids needed as seed sludge

gallons = 5,400 ÷ (0.05 x 8.34 x 0.5) = 25,900 gallons of seed sludge

4.2.2 Given volume and concentrations, calculate impact of digester supernatant on plant loading.

Three factors affecting plant loading are volume and strength of:

1. BOD
2. Ammonia
3. Suspended solids (SS)

Given:
Volume of supernatant = 2,000 gallons/day
BOD of supernatant = 1,500 mg/L
Concentration of ammonia = 300 mg/L
Concentration of SS = 2,000 mg/L

Formula:

pounds = volume (MGD) x concentration (mg/L) x 8.34

BOD loadings #/day = .002 x 1,500 x 8.34 = 25.0 #/day

ammonia loadings #/day = .002 x 300 x 8.34 = 5.0 #/day

suspended solids #/day = .002 x 2,000 x 8.34 = 33.4 #/day

4.2.3 Given volumes of feed sludge, sludge concentrations, volatile solids, and volume of a digester, calculate the organic loading rate.

Given:
Digester volume = 40,000 cubic feet
Raw sludge volume = 5,000 gallons per day
Sludge concentration = 5%
Volatile solids = 80%

Formula:

pounds per day = volume (GPD) x % solids x 8.34 x % volatile

Note: % expressed as decimal

loading #'s volatile solids/day/ft^3 = pounds per day ÷ digester vol. cubic feet

loading = (5,000 x .05 x 8.34 x 0.8) ÷ 40,000

loading = 1,668 ÷ 40,000 = 0.042 # volatile solids/day/ft^3

4.2.4 Given data calculate the amount of time to recirculate the volume of sludge in a digester.

Given:
Digester volume = 320,000 gallons
Recirculation pump = 300 GPM

Formula:

time = digester volume (gals.) ÷ pump capacity (GPM)

recirculation time = 320,000 ÷ 300

time = 1,067 minutes

time = 1,067 minutes ÷ 60 min/hour = 17.8 hours

4.2.5 Given data calculate percent efficiency of an anaerobic digester.

Given:
% volatile solids vs. in = 70%
% volatile solids vs. out = 50%

Formula:

% efficiency = % vs in - % vs out ÷ [% vs in - (% vs in x % vs out)] x 100

Note:
VS = volatile solids
% volatile solids expressed as decimal number

% efficiency = .70 - .50 ÷ [.70 - (.70 x .50)] x 100

% efficiency = .20 ÷ (.70 - .35) x 100

% efficiency = .20 ÷ .35 x 100 = 57%

4.2.6 Given gallons of sludge pumped, sludge concentration, and volatile solids in and out of the digester, estimate digester gas production.

Given:
Raw sludge pumped = 12,000 gallons/day
Raw sludge concentration = 5%
Raw sludge volatile solids = 70%
Digested sludge volatile solids = 45%
Gas production rate/pound of volatile solids destroyed = 9 ft^3/day

Formula:

pounds per day = volume (gal) x % concentration x 8.34 x % volatile

Note: % expressed as a decimal

gas production = volatile solids destroyed x est. gas production

raw volatile solids #/day = 12,000 x 0.05 x 8.34 x 0.70

= 3,503 pounds of vol. raw solids/day

raw fixed solids/day = 12,000 x 0.05 x 8.34 x (1 - 0.70)

raw fixed solids = 12,000 x 0.05 x 8.34 x .30

= 1,501 pounds of fixed raw solids/day

Fixed solids remain constant in the sludge so the digested fixed matter is (1-0.45) = 0.55

fixed. The volatile matter destroyed is equal to the volatile solids in the raw sludge minus the volatile solids in the digested sludge.

volatile #'s of digested sludge = 1,501 x (0.45 ÷ .55) = 1,228 #/volatile

pounds volatile solids destroyed = 3,503 - 1,228 = 2,275 #'s/day

estimated gas production = 2,275 x 9 = 20,500 cubic feet/day

Or another method:

% reduction = % V.S. in - % V.S. out ÷ [% V.S. in - (% V.S. in x % V.S. out)] x 100

% reduction = .70 - .45 ÷ [.70 - (.70 x .45)] x 100

% reduction = .25 ÷ .385 x 100 = 64.94%

pounds of destroyed V.S. = % reduction x pounds of raw V.S.

pounds = .6494 x 3,503

= 2,275 pounds/day

4.2.7 Given data, calculate the volume in cubic feet and gallons of a digester.

Given:
Digester diameter = 40 feet
Digester height = 20 feet (not counting the cone)
Depth of bottom cone = 6 feet
1 cubic foot = 7.5 gallons

Formula:

volume = volume of cylinder + volume of cone

volume = 3.14 x r^2 x h + [(3.14 x r^2 x h) ÷ 3]

volume = 3.14 x 20 x 20 x 20 + [(3.14 x 20 x 20 x 6) ÷ 3]

volume = 25,120 + 2,512

volume = 27,632 cubic feet

volume = 27,632 x 7.5 = 207,240 gallons

4.2.8 Given data, calculate the theoretical hydraulic detention time of a digester.

Given:

Digester volume = 33,500 cubic feet
Average daily sludge pumping = 6,000 gallons
1 cubic foot = 7.5 gallons

Formula:

detention time = volume ÷ pumping rate

detention time = 33,500 ft^3 x 7.5 gallons/ft^3 ÷ 6,000 gallons/day

= 42 days

4.2.9 Given data, calculate for changes of volumes (V1, V2) or concentrations (C1, C2) of sludge.

Given:
Initial sludge volume = 6,000 gallons
Initial sludge concentration = 5%
Thickened sludge concentration = 8%

Find: new sludge volume at 8%

Formula:

C1V1 = C2V2

6,000 x 5 = V2 x 8

V2 = 6,000 x 5 ÷ 8

V2 = 3,750 gallons

References and Resources

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