BIOENERGYTRAINING
Modular Course Series

ANDIG4

Start Up, Operation and Control

Anaerobic Digestion Course Series

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BIOENERGYTRAINING
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Module 4: Anaerobic Digester Start-up, Operation and Control

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Summary

This module provides information on the start-up, operation and control of a digester, and sets forth the reasons why digesters fail. Included in this module are standards for best operating procedures and safe operation of digesters.

Learning Objectives

1. Explain the process for starting a digester.
2. Explain aspects of digester operation and control to clients.
3. Suggest potential reasons for digester malfunction.
4. Work with farmers to develop best operating practices for their digester.
5. Understand the safety issues when operating a digester.

Unit 4.1: The Anaerobic Digestion Process

Background

Anaerobic digestion is a complex biochemical reaction carried out in a number of steps by several types of microorganisms that require no oxygen to live. This reaction produces biogas, which is primarily composed of methane and carbon dioxide.

Guiding Questions

- What are the four steps for anaerobic digestion?
- What is the typical composition of biogas?

The Anaerobic Digestion Process

In an anaerobic environment, specialized microorganisms break down complex organic matter (carbohydrates, proteins, and fats) into molecules with a smaller atomic mass that are soluble in water (sugars, amino acids, and fatty acids). Methane and carbon dioxide are the primary end products of this process, which is known as biogas. Table 1 lists the typical composition of biogas. More importantly, anaerobic digestion stabilizes the slurry in the digester (see Unit 2.4 in ANDIG 2).

The overall conversion process of complex organic matter into methane and carbon dioxide can be divided into four steps as shown in Fig. 1, namely hydrolysis, acidogenesis, acetogenesis and methanogenesis. The circled number in Fig. 1 corresponds with each step described below. It should be pointed out that some researchers combine the acidogenesis and acetogenesis steps and make it a three step conversion process. An example of that is found in Unit 2.1 in ANDIG 2.

In an anaerobic digester, the four processes occur simultaneously. When an anaerobic digester performs properly, the conversion of the products of the first three steps into biogas is virtually complete, so that the concentration of these products is low at any time. Biarnes (2012) de-scribes each step as follows:

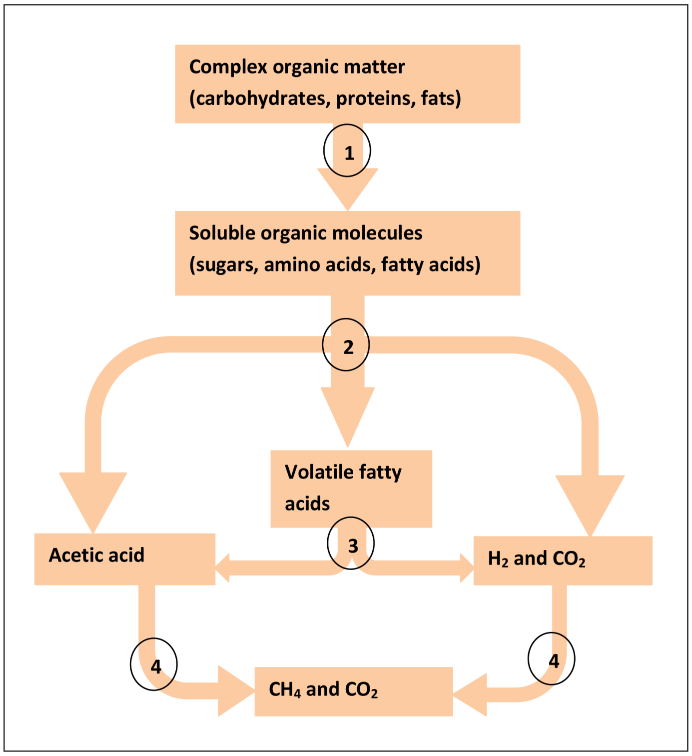

Figure 1: Four stages of the anaerobic digestion process.
Source: Technologies for Economic Development

Step 1: Hydrolysis

In anaerobic digestion, hydrolysis is the essential first step, as biomass is normally comprised of very large organic polymers, which are otherwise unusable. Through hydrolysis, these large polymers, namely proteins, fats and carbohydrates, are broken down into smaller molecules such as amino acids, fatty acids, and simple sugars. While some of the products of hydrolysis, including hydrogen and acetate, may be used by methanogens later in the anaerobic digestion process, the majority of the molecules, which are still relatively large, must be further broken down in the process of acidogenesis so that they may be used to create methane.

Step 2: Fermentation or Acidogenesis

Acidogenesis is the next step of anaerobic digestion in which acidogenic microorganisms further break down the biomass products after hydrolysis. These fermentative bacteria produce an acidic environment in the digester while creating ammonia, H_2, CO_2, H_2S, shorter volatile fatty acids, carbonic acids, alcohols, as well as trace amounts of other byproducts. While acidogenic bacteria further breaks down the organic matter, it is still too large and unusable for the ultimate goal of methane production, so the biomass must next undergo the process of acetogenesis.

Step 3: Acetogenesis

In general, acetogenesis is the creation of acetate, a derivative of acetic acid, from carbon and energy sources by acetogens. Acetogens catabolize many of the products created in acidogenesis into acetic acid, CO_2 and H_2, which are used by methanogens to create methane.

Step 4: Methanogenesis

Methanogenesis constitutes the final stage of anaerobic digestion in which methanogens create methane from the final products of acetogenesis as well as from some of the intermediate products from hydrolysis and acidogenesis. There are two general pathways involving the use of acetic acid and carbon dioxide, the two main products of the first three steps of anaerobic digestion, to create methane in methanogenesis:

$$CO_2 + 4\,H_2 \rightarrow CH_4 + 2H_2O$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

Biogas component	Composition of biogas (%)
Methane (CH_4)	45-65%
Carbon Dioxide (CO_2)	30-40%
Hydrogen Sulfide (H_2S)	0.3-3%
Ammonia (NH_3)	0-1%
Moisture (H_2O)	0-10%
Nitrogen (N_2)	0-5%
Oxygen (O_2)	0-2%
Hydrogen (H_2)	0-1%

Table 1: Typical Composition of Biogas Gas (volumetric percent) Source: Becky Larson

While CO_2 can be converted into methane and water through the reaction, the main mechanism to create methane in methanogenesis is the path involving acetic acid. This path creates methane and CO_2, the two main products of anaerobic digestion.

Conclusions

Biogas is produced in an anaerobic environment by specialized microorganisms that break down complex organic matter into biogas. The production of biogas is a complex process involving four stages: hydrolysis, fermentation, acetogenesis and methanogenesis. Biogas is typically 45-65 percent methane and 30-40 percent carbon dioxide with trace gases and moisture. Anaerobic digestion stabilizes the slurry in a digester.

Self Test Questions

1. What are examples of complex organic matter?
   a. Carbohydrates, proteins and fats
   b. Sugars, amino acids
   c. Fatty acids
   d. Methane
2. Anaerobic digestion will not occur if this major element is present?
   a. Carbon dioxide
   b. Oxygen
   c. Calcium chloride
   d. Ammonium sulfate
3. Biogas has a typical carbon dioxide content of what percent?
   a. Over 60 percent
   b. 50 to 60 percent
   c. 40 to 50 percent
   d. 30 to 40 percent
4. What are the steps of anaerobic digestion (in order)?
   a. Methanogenesis, Hydrolysis, Acidogenesis, Acetogenesis
   b. Hydrolysis, Acidogenesis, Acetogenesis, Methanogenesis

   c. Acidogenesis, Acetogenesis, Methanogenesis, Hydrolysis
   d. Acetogenesis, Methanogenesis, Hydrolysis, Acidogenesis

5. What is the typical methane composition of biogas?
   a. Less than 35 percent
   b. 35 to 45 percent
   c. 45 to 65 percent
   d. More than 80 percent

Key

1. a
2. b
3. c
4. d
5. c

Unit 4.2: Start Up

Background

Getting any biological system to operate requires careful attention to a number of parameters. While those parameters that assure a good start up are not technically difficult, failure to follow the correct procedure or to properly monitor the startup methods result in either a long delay in the anaerobic digestion startup process or a total failure of the system to produce biogas.

Guiding Questions

- How do you start biogas production in a digester?
- What is the advantage of adding “seed sludge or effluent” for digester start-up?
- Why is starting a digester difficult in the winter?

Start-up

Balsam (2006) recommends the following process to prep the digester for biogas production. Fill the digester tank with water and then heat it to the desired temperature. Add “seed” sludge from a municipal sewage treatment plant or farm digester (that is operating in the same temperature range) to 20 to 25 percent of the tank’s volume. Over a 6-8 week period of time, gradually increase the amount of fresh manure that is added to the digester until the desired loading rate is reached. Assuming that the temperature within the system remains relatively constant, steady gas production should occur in the fourth week after start-up. The bacteria may require two to three months to multiply to an efficient population. Purging the anaerobic digester with CO2 or another non-oxygen gas can help decrease start-up time and reduce the danger of explosion during the start-up phase.

Seeding a new digester with effluent from an operating digester is the ideal. The effluent will already contain all the fermenting bacteria and methanogens necessary to produce biogas. Inoculating the digester with effluent from an operating digester speeds up the time it takes the digester to produce burnable biogas, meaning that methane is the primary constituent of the biogas and not carbon dioxide. This assumes all other factors (temperature, pH, volatile acid concentration, etc.) are at appropriate levels. If seed effluent cannot be obtained, using pre-conditioned raw manure will improve the start-up time. Preconditioned manure is manure stored for at least two weeks in an anaerobic state before it is introduced into the digester ves-sel.

During start-up, it is important to monitor pH, fatty acid levels, biogas composition and temperature. The pH of the digester should be moving toward pH 7.0. Volatile fatty acid and carbon dioxide concentrations should decrease as biogas production increases. If pH drops or the volatile acid level of the digester effluent increases, feedstocks should not be added to the digester for two days until the condition of the digestate becomes stable. Feeding should then be resumed. Temperature fluctuations, even small ones, affect anaerobic microorganisms and thereby biogas production. Mesophilic systems should be kept around 100 degrees Fahrenheit, thermophilic systems around 135 degrees Fahrenheit.

Feeding the Digester After Start Up

Once a successful digester startup has been accomplished, the next step is daily feeding. The best feed schedule is continuous at a low rate. The next best is frequent pumping for short periods and once a day is the worst. Calculating the daily loading rate was discussed in Unit 2.3 in ANDIG 2. A digester operator can feed less volatile solids, but should not feed more. Feeding more will result in undigested material being pushed out of the digester as well as inhibit gas production. To maintain a steady state environment within the digester, factors such as those mentioned in Unit 2.5 in ANDIG 2 need to be monitored and controlled.

Starting the Digester During Cold Weather

Supplemental heating is always needed during startup, regardless of the season. However, getting a digester from ambient temperature to mesophilic temperature during the winter requires a lot of energy, which means it is more expensive to start a digester in the winter. Typically propane is used to heat the digester. Commissioning a digester at other times of the year other than late fall or early winter may be less expensive.

Conclusion

The quickest path to biogas production from a new digester is to seed it with anaerobic microorganisms found in effluent or sludge from a properly functioning digester and slowly meter in manure over a 6-8 week period of time. Monitor pH, fatty acid levels, biogas composition and temperature and correct as necessary. Commissioning a digester in cold weather is expensive to do. It is better to commission a digester during warmer times of year.

Self Test Questions

1. How long does it normally take to achieve steady state gas production from an anaerobic digester?
   a. Less than four weeks
   b. 4 to 8 weeks
   c. 2 to 3 months
   d. At least six months
2. Purging an anaerobic digester with an inert, non-oxygen gas will reduce the amount of oxygen that goes into solution and gives the anaerobic microorganism an opportunity to reproduce faster.
   a. True
   b. False
3. How do you start biogas production in a digester?
   a. Fill the digester half full of seed sludge and meter in the feedstock until the digester is at capacity.
   b. Fill the digester with manure until it is at capacity.
   c. Fill the digester with water, bring the water to operational temperature, and then slowly add feedstock.
   d. Inject a blend of 75 percent food waste, 25 percent manure and 15 pounds of yeast into the digester.
4. What is the advantage of adding “seed sludge or effluent” for digester start-up?
   a. There is no advantage.
   b. Biogas production in the winter.
   c. Aids in the breakdown of cellulosic materials.
   d. Seed sludge or effluent will contain all the ferment ing bacteria to ensure a quicker start up for biogas production.
5. Starting a digester during the winter is easy to do because methanogens are cold-tolerant organisms and will produce copious amounts of biogas when temperatures are below freezing.
   a. True
   b. False

Key

1. b
2. a
3. c
4. d
5. b

Unit 4.3: Operation and Control

Background

Anaerobic digesters operate in a stable way when operation and control procedures are established and followed.

Guiding Questions

- What is the purpose for operation procedures?
- What operational procedures can be set in place to prevent possible problems and improve feedstock digestion?

Operation and Control Procedures

As has been mentioned before, anaerobic digestion is a complex process which requires strict anaerobic conditions to proceed, and depends on the coordinated activity of a complex microbial association to transform organic material into mostly carbon dioxide and methane. Problems arise when this “coordinated activity” is disrupted (this will be covered in more detail in Unit 4.4). Therefore, operating a digester to achieve a steady state basis is the goal. Zickefoose and Hayes (1976) recommend seven operational procedures to prevent possible problems and improve digestion results. These procedures are briefly summarized below and are correlated with units in the anaerobic digestion curriculum. It should be noted that in their manual, Zickefoose and Hayes provide a detailed operations checklist for the first five operational procedures.

a. Set up a feeding schedule

Keeping excess water at a minimum and feeding at regular intervals are important features of a feeding schedule.

b. Control loading

The pounds of volatile solids fed to a digester daily and the usable volume of the digester are used to calculate the loading rate to avoid digester upset (see Unit 2.3 in ANDIG 2).

c. Control digester temperature

Digester temperature must be held constant (see Unit 2.5 in ANDIG 2).

d. Control mixing

The goal of mixing is to bring fermenting bacteria and methanogens in contact with food and keep scum and grit formations to a minimum (see Unit 2.4 in ANDIG 2).

e. Control supernatant (e.g. slurry) quality and effects

Feedstock inputs and digester types impact slurry quality (see Units 2.1 and 2.2 in ANDIG 2 and ANDIG 3).

f. Control sludge (e.g. digestate) withdrawal

Odors may be a concern if not digested for the proper length of time (see Unit 1.4 in ANDIG 1). Digestate that has been properly treated can be land applied or used for other value added purposes (see Unit 1.3 in ANDIG 1).

g. Use lab tests and other information for process control

There are certain indicators which measure the progress of digestion and warn about impending upset. No one variable can be used alone to predict problems, several must be considered together. Control indicators in order of importance are:

1. Volatile acid to alkalinity ratio (see Unit 2.5 in ANDIG 2)
2. Gas production rates, both methane and carbon dioxide (see Unit 2.1 in ANDIG 2)
3. pH (see Unit 2.5 in ANDIG 2)
4. Volatile solids destruction (see Unit 1.3 in ANDIG 1)

Zickefoose and Hayes caution against looking at absolute numbers from lab analysis. The rate of change is much more significant. They point out that indicator trends are the most useful to predict the progress of digestion and as signals of process upset.

Conclusions

Seven operational procedures can be implemented to enable a digester to achieve a steady state basis with a minimum of problems.

related agencies) and includes application timing, application rates, and setback distances to water sources and wells. Each state is also required to outline specific guidelines for discrete discharges as mentioned previously.

Self Test Questions

1. The purpose for operation procedures is to enable a digester to operate on a steady state basis.
   a. True
   b. False
2. Operational procedures are not designed to prevent possible problems and improve feedstock digestion.
   a. True
   b. False

Key:

1. A
2. B

Unit 4.4: Reasons for Digester Failure

Background

Labatut and Gooch (undated) state that correct design and control of the digester system's parameters are essential to maximize process efficiency, increase stability, and prevent sys-tem failure. Up to 1998, failure rates of on-farm anaerobic digesters in the U.S. were at a staggering 70% and 63% for complete-mixed and plug-flow reactors, respectively. Today, with improved system design, better construction practices, and an increased number of qualified companies to develop anaerobic digestion projects, the probability of long-term system fail-ure is likely to be somewhat lower. Nevertheless, underperformance and short-term failure are still common problems in on-farm anaerobic digestion systems across the U.S.

Guiding Questions

- Why do digesters fail?

Reasons For Digester Failure

According to Frame and Madison (2001), there are four reasons why digesters fail. The primary reason is bad design and/or installation. Manure is flow-able and pumpable, but it is essentially a semi-solid semi-plastic material under certain temperature and pressure conditions. These properties mandate close attention to hydraulics, which are a critical part of digester design. Whether working with more fluid, low-solids materials such as swine manure or with higher solids manure on dairy farms, farmers investigating installing a digester on their farm need to thoroughly vet the track record of the technology provider. Any grant for digesters should involve an engineering review to expose any technology failures and validate the design plan with the specific materials for the digester under the specific farm conditions.

The second most common reason for digester failure is the selection of poor equipment and materials. In general, cost-conscious farmers have tended to "buy cheap" and install used engines they have refitted for continuous operation. Sometimes this strategy meets with success, but not always. Hours lost to maintenance difficulties have discouraged farmers and given anaerobic digesters in general a bad name. The best choice tends to be a newer or brand new modern engine designed specifically for continuous operation. This is true for materials and other equipment as well. While it is entirely possible to cobble together a digester and make electricity, a modern anaerobic digester installation can truly integrate anaerobic digestion into the economic life of the farm.

The third reason for digester failure is poor farm management. If farmers or other operators are screwdriver friendly, and committed, the digester is far more likely to succeed. A happy healthy digester is one whose owner monitors it, consistently feeds it and takes care of it. Depending on the technology, operations and maintenance of a farm-based digester takes approximately 15-30 minutes per day. Historically, many farmers have treated digesters as self-maintaining systems. In some failed cases, farmers did not provide manure inputs for two or three days and then overfed their digesters in an attempt to make up for lost time. This caused digesters to go sour, resulting in diminished biogas production and other problems. Farmers therefore concluded that their digester "didn't work" and decided not to operate it anymore. It should be noted that many farmers turn over the control of the digester to companies who specialize in digester operation. This allows the farmer to concentrate on what he or she does best, i.e. growing livestock and/or crops.

The final reason for digester failure has to do with introducing toxic products into the digester. Common products found on commercial farms that are mixed with manure or specific compounds in livestock diets that pass through the manure and are injected into the digester can cause problems with the digestion process. Examples include:

- High protein diets can result in excessive ammonia production in the digester, which can inhibit or kill methanogens.
- Rumensin® or similar products kill anaerobic microorganisms. A digester relies on these organisms to digest the manure and produce methane.
- Common products found on commercial farms, such as cow foot bath chemicals, pesti-cides and fertilizers, can be toxic to anaerobic microorganisms.

Conclusion

There are four reasons why digesters fail - bad design and/or installation, selection of poor equipment and materials, poor farm management and introducing products into the digester that are toxic to anaerobic microorganisms. Failure rates have been reduced with improved sys-tem design, better construction practices and an increased number of qualified companies to develop anaerobic digestion projects.

Self Test Questions

1. What are the reasons why digesters fail?
    a. Bad design and/or installation
    b. Selection of poor equipment and materials
    c. Poor farm management
    d. Introducing products into the digester that are toxic to anaerobic microorganisms
    e. All of the above
2. Why have failure rates been reduced in recent years?
    a. Improved system design
    b. Better construction practices
    c. Increased number of qualified companies to develop anaerobic digestion projects
    d. All of the above
3. An engineering review should be conducted to expose any technology failures and validate the design plan with the specific materials for the digester under the specific farm conditions.
    a. True
    b. False
4. Farmers who are considering installing a digester on their farm should do due diligence in selecting a technology provider to make sure the entity is reputable and uses proven digester technology.
    a. True
    b. False
5. What toxic products can kill anaerobic microorganisms if they are introduced into the digester?
    a. Rumensin and products like it
    b. Pesticides
    c. Cattle foot bath
    d. All of the above

Key

1. E
2. D
3. A
4. A
5. D

Unit 4.5: Implementing Safety Procedures

Background

It is estimated there are over a million digesters in operation around the world. Anaerobic digester systems have a very good safety record around the world. Any system can and will fail, but with proper design, inspection and monitoring, these failures do not have to be life-threatening.

Guiding Questions

- What are the human health risks associated with an anaerobic digester?
- What can be done to reduce or eliminate risk to human health from a digester?

Digester Operation Precautions and Safety Measures

Digester operation precautions and safety measures Al Seadi et al. (2008) point out that the operation of a digester is related to a number of important safety issues, potential risks and hazards for humans, animals and the environment. They list the following precautions and safety measures to avoid risk and hazardous situations in the operation of a digester:

- Fire prevention
- Mechanical dangers
- Statically sound construction
- Electrical safety
- Lightning protection
- Thermal safety
- Noise emissions protection
- Asphyxiation, poisoning prevention
- Hygienic and veterinary safety
- Avoidance of air polluting emissions
- Prevention of ground and surface water leakages
- Avoidance of pollutants release during waste disposal
- Flooding safety

Human Health Risks

Asphyxiation, explosion, burns, electrical shock and falls are human health risks associated with working around an anaerobic digester and associated equipment.

Asphyxiation

Hydrogen sulfide (H2S) is an inflammable, colorless, highly poisonous gas. H2S has the characteristic odor of “rotten eggs”, which is obvious even at extremely low concentrations (0.05 - 500 ppm). It is soluble in water, forming a weak acid. H2S is comparable to hydrogen cyanide in its toxicity. It is lethal at 1.2 - 2.8 mg per liter of air (0.117 percent). At 0.6 mg H2S per liter of air (0.05 percent) a person is dead within 30 minutes to one hour.

H2S inhibits oxygen transport in the blood, changing the red blood pigment to a brown or olive color. The person suffocates “internally.” Exposure to low concentrations of H2S causes irritation of the mucous membranes (including the eyes), nausea, vomiting, difficulty in breathing, cyanosis (discoloration of the skin), delirium and cramps, then respiratory paralysis and cardiac arrest. At higher concentrations the symptoms are immediate respiratory paralysis and cardiac arrest. Even if a person survives H2S poisoning, long-term damage to the central nervous system and to the heart may remain.

Entering Confined Spaces

Kirk (2011) states that improper training on confined space entry is a leading cause of accidents related to anaerobic digestion systems. There are no documented deaths associated with on-farm digesters in the U.S.; however, there have been numerous fatalities linked to manure and feed storages on farms. Under no circumstance should a person enter a confined space (an anaerobic digester, manure storage or feed bin) without proper training and safety equipment. Some basic precautions related to confined space entry that every person associated with an anaerobic digester should be aware of include:

- When entering a confined area, always have another person observing outside the confined area.
- At a minimum, air quality in the confined space should be monitored for oxygen and explosive levels before and during any entry.
- Wear a self-contained breathing apparatus (SCBA).
- Provide a continuous supply of fresh, ventilated air (due to the presence of biogas, an explosion-proof blower should be used).
- Maintain constant conversation with the person so he/she can tell if they get into trouble or start acting “funny” while in confined space.
- Wear a harness or safety belt with a lifeline secured to mechanical equipment – such as a winch, hoist or pulley – outside of the confined space area. People using this equipment should be instructed on its operation.
- Keep ignition sources far away from confined

space and sources of biogas.
- Never enter a confined space in which another person is unconscious unless all precautions are taken into account (i.e. buddy system, safety equipment above the precautions
  of the unconscious person, all other mentioned precautions).

Anaerobic digester operators and owners should receive training on the proper procedures and equipment necessary to enter confined space. Contact the Occupational Safety and Health Administration in your state to learn more about training opportunities in your area.

Explosion/Burns

Methane, the major component of biogas, is odorless, colorless, and difficult to detect. It is highly explosive if allowed to come into contact with atmospheric air at levels of 6 to 15 percent methane. It is lighter than air and can collect at the top of confined areas. For these reasons, it is recommended that buildings be well ventilated. Motors, wiring, and lights should be explosion-proof. Flame arrestors should be used on gas lines, and alarms and gas-detection devices should be employed to identify biogas leaks.

Other Risks

Other risks exist that can cause harm to human health. Examples include skin burns through unprotected contact with the heating or cooling systems (e.g. motor coolers, digester heating, heat pumps). This also applies to parts of the CHP unit and to the gas flare. Fatal electrical shock can occur when equipment like pumps and the CHP unit are improperly installation or operated. All electrical work should be done according to code by qualified electricians. Other risks include falling from ladders or uncovered areas (e.g. feed funnels, maintenance walkways) or injury by movable parts (e.g. agitators).

Proper Training, Signage and Fencing

Clear warnings must be placed in the respective parts of the facility. Some areas, such as around a manure pit, not only need signage but also a fence around it to keep animal and people from falling in. Personnel operating the digester must be trained. Common sense, following established safety protocols and utilizing protective equipment can help mitigate dangerous working conditions.

A Digester Hazard Self-Assessment Tool for Farmers

Nellie J. Brown, director of workplace health and safety programs in the Cornell University School of Industrial and Labor Relations, has developed an excellent self-assessment tool for use by individuals on farms with responsibility for the operation and/or maintenance of anaerobic digesters and their related processes. It provides guidance for process and job evaluation with suggestions based on typical potential hazards for farm digester systems and their associated preventive measures. The self-assessment tool, entitled Conducting a Safety Walk-through on a Farm: Hazards of the Manure Handling System, Anaerobic Digester, and Biogas Handling System (A Self-Assessment Guideline for Farmers) can be found at http://digitalcommons.ilr.cornell.edu/manuals/13/. It is strongly recommended that all farms with digesters complete this assessment.

Conclusions

Anaerobic digester systems have a very good safety record around the world. However, there are potential risks and hazards for humans, animals and the environment inherent in digester operation. Improper training on confined space entry is a leading cause of accidents related to anaerobic digestion systems. Following safety precautions and measures aid in avoiding risk and hazardous situations that can lead to injury and death. All individuals with digester operation and/or maintenance responsibilities should complete the self-assessment tool. This tool provides guidance for process and job evaluation and has suggestions based on typical potential hazards for farm digester systems and their associated preventive measures.

Self Test Questions

1. Asphyxiation, explosion, burns, electrical shock and falls are human health risks associated with working around an anaerobic digester and associated equipment.
   - a. True
   - b. False
2. ____________ is an inflammable, colorless, highly poisonous gas.
   - a. Sodium chloride
   - b. Copper sulfate
   - c. Hydrogen sulfide
   - d. Carbon dioxide
3. Hydrogen sulfide inhibits __________ transport in the blood, changing the red blood pigment to a brown or olive color.
   - a. Calcium
   - b. Oxygen
   - c. Sodium
   - d. Iron
4. Hydrogen sulfide has the characteristic odor of __________.
   - a. Vinegar
   - b. Sour milk
   - c. Rose petals
   - d. Rotten eggs
5. Exposure to low concentrations of hydrogen sulfide causes:
   - a. Irritation of the mucous membranes (including the eyes)
   - b. Nausea, vomiting and difficulty in breathing
   - c. Cyanosis (discoloration of the skin)
   - d. Delirium and cramps, then respiratory paralysis and cardiac arrest
   - e. All of the above
6. Improper training on confined space entry is a leading cause of accidents related to anaerobic digestion systems.
   - a. True
   - b. False
7. When entering a confined area, it is not necessary to have another person observing outside the confined area.
   - a. True
   - b. False
8. _____________, the major component of biogas, is odorless, colorless, and difficult to detect. It is highly explosive if allowed to come into contact with atmospheric air. It is lighter than air and can collect at the top of confined areas.
   - a. Hydrogen sulfide
   - b. Hydrogen peroxide
   - c. Methane
   - d. Sulfur dioxide
9. Clear warnings must be placed in the respective parts of the facility. Examples include:
   - a. Fences around pits
   - b. Signs
   - c. Both a and b
   - d. Equipment operation training
10. The self-assessment tool provides guidance for process and job evaluation with sugges-tions based on typical potential hazards for farm digester systems and their associated preven-tive measures.
    - a. True
    - b. False

Key

1. A
2. C
3. B
4. D
5. E
6. A
7. B
8. C
9. C
10. A

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