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Biomethane Production Technology

Jactone Arogo Ogejo, Extension Specialist, Biological Systems Engineering, Virginia Tech
John Ignosh, Extension Specialist, Biological Systems Engineering, Virginia Tech
Eric Bendfeldt, Extension Specialist, School of Plant and Environemental Sciences, Virginia Tech

Purpose

This publication provides a general overview of anaerobic digestion and the current status of biomethane technology on livestock farms in the United States. Most of the discussion uses dairy manure as an example of feedstock for an anaerobic digester. Resources which provide more detailed information on anaerobic digesters are listed.

Biogas Technology

Biomethane (biogas) is an alternative and renewable energy source produced through the anaerobic (oxygen free) digestion of organic matter whereby the organic matter is converted into a combustible biogas rich in methane (CH_4) and a liquid effluent (Figure 1). In general, biogas consists of 55 percent to 80 percent methane and 20 percent to 45 percent carbon dioxide (CO_2). However, depending on the source of the organic matter and the management of the anaerobic digestion process, small amounts of other gases such as ammonia (NH_3), hydrogen sulfide (H_2S), and water vapor (H_2O) may be present. It is the methane component of the biogas that will burn or produce energy. The gas can be used to generate heat or electricity or both. It can be burned in a conventional gas boiler to produce heat for nearby buildings or to heat the digester, or used in a gas engine to produce electricity. As the organic material (feedstock) is added to the system, the digested effluent is pumped from the digester. The effluent can be stored in a tank and later applied to the land at an appropriate time as a fertilizer without further treatment. Or, the effluent can be separated into solids (fiber) and liquids. The solids can be composted prior to sale for use as a compost or animal bedding. The liquid still contains nutrient that can be sold or used on the farm as a liquid fertilizer as part of a crop nutrient management plan.

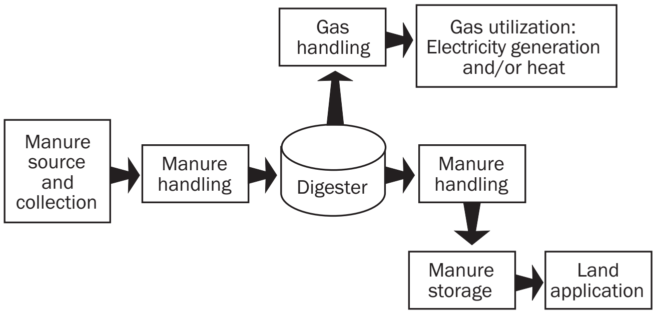

Figure 1. Basic material flow in an anaerobic digestion system.

Sources of organic matter that have been used to produce biogas include animal manure, sewage sludge, municipal solid waste, food-processing wastes, and industrial wastes.

A typical biogas system consists of manure collection, anaerobic digestion, storage for digester effluent, and gas handling and gas use equipment (Figure 2).

Anaerobic digesters have been used successfully in municipal and industrial wastewater treatment plants and on a number of livestock farms for many years. However, the use of anaerobic digestion technology on livestock farms in the U.S. for manure treatment and energy production has increased over the past few years. According to the EPA AgStar program, some of the factors influencing the increased demand for anaerobic digesters are increasing technical reliability of anaerobic digesters through the deployment of successful operating systems; growing concern of farm owners about environmental quality; increasing num-

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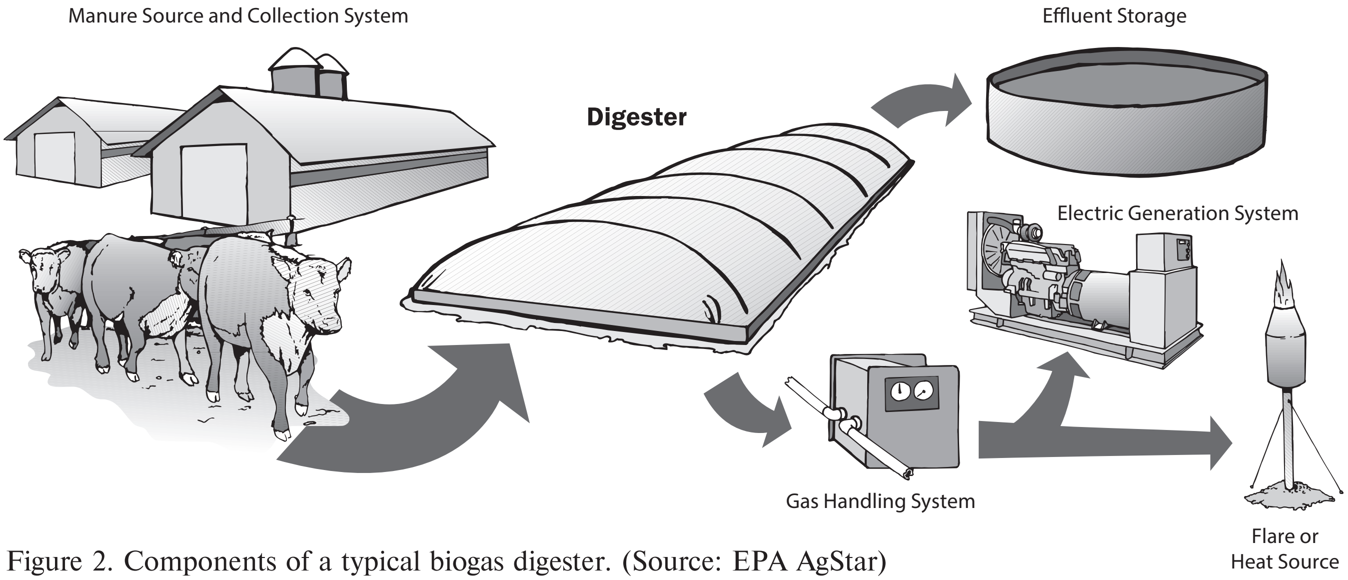


Figure 2. Components of a typical biogas digester. (Source: EPA AgStar)

bers of state and federal programs designed to share costs in the development of these systems; spiraling energy costs; the need for energy security; and emerging new energy policies (federal and state) designed to expand growth of reliable renewable energy and green power markets.

Properties of Methane

Pure methane is an odorless gas made up of one atom of carbon and four atoms of hydrogen. It occurs naturally as a component of "natural gas" and is lighter than air and highly flammable. Methane can form mixtures with air that are explosive at concentrations of 5 percent to 15 percent. Methane is not toxic, but it can cause death due to asphyxiation by displacing oxygen in confined environments or spaces. The heating value of pure methane gas is 1,000 BTU per cubic foot. Additionally, methane is considered to be a powerful greenhouse gas that can remain in the atmosphere for up to 15 years, and is about 20 times more effective in trapping heat in Earth's atmosphere than carbon dioxide (EPA AgStar 2006).

Benefits and Challenges of Biogas Technology

Anaerobic digestion can convert organic wastes into profitable byproducts as well as reduce their environmental pollution potential. Anaerobic digestion offers the following benefits to an animal feeding operation and the surrounding communities:

- Electric and thermal energy.
- Stable liquid fertilizer and high-quality solids for soil amendment.
- Odor reduction.
- Reduced groundwater and surface water contamination potential.
- Potential revenue from sales of digested manure (liquid and solids) and excess electricity and/or processing off-site organic waste.
- Reduction of greenhouse gas emissions; methane is captured and used as a fuel.
- Revenue from possible reuse of digested solids as livestock bedding.
- Potential revenue from green energy and carbon credits.

The cost of installing an anaerobic digester depends on the type and size of system, type of livestock operation, and site-specific conditions (EPA AgStar, 2006). In general, consider the following points when estimating installation/operating costs:

- Estimate the cost of constructing the system.
- Estimate the labor and cost of operating the system.
- Estimate the quantity of gas produced.
- Estimate the value of the gas produced.
- Compare operation costs to benefits from

operation (include value as a waste-treatment system and the fertilizer value of the sludge and supernatant).

The main financial obligations associated with building an anaerobic digester include capital (equipment and construction and associated site work), project development (technical, legal, and planning consultants; financing; utilities connection; and licensing), operation and maintenance, and training costs.

In making a decision to install a digester, one must realize that the system will require continuous monitoring and routine maintenance and repair that should not be underestimated. Components should be maintained as recommended by the manufacturers because manure and biogas can be corrosive on metal parts. In fact, the majority of digester failures over the past few decades were the result of management, not technological, problems.

Potential problems with an anaerobic digester

All the problems of an anaerobic digester can be minimized or removed completely with a good design and proper operation and management. Anaerobic digester projects have significant capital and operating costs and, therefore, may not be financially viable. Potential emissions of gas and the release of digester effluent to the environment, traffic movement, noise, health and safety, as well as visual impact are some of the potential problems associated with anaerobic digesters.

Types of Digester Facilities

Digester facility types differ in size, location, feedstock, and process used. Three common facility types are on-site, centralized, and co-digestion plants. On-site digestion technology can be used by single farms or a co-operative enterprise (among several farms); centralized systems are used to process organic waste supplied from various sources within a geographical area. Co-digestion involves use of animal manure with other organic wastes. Co-digestion has the primary advantage of enhancing biogas yield per cubic foot of reactor, more efficient digestion of certain organic material, and can help achieve better nitrogen, phosphorus, and potassium ratios. Facilities or operations that produce electricity can sell excess electricity through the local electrical grid. Details concerning the distribution of excess power through the electrical grid vary considerably among regions, utility providers, and with changing regulations.

Methane Production by Anaerobic Digestion

Anaerobic digestion involves several different types of bacteria working together to break down complex organic material in stages to produce biogas (Figure 3). Step 1 is hydrolysis, which involves bacteria that can convert insoluble carbohydrates, proteins, and fats into simple sugars, fatty acids, amino acids, and peptides. Step 2 is a fermentation process where acid-forming bacteria, also known as acidogens, convert the products of hydrolysis into simple organic acids, alcohols, carbon dioxide, and hydrogen gas. Volatile acids longer than two carbons are converted to acetate and hydrogen gas by acetogenic bacteria that only produce hydrogen. Finally, Step 3, methane-forming bacteria (methanogens) produce biogas from acetic acid or hydrogen and carbon dioxide.

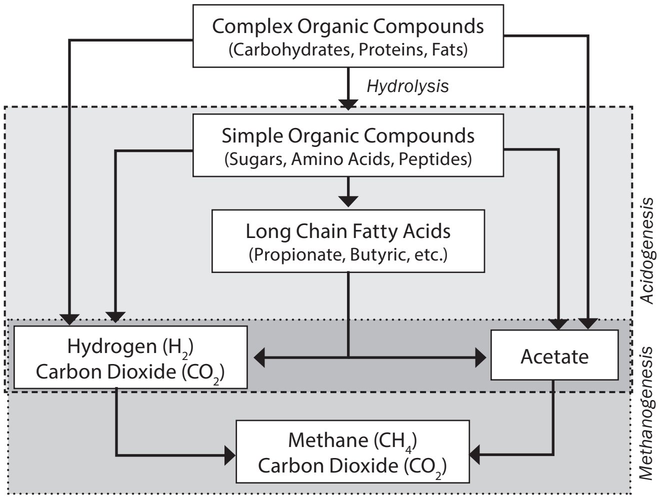


Figure 3. Steps involved in the breakdown of organic materials to produce biogas.

The acid-forming bacteria can reproduce rapidly and are not very sensitive to changes in their environment compared to methane-forming bacteria. Methane-forming bacteria reproduce more slowly and are much more sensitive to environmental conditions. They will cease activity or die when conditions in the digester are not right. When the methane-forming bacteria die, the acid-formers may continue to grow and produce high concentrations of volatile acids, leading to a decrease in the pH of the digester contents, resulting in what is commonly known as digester failure.

Although anaerobic digestion is a natural process, managing the digester to obtain the proper breakdown of organic matter and yield the maximum amount of biogas can be complex. The digester requires careful management to maintain optimal temperature, water content, acidity (pH), and feedstock composition and volumes. Additionally, it is critical to address any toxic elements that may be inherent to a particular feedstock or that are produced through the anaerobic digestion process.

Factors Influencing Biogas Production from Manure

Bacteria must have suitable food and environment in order to grow and develop. The factors that influence the quantity and quality of biogas production include: manure quality, temperature, retention time, composition, loading, and toxicity.

Quality and characteristics of manure

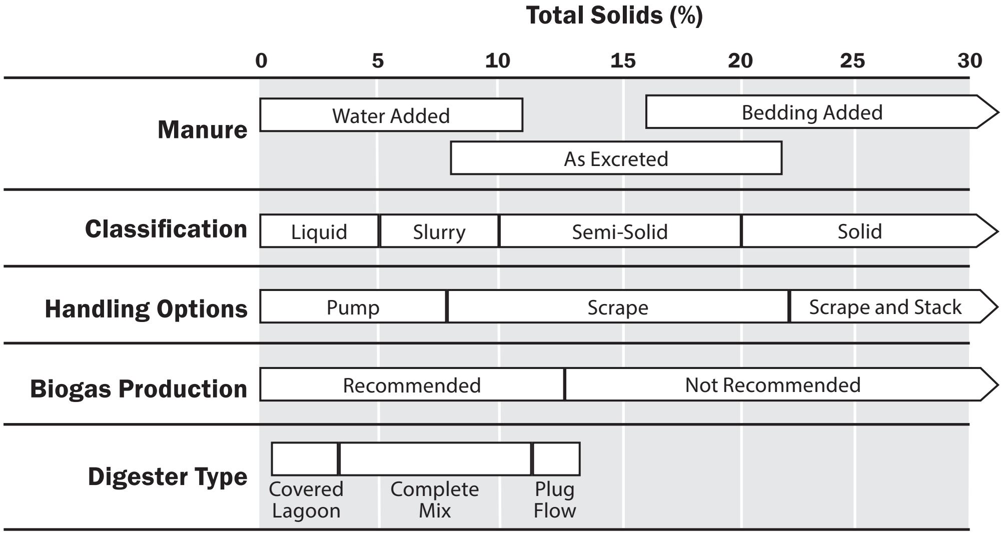
Anaerobic digestion is applicable to manure that is collected fresh or generally less than seven days old. Ideally, manure should be free of soil, sand, stones, and fibrous bedding material. The quality of the manure is affected by animal diet, manure handling, and storage method. Manure from animals fed with higher energy feed (e.g. grain-based diets) has the potential to yield more methane gas compared to manure from animals fed a roughage diet. Materials with high cellulose do not digest well. In fact, materials with high cellulose content act as filler and reduce the capacity of the digester to produce gas. Materials that float to the top of the digester or sink to the bottom of the digester are undesirable. Floating materials form scum, and those that sink may clog the bottom of the reactor. In short, materials that are highly degradable produce more biogas.

Manure and water are the major ingredients of digester feed. The amount of water added to the digester is controlled by the solids content of the manure and the type of digester used (Figure 4). High solids-content manure requires more dilution. The quality and age of manure also matters. Old manure will not produce as much gas as fresh manure. Manure exposed to the air will dry out and may lose fertilizer value, especially nitrogen, due to the volatilization of ammonia.

Digester temperature

Bacteria can form methane gas at temperature ranges of 40° to 167°F. In general, methane production increases with increasing temperature. The three temperature regimes used in anaerobic digesters are psychrophilic, mesophilic, and thermophilic with optimum temperature ranges for the growth of methane-forming bacteria of 41° to 77°F, 86° to 104°F, and 122° to 144°F, respectively. Different bacteria dominate at different temperatures. Imbalances between different bacteria groups may develop, causing methane production to be reduced and other gases to be given off. The bacteria give up heat from respiration as they work. However, this heat is usually not adequate to keep the liquid warm, and supplemental heat has to be added. Uniform temperature is desired throughout the digester and should be maintained to prevent localized zones of depressed temperature and undesired bacterial activ-

Figure 4. Appropriate manure characteristics and handling systems for specific types of biogas digester systems. (Source: AgStar – Managing manure with biogas recovery systems)



ity. Temperature fluctuations in the digester will affect the activity of the methane-forming bacteria.

Retention time

The number of days the organic material stays in the digester is called the retention time. There are two significant retention times in an anaerobic digester: solids retention time (SRT) and hydraulic retention time (HRT). The SRT is the average time the bacteria (solids) are in the anaerobic digester. The HRT is the time the liquid is in the anaerobic digester. SRT is the more important retention time, and should be determined correctly because it indicates the potential of bacteria washout. If a significant washout of bacteria occurs, the digester can fail.

The advantages of high SRT values in anaerobic digesters include maximizing the gas recovery capacity and the buffering capacity to protect against the effects of shock loadings and toxic compounds in feedstock, as well as permitting the bacteria to acclimate to toxic compounds.

Alkalinity and pH

Alkalinity serves as a buffer that prevents rapid change in pH. Maintaining an acceptable pH in the digester is important for the system to work well. Acid-forming bacteria prefer a pH above 5.0 and methane-forming bacteria prefer a pH above 6.2. Most anaerobic bacteria will perform well in the pH range of 6.8 to 7.2. The pH of the digester will decrease initially when organic material is first loaded into the digester and volatile acids are produced. However, as the methane-producing bacteria consume the acids, alkalinity is produced and the pH of the digester will increase and then stabilize. Note that the initial acid production may drop pH to 6.0 or lower, accompanied by high production of carbon dioxide (CO_2). In a properly operating anaerobic digester, a pH of 6.8 to 7.2 occurs as volatile acids are converted to methane and carbon dioxide. Digester stability is enhanced by alkalinity concentration.

An acceptable pH, by itself, does not provide assurance that the digester will work properly. In the event that rapid production of excess acids occurs through the slug loading of a waste (e.g., loading of large volumes of material in one single batch), the methane-formers may not reproduce fast enough to utilize the volatile acids being produced. Rapid changes in pH can be moderated if the digester liquid contains enough buffering capacity. Once the system has become well buffered, it should be possible to add the organic material for which it was designed on a regular basis with good results.

Loading rate

The ability of a digester to convert organic material into methane is related to its loading rate. Loading rate is commonly defined as the amount of volatile solids fed to the digester per day per unit volume of the digester. Volatile solids are a measure of the amount of digestible organic material in a feedstock. Table 1 shows the characteristics of dairy, beef, swine, and poultry manure as excreted and the probable biogas yield per pound of volatile solids fed to the digester. In general, materials with high volatile-matter content produce more biogas if digested properly.

Table 1. Characteristics of manure production and methane production potential from different animal species. (Source: ASABE Standard D384.2 Manure production characteristics; NCSU EBAE 071-80)

	Animal Type				
Parameter	**Dairy (lactating)**	**Poultry (Broiler)**	**Turkey (Males)**	**Swine (Grow-Finish)**	**Beef (Finishing Cattle)**
Total manure and urine (gal/day-animal)	18	0.027	0.073	1.25	7.82
Total solids content (lbs/day-animal)	20	0.058	0.150	1	5.10
Total volatile solids (lbs/day-animal)	17	0.044	0.120	0.825	4.18
Moisture content (% wet basis)	87	74	74	90	92
Retention time, days	15	22.5	-	20	12.5
Probable volatile solids destruction (%)	35	60	-	50	45
Biogas yield per lb volatile solids destroyed, ft^3/lb	11	13	-	12	13
Biogas yield per animal per day (ft^3)	66	0.34	-	5	24

Toxicity

Substances that inhibit microbial activity should be kept out of the digester. Digesters treating municipal wastewater have failed on occasion because of the presence of copper, zinc, chromium, and nickel. High concentrations of alkali metals like magnesium, calcium, sodium, and potassium can be toxic to anaerobic bacteria. The digestion of livestock waste containing high nitrogen to carbon ratios is more likely to result in toxic conditions for bacteria arising from the concentration of free ammonia.

Anaerobic Digester Configurations

Anaerobic digesters are engineered containment vessels designed to exclude air and promote the growth of methane bacteria. Several different types of anaerobic digesters are used worldwide for municipal, industrial-food, and agricultural waste treatment. The digester may be a tank, a covered lagoon, or a more complex design, e.g., a tank provided with internal baffles or with surfaces for attached bacterial growth.

This section will focus only on digesters currently used to generate biogas from animal manure. Some common anaerobic digester configurations used on farms include covered lagoons and complete-mix, plug-flow, and fixed-film digesters. Manure total solids and collection technique determine the type of anaerobic technology to use (Figure 4). A summary of the characteristics of digesters commonly used on livestock farms is provided in Table 2.

Covered lagoon

An anaerobic lagoon is a biological treatment system designed to break down the organic matter in animal wastes to more stable end products. Lagoons generally are constructed by excavating and building an embankment or a berm around the top edge. Anaerobic lagoons are typically covered with synthetic fabric to facilitate capturing biogas (Figure 5). This system works best with flush manure systems of less than three percent solids (Figure 4). Covered lagoons function like mixed reactors, but are not heated and work under ambient temperatures. The production of methane will vary with temperatures and may cease entirely without supplemental heating in colder regions. Depending on the design parameters, sometimes, it may be necessary to separate the coarse solids from manure before feeding to the digester. Covered lagoon digesters operating at ambient temperatures for energy recovery work well in moderate to warm climates, generally located below the 40th parallel in the U.S. (Figure 6).

Figure 5. Covered lagoon. (Source: Jay Cheng, North Carolina State University)

Table 2. Summary characteristics of digester technologies. (Source: EPA AgStar Handbook)

Characteristic	Digester Type			
	Covered Lagoon	**Complete Mix**	**Plug Flow**	**Fixed Film**
Digestion Vessel	**Deep Lagoon**	**Round/Square In-/ Aboveground**	**Rectangular Inground Tank**	**Aboveground Tank**
Level of technology	Low	Medium	Low	Medium
Supplemental heat	No	Yes	Yes	No
Total solids	0.5 to 3%	3 to 10%	11 to 13%	3%
Solids characteristics	Fine	Coarse	Coarse	Very Fine
Hydraulic retention time (days)	40 to 60	15 +	15 +	2 to 3
Farm type	Dairy, Hog	Dairy, Hog	Dairy Only	Dairy, Hog
Optimum location	Temperate and Warm Climates	All Climates	All Climates	Temperate and Warm Climates

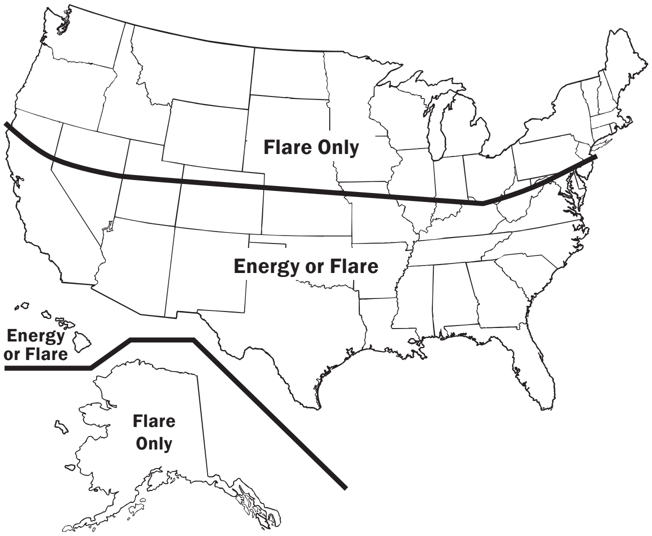


Figure 6. Locations suitable for biogas production using covered anaerobic lagoons. (NRCS 2005)

Depending on how manure is handled in the barns, it may be necessary to separate solids before it is introduced into the lagoon. A two-cell lagoon system (Figure 7) is preferred with the primary cell being the anaerobic digester and the secondary cell the storage for effluent from the digester. Covered lagoons require large land areas, gas-tight covers, and careful sealing to prevent nutrients from leaching into the groundwater.

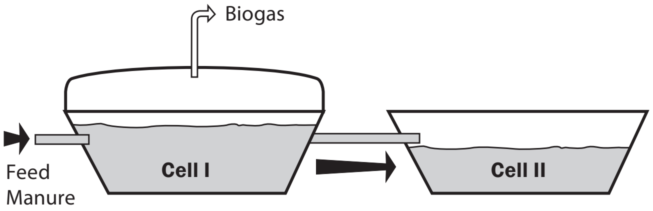


Figure 7. Schematic of a two-cell lagoon system. Cell I is covered for biogas production and Cell II is for effluent storage.

Complete-mix digester

A complete-mix digester is a controlled-temperature, constant-volume, mechanically mixed unit (Figure 8) designed to process slurry manure with a solids concentration of from 2 percent to 10 percent (Figure 4). The digester contents should be continuously or intermittently mixed to prevent separation. Therefore, an appropriate mixing device should be provided to assure a complete mixing process. A complete-mix digester can be an above- or in-ground tank that is circular, square, or rectangular in shape. The digester should be heated and insulated. The digester should be covered with a gas-tight cover to collect and direct gas to the gas utilization system. This system generally is considered to be the most robust in terms of the variety of manures that can be processed. A supplemental effluent storage usually is required.

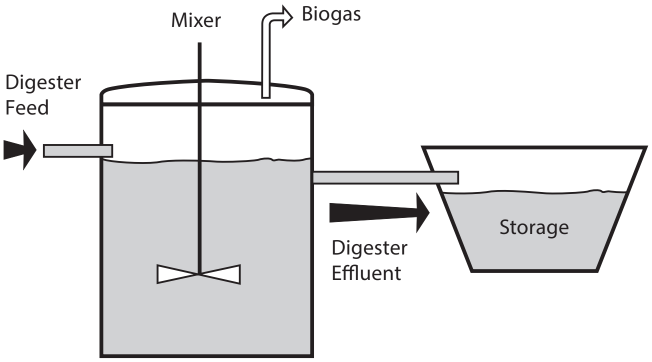


Figure 8. Schematic of a complete-mix reactor.

Plug-flow digester

A typical plug-flow digester design consists of a covered reactor where the material to be digested enters at one end of the reactor and exits at the opposite end (Figure 9). Manure is added daily to one end of the digester and an equal volume of digested manure is forced out at the other end. Plug-flow digesters work best for dairy manure with 11 percent to 14 percent total solids (Figure 4). Plug-flow systems are subject to stratification; heavier materials settle to the bottom while the lighter materials float to the surface. In general, a horizontal plug-flow digester's length to width ratio is between 3.5:1 and 5:1. The ratio of the flow-path width to fluid depth should be less than 2.5:1.

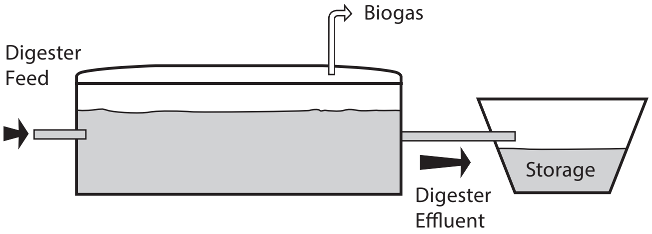


Figure 9. Schematic of a typical plug-flow digester system.

Fixed-film digester

These units contain a plastic packing that serves as a structure on which bacteria attach, grow, and create a biofilm (Figure 10). They are designed to treat manure with less than 3 percent total solids (Figure 4), usually, systems where manure is subjected to dilution water for transport or processing. The biofilm serves as a medium to encourage and keep the methane-generating bacteria in the system while processing a high volume of liquid manure. Fixed-film digesters are a relatively new design, and as a result fewer farms are currently using these systems.

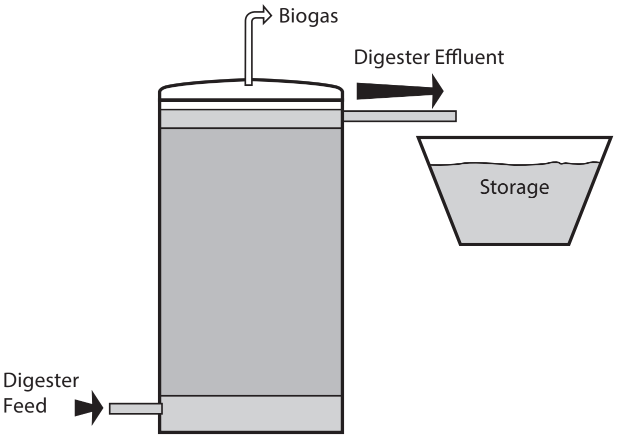


Figure 10. A typical fixed-film digester showing the media on which bacteria grow.

The fixed-film systems have a much smaller retention time than the other digester types, typically two to five days, depending on the biodegradability of material to be digested. No agitator is needed in the tank, so there are fewer moving parts, and there is less chance that the bacteria will be washed out of the digester.

Products of Anaerobic Digestion and Their Use

A properly operating digester will convert most of the volatile solids into biogas. The remaining volatile solids and other solids that are not biodegradable become part of the supernatant liquid and sludge in the digester. There is very little volume reduction of the feedstock in an anaerobic digester. Although the digested material will be more stable with a relatively non-offensive odor, it will still contain most of the original nutrients such as nitrogen, phosphorous, and potassium. Storage and handling facilities similar to those used in manure management are still required to handle the effluent. The nitrogen in the digester effluent will be in a more readily available form, so the digester sludge and liquid are excellent fertilizers.

Biogas utilization

Gas utilization equipment should be designed and installed according to the standard engineering practice and manufacturers' recommendations. As a minimum, the biogas digester should include a flare to burn off the collected gas. Biogas may be burned for space heating, drying, cooking, or water heating. It can also be used to fuel an engine generator to produce both heat and electricity. Converting biogas to electrical energy is convenient, but it requires additional management and capital expense. In some instances, biogas has been further refined or processed to produce a transportation fuel. A comparison of biogas containing about 60 percent methane with other heating-fuel sources is provided in Table 3. Biogas has a lower energy density than the comparable fuels. Natural gas and liquefied petroleum gas (LPG) appliances will run on biogas without modification, but their heat output will be reduced to about half that of natural gas and about one-third that of LPG.

Biogas storage

On most livestock farms, biogas generally is used to produce both heat and electricity. The biogas is usually used soon after generation without storage. However, should gas storage be necessary to balance the mismatch between gas production and its use, some primary gas storage options include:

- The space between the manure and the flexible top cover of the digester. The cover will deflate as the gas is used, so the digester will need to be sheltered to some degree to protect its cover from wind damage.

- Low-, medium-, or high-pressure containers. By doubling the pressure of the gas, the volume can be cut in half. However, fabrication of high-pressure storage containers requires skills and fabrication equipment not usually available to most farmers. Pressurization equipment may consume as much energy as is contained in the gas being stored. Low-pressure storage generally will be the most practical alternative. Old water tanks or other salvaged containers should not be used; a weak tank at high pressure can be dangerous. It is important to ensure that the storage tank is safe at the pressure being used.

- If the gas is used as it is generated (no storage), any excess should be flared off.

Biogas cleaning

In addition to the relatively large amount of methane gas produced in anaerobic digesters, there is a small percentage of hydrogen sulfide, water vapor, carbon dioxide, and other gases. Hydrogen sulfide is highly corrosive, corroding the digester, gas pipes, gas storage, and gas burner or engine. Removing hydrogen sulfide is desirable for biogas used in engines or piped long distances. Scrubbing the biogas with iron-impregnated wood chips has been used in anaerobic digesters in municipal waste treatment plants to remove hydrogen sulfide in the gas line.

Removing water vapor may also be necessary to prevent condensation that fouls the burners and other control devices in biogas utilization. Water will increase the rate of corrosive attack on metals. Water traps or water absorption media such as calcium chloride or organic absorbents can be installed in the line before the point of biogas utilization. Additionally, it may be necessary to remove carbon dioxide if the gas is to be sold commercially.

Biogas meters

A standard gas meter can be used to measure the quantity of gas produced, provided all the water has first been removed.

Safety

Biomethane production from animal manures presents potential for hazardous gases , such as hydrogen sulfide and ammonia to be produced in larger quantities than normal, therefore, safety is of paramount importance. The digester should be located away from farm buildings. As mentioned earlier, methane can cause explosions even at concentrations as low as 5 percent to 15 percent in air. It is desirable to install a gas detector (to monitor either the level of oxygen or methane in the room or space) and alarm devices in buildings with potential explosion hazards. Apart from being explosive, methane can displace the oxygen in a confined space and may result in injuries or even death due to asphyxiation. Fire traps should be placed in the gas line between the digester and the gas storage system. Discuss detailed safety concerns specific to your unit and develop a comprehensive response and management plan to the hazard with the consultant or engineer designing the digester.

Biogas and Your Farm

A list of 100+ questions to ask when considering an on-farm anaerobic digester operation has been published for dairy farmers by the Dairy Practices Council (Weeks et al. 2007). Although this publication is specific to dairy operations, the content is applicable for other facilities with feedstock suitable for biomethane production. Consider the following factors to determine if a biogas recovery system is the best choice for your farm.

Quantity and quality of manure

The aim of managing the quantity and quality of the feedstock for the digester is to maximize biogas production to get the most economic and environmental benefits from the feedstock. Do you have enough manure or other organic material to feed the digester all year round? A digester will require a stable supply of manure. How old is the manure or how much volatile organic matter is in the feedstock? Old manure or feedstock may have undergone some degradation and therefore lost some of its biogas production potential. Anaerobic digesters work best when the digestion process is stable and the feed is consistent.

Manure handling and collection frequency

Biogas digester systems can accommodate a wide variety of manure handled as a liquid, slurry, or semisolid (i.e. with little or no bedding added). The total solids content of the manure (a measure of manure thickness) determines these classifications. Figure 4 shows the manure total solids and handling systems that are appropriate for specific types of biogas digester systems. Systems that handle manure as a slurry are better suited for biogas production. As the manure solids content increases, the manure will need to be dil**uted before being used in anaerobic digeste**rs. There are ongoing studies on systems that produce biogas from high solids content feedstock. Dairies using sand for bedding may not be suitable for anaerobic digestion because of challenges associated with manure handling and equipment maintenance. Farms best suited for biogas digester systems typically have stable year-round manure production, and collect at least 50 percent of the manure daily.

Biogas use

Several gas-use options are available, including engines, chillers, and boilers, or gas can simply be flared. When choosing a use for the gas produced, consider economics, the labor requirements associated with the option, and the skills needed to maintain and repair energy producing equipment.

System Management and Economics

Are you or the digester operator mechanically inclined? The operator will need to dedicate some time every day for system maintenance. In addition, the digester will require a long-term financial commitment.

Summary

Technology currently exists to enable individuals to adopt and install methane generation systems for on-farm processing of livestock manure and organic materials. However, an anaerobic digester is sensitive to the specific operating conditions and management of individual farms. Therefore, an on-farm, site-specific economic feasibility analysis is always necessary. As other forms of energy become increasingly expensive, private businesses and innovative farmers are developing and operating reliable systems for on-farm methane generation as an alternative and renewable energy source. The US EPA Agstar program (https://www.epa.gov/agstar) keeps a database of the current status of digesters on farms in the US and other useful information and resources about digesters. A list of some references is provided below for the reader interested in further study of anaerobic digesters.

Glossary

Acetogenic bacteria: single-cell organisms that generate acetate as a product of anaerobic respiration.

Anaerobic digestion: the process by which biological material is broken down by bacteria in the absence of oxygen.

Biochemical reaction: a chemical change that occurs inside a living cell.

Biodegradable volatile solids: the fraction of volatile solids that can be degraded by bacteria.

Biogas: the gas produced by anaerobic bacteria in the anaerobic digestion process. It is composed primarily of methane and carbon dioxide, with low levels of other gases such as ammonia, hydrogen sulfide, hydrogen, and water vapor.

BTU: British Thermal Units: one BTU is the amount of heat required to raise one pound (one pint) of water by 1ºF.

Effluent: the liquid end product of a treatment process.

Flare: a device for burning off excess biogas without recovery of heat or any other form of energy.

Greenhouse gas: a gas that traps heat in the atmosphere.

Hydraulic retention time: the average length of time the liquid manure remains in the digester.

Hydrolysis: the biochemical process of decomposition involving the splitting of a chemical bond and the addition of water.

Solids retention time: the average amount of time that a solid particle of manure remains in the digester.

Total solids: the amount of dry solids or dry matter in a material.

Volatile solids: the organic or carbon containing fraction of total solids.

Washout: process that reduces the concentration of bacteria in a digester to levels that cannot sustain the desired reactions or activities.

Resources and Selected Material for Further Reading

Barker, James C. 2001 "Methane Fuel Gas from Livestock Wastes: A Summary" EBAE 071-80

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