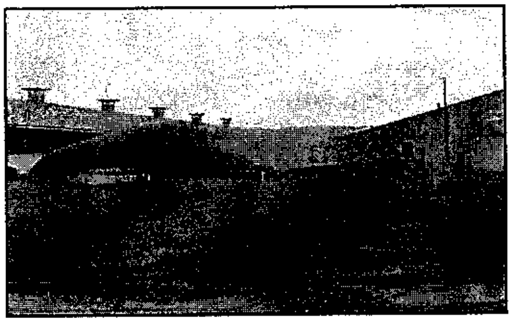

Figure 5.7: Photograph of plug-flow anaerobic reactor (P. Wright, 2001).

A pre-heat chamber is recommended for plug-flow reactors located in cold climates. Fresh manure should be heated to a temperature of 27° C (80° F) before it enters the reactor in order to prevent cold manure from sinking and settling to the floor of the digester. There are three possible configurations for a pre-heat chamber. The first is to partition the plug-flow reactor into two sections by an internal wall. The manure enters the first section, thoroughly warmed, and moved to the digester section. The second configuration is to position a separate chamber directly adjacent to the opening of the reactor. The third design is to have a heated **hopper** at the barn to heat the manure. Heated hoppers are only efficient if the distance from the barn to the digester is very short to minimize heat loss.

Plug-flow reactors contain few moving parts. This decreases the maintenance requirements, but periodic cleaning is required. The digester must be shut down during cleaning, which can be costly.

5.5.4 Lagoon

There are two basic forms of anaerobic lagoons—the ambient temperature lagoon and the heated mixed lagoon.

a. Ambient Temperature Lagoon

Ambient temperature anaerobic lagoons are the least expensive anaerobic digester design. **Figure 5.8** is a diagram of an anaerobic lagoon. Anaerobic lagoons are large ponds dug into the earth so that the lagoon operates at ground temperature. This temperature most often falls into the psychrophilic range. The reaction rate may be affected both by low temperature and by seasonal temperature fluctuations, therefore so this type of digester is recommended for temperate climates only. In the US, the most successful ambient anaerobic lagoons tend to be located south of the Mason-Dixon Line (Moser, 2003).

Because anaerobic lagoons can process liquid manures with less than two percent solids (Frame et al., 2001), This digester type is suitable for flushed dairy or swine manure. The dilute manure can be collected through flush or pull-plug systems for treatment year around. Anaerobic lagoons are not compatible with manures containing high concentrations of sand or silt. When the incoming manure is high in non-**biodegradable** material, solids will accumulate on the lagoon floor, reducing the effective reactor volume.

Hopper: A funnel-shaped receptacle that moves the manure via gravity to storage or treatment units.

Biodegradable: A material that can be broken down by biological processes.

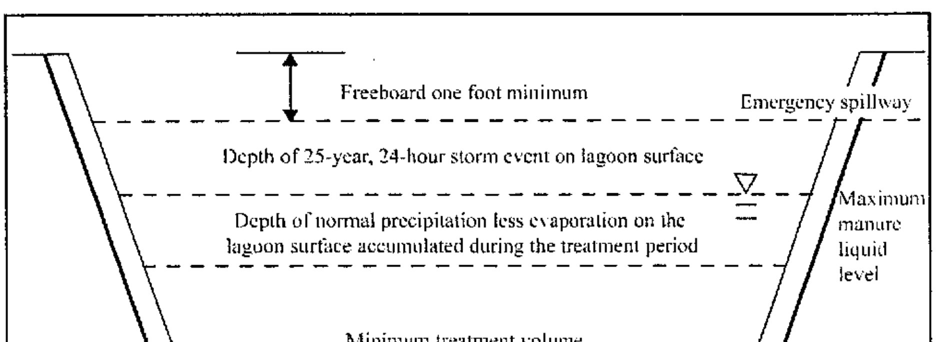

Figure 5.8: Diagram of anaerobic lagoon (United States Department of Agriculture, 1992).

Since anaerobic lagoons are primarily earthen structures, care must be taken to provide a sealed bottom. Compacted clay or plastic liners should be used to prevent the leaching of contaminants to groundwater.

The lagoon cover must be impermeable. The cover must contain the biogas in the lagoon while preventing atmospheric gases from entering the lagoon. Atmospheric gases, including oxygen, will contaminate the biogas and increase the rate of corrosion in the gas collection system. See Chapter 2, Storage Covers for more information on covers. Flexible covers are most often used for lagoons. **Figure 5.9** is a photograph of an anaerobic lagoon.

b. Heated Mixed Lagoon

Heated mixed lagoons are a variation of the typical lagoon design. The ability to mix the lagoon contents allows for manures of three to six percent solids to be treated and for shorter HRTs than for ambient lagoons. They are smaller than ambient temperature lagoons but offer the same level of treatment with a steadier biogas production. However, a heated mixed lagoon is more expensive to construct than an ambient temperature lagoon. The mixing and heating equipment can be expensive to install and maintain and must not interfere with the ability to sustain an anaerobic environment.

5.6 Biogas Collection and Utilization

Biogas may be a useful byproduct of anaerobic digestion. Methane and carbon dioxide account for approximately 60 and 40 percent of biogas volume respectively (Koelsch et al., 1990). Hydrogen sulfide, a highly corrosive and saturated compound, is also present in biogas at very low levels—0.2 to 0.4 percent by volume (Koelsch et al., 1990).

On-farm biogas production has two practical uses:

1. Replacement of heating fuels by burning biogas in boilers and furnaces, and
2. Cogeneration of electricity and hot water by using biogas as a fuel for an internal combustion engine driving a generator; excess electricity may be sold back to the utility (Koelsch et al., 1990).

While selling the excess energy to the utility offers financial gains, some of the most viable biogas systems consume the biogas themselves. The replacement of farm heating fuels is the simplest use of biogas.

If biogas use is not something a farm wishes to pursue, the biogas must be flared off to prevent explosive situations. All anaerobic digesters require a flare to eliminate biogas produced during start-up and as a back-up to cogeneration.

5.6.1 Biogas Production

Methane generation systems are most appropriate for farms with at least 300 head of livestock where the manure is recoverable, the moisture content of

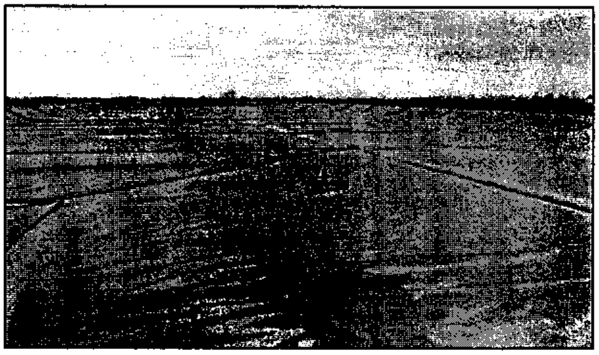

Figure 5.9: Photograph of an anaerobic lagoon (RCM Digesters, Inc., 2004).

the manure is relatively constant, and the bedding is compatible (Frame et al., 2001). The feed ration also plays an important part in biogas production—higher energy diets can double the amount of biogas produced. The HRT and pH of the digester also affect the biogas production rate.

For every 0.45 kilograms (one pound) of volatile solids destroyed during anaerobic digestion, 159 liters (5.6 cubic feet) of methane are produced (Burke, 2001). One thousand **BTUs** of energy are contained in 28.3 liters (one cubic foot) of methane (Burke, 2001). At 35 percent conversion efficiency, 0.45 kilograms (one pound) of volatile solids destroyed produces 0.58 **kWh** of energy.

Five hundred milking cows can produce 850 to 1416 cubic meters (30,000 to 50,000 cubic feet) of biogas per day (Frame et al., 2001), or approximately one kWh for every seven to ten cows (Focus on Energy, 2003). **Table 5.3** shows the amount of biogas production and energy equivalents for several different kinds of animals on a weight basis.

5.6.2 Biogas Storage

Biogas is usually stored for a period in the digester in the space above the manure surface under the cover. Flexible covers will deflate and inflate with biogas production. However, flexible covers should be sheltered to protect the cover from wind damage. Biogas may be conveyed from the digester to rigid tanks or to flexible storage bags, which can store biogas in a low-pressure environment.

Biogas has a lower energy density than common fuels. This makes storing large volumes of biogas difficult. In a rigid tank the biogas may be compressed to a medium pressure, 200 pounds per square inch (Koelsch et al., 1990). However, 130 gallons of biogas, compressed to 200 psi, is only equal to about one gallon of diesel fuel as depicted in **Figure 5.10** (Koelsch et al., 1990). To compress the gas to high pressure, 2000 psi, requires a compressor with a relatively high energy demand (Koelsch et al., 1990). Carbon dioxide and water vapor must be removed from the biogas to achieve high compression. This means that biogas cannot be compressed and stored or transported like traditional fuels. Biogas is best utilized on a continual basis at the site of production.

5.6.3 Biogas Cogeneration

Biogas utilization equipment is very similar to natural gas equipment. Retrofitting natural gas appliances for biogas involves making accommodations for the distinctive properties of biogas. One of these properties is the lower energy density of biogas relative to other common fuels. This requires the use of larger nozzles in heating appliances and carburetors that deliver equal amounts of energy to the point of combustion in engines.

BTU: British Thermal Units; a measure of energy; the amount of heat required to raise the temperature of one pound or one pint of water one degree Fahrenheit. One BTU is roughly equivalent to 1055 Joules or 252 calories.

kWh: Kilowatt-hours, a measure of energy. One kWh is roughly equivalent to 3,600,000 Joules or 3.6 Megajoules.

Table 5.3: Anticipated biogas production for anaerobic digestion of manure from 1000 lbs of livestock and poultry (Miner et al., 2000).

Animal	Biogas Production (ft^3/1000 lb animal)	Heat Value (BTU/day)	Propane Equivalent (gal/day)	Electrical Energy (kWh/day)
Dairy cow	39	20700	0.22	1.21
Beef cow	22	11700	0.13	0.68
Swine	28	16400	0.18	0.96
Poultry (layer)	37	22700	0.25	1.33
Poultry (broiler)	51	30400	0.33	1.78

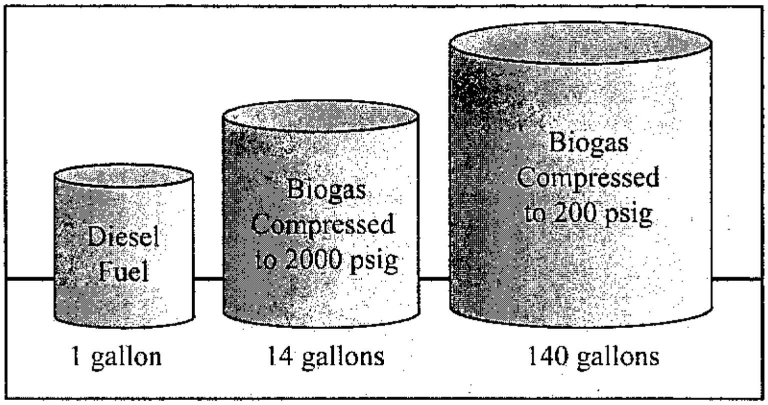

Figure 5.10: Comparison of fuel energy densities (R.K. Koelsch, et al., 1990).

Cogenerators continually operate at a level set by the biogas production rate. This allows for a constant rate of electrical production and eliminates the need for gas storage. A cogenerator should operate in parallel with the utility—it needs to work at the same voltage and frequency. Otherwise, the energy produced by the methane is not compatible with the utility grid.

The cogenerator size should be based on the peak biogas production, usually occurring during the summer time. The expected electrical production should be based on the average biogas production. An improperly sized cogenerator will neither operate efficiently nor optimize potential income. The cogenerator should be located in a well-vented area with easy access for maintenance. The control room should be located in a separate building to minimize the effects of corrosion.

Biogas utilization produces heat. Up to 75 percent of fuel energy in a spark ignition engine is released as waste heat (Koelsch et al., 1990). The heat may be recovered for digester heating and water and space heating on the farm. Heat exchangers, as discussed in Section 5.4.3 d, can accomplish this. A radiator or fan should be available to dump the excess heat as well.

5.7 Anaerobic Digester Operation and Maintenance

The primary reasons that anaerobic digesters fail are bad design, inadequate installation, selection of inferior equipment and materials, and poor operation and maintenance. An anaerobic digester, like any treatment technology, must be engineered specifically for an individual farm operation.

5.7.1 Start-Up

Starting an anaerobic digester for the first time or after a period of shut down requires planning and time. Start-up in warm weather is recommended. The start-up process can be expedited if there is enough manure in storage to entirely fill the reactor at one time; an entire HRT may pass while waiting for the animals to produce enough manure to fill the reactor. Completely filling the reactor with manure will seal all the openings and provide a larger thermal mass. Once the reactor is filled, the manure should be heated to 35° C (95° F) with no further additions of manure (Koelsch et al., 1990). After the reactor has reached operating temperature, the manure feed rate should be increased slowly for the first few days to avoid overwhelming the bacterial population.

No seeding of bacteria or additives are necessary—anaerobic bacteria exist naturally in the manure (Miner et al., 2000). Biogas production is a good indicator of healthy microbial action. Some biogas will be produced around 21° C (70° F) and production will increase steadily to the maximum rate one or two weeks after the reactor reaches or exceeds 35° C (95° F) (Koelsch et al., 1990).

During the initial loading process, a potentially explosive mixture of biogas and air exists. All biogas should be vented for 24 hours after the reactor has been completely sealed with manure (Koelsch et al., 1990). This venting allows for newly formed biogas to displace the air in the reactor.

5.7.2 Maintenance

A regular repair schedule is important to keep the digester running smoothly and to prevent any catastrophic failure. Preventative maintenance may require as little as ten minutes or as much as two hours each day (Koelsch et al., 1990). Major repairs may take ten or more hours (Koelsch et al., 1990). The digester should be emptied for solids removal and repaired every one or two years (Koelsch et al., 1990). The start-up process after maintenance is the same as the initial start-up. The manure from the digester should be retained for seeding the start-up. All digesters should be designed with a way to divert fresh manure from the reactor during maintenance.

The design of the digester should allow for the ability to drain and refill the digester quickly to perform maintenance. A design that minimizes short-circuiting, solids accumulation, and floating solids will be easily maintained. The internal digester components such as the heat exchanger and gas pipes should be placed for easy removal during routine maintenance and solids removal.

Appropriate maintenance also includes preventing ammonia and hydrogen sulfide emissions. Air strippers may be used to control ammonia. An iron sponge filter, wood chips coated with iron oxide, will control hydrogen sulfide.

5.7.3 Safety

Anaerobic digestion produces potentially harmful gases. Methane is explosive. Manure storage and treatment related deaths occur every year. The Occupational Safety and Hazard Association (OSHA) limit for hydrogen sulfide in the workplace is 20 parts per million (ppm) (Koelsch et al., 1990). At 50 ppm, hydrogen sulfide exposure will cause headache, nausea, dizziness, vomiting, confusion, and weakness (Koelsch et al., 1990). Exposure to hydrogen sulfide at 300 ppm is life threatening in 30 minutes (Koelsch et al., 1990). Monitoring both hydrogen sulfide levels and methane levels is extremely important. It is very important that if someone falls into a manure storage chamber or falls ill due to hydrogen sulfide that you call emergency personnel right away. Do not attempt to rescue anyone if you are inadequately trained, as you may endanger yourself.

5.8 Summary

Anaerobic digesters utilize the presence of naturally occurring anaerobic bacteria to convert manure to biogas in an oxygen-free environment. Anaerobic digestion does not alter the nutrient content of the manure, but does stabilize the manure for storage and further treatment. Anaerobic digestion occurs in three steps—liquefaction, acidogenesis, and methanogenesis. There are several types of anaerobic digestion reactors to choose from, depending on the available space, capital, and characteristics of the manure. The biogas produced in anaerobic digestion may be flared off, converted to electricity, or used on the farm or sold to the electric utility. Biogas is highly explosive and should be handled with care.

5.9 A Closer Look At Anaerobic Digestion

The AA Dairy is a family farm established in 1943. Bob Aman, owner and operator, took over the 2200 acre upstate New York farm in 1964 and converted it to a dairy in 1993. The farm is presently milking nearly 600 cows, with plans to expand the milking herd to 1000 cows.

For five years, manure was stored in an underground pit and pumped to slurry trucks every day for spreading. Residents' concerns about odor, truck traffic, and water quality threats prompted the dairy to pursue an alternative treatment technology. Bob installed a plug flow anaerobic digester, solids separator, **(figure 5.11)** and outdoor composting facility in June of 1998.

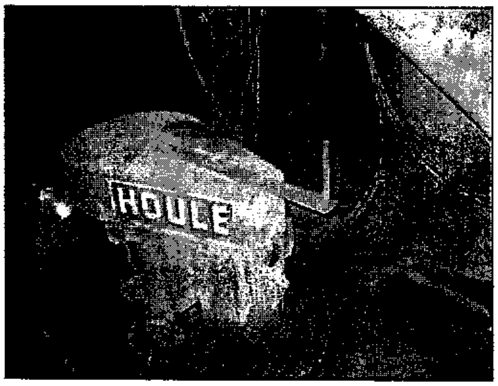

Figure 5.11: Solids separator (J. Robbins, 2004).

The digester **(figure 5.12)** is partially located below grade and is kept at approximately 100° F for optimal biodegradation. The cover is an expandable rubberized dome which expands and deflates with biogas production. Approximately 15,000 gallons of manure is added to the digester each day. The manure is retained in the digester for about 40 days; this is twice the design hydraulic retention time, but the digester is sized for a larger operation to meet the farm's future expansion plans. As more cows are added, the efficiency of the digester unit will increase. After digestion, the slurry is put through a screw press solids separator and the solids are composted outdoors in turned windrows **(figure 5.13)** and marketed as Fields of Dreams Compost. The liquid portion is stored in a lined storage pond and used for fertigation.

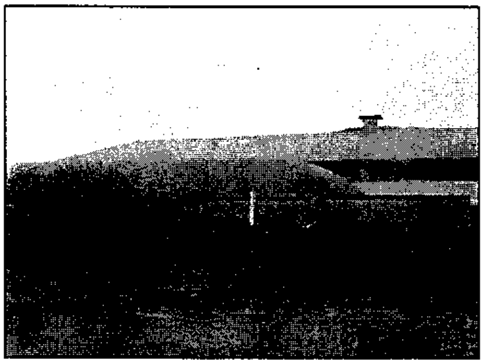

Figure 5.12: Digester (J. Robbins, 2004).

Since the digester has been operational, only the liquid fraction of the digested slurry is land applied, and complaints and concerns from the public have been greatly reduced. Bob Aman hasn't made any modifications to the seven-year old digester. The AA Dairy has used the biogas generated by the digester to create electricity for the farm for six years; any excess is sold to the utility. The farm lacks the infrastructure to use the waste heat from the generator for anything but heating the digester.

Daily maintenance of the treatment system includes monitoring. About 20 minutes per day is spent on preventative maintenance for the digester and an hour and a half on the solids separation and composting. Once a week the cogenerator receives an oil change, and every three years the engine and generator are overhauled. In seven years of operation, the digester has been down for a total of six weeks.

Bob views manure management as a necessity and feels that the biggest obstacle is being a good neighbor and environmental steward while still maintaining a simple system. He acknowledges that anaerobic digestion is expensive, and that the dairy is still feeling the effects from the capital cost of the treatment technology. Bob's advice to others contemplating alternative technologies is to make sure the technology system fits the management and size of the operation.

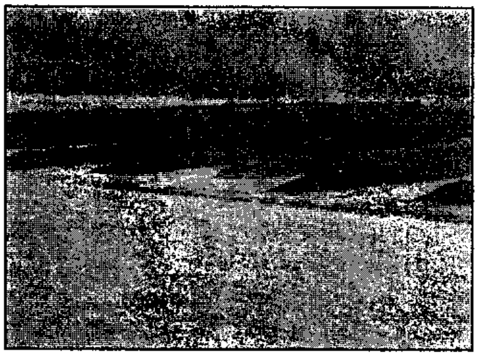

Figure 5.13: Turned windrows (J. Robbins, 2004).

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