ON-FARM
BIOGAS PRODUCTION

COOPERATIVE EXTENSION
Northwest Region Agricultural Engineering Service
AUTHOR

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Acknowledgments: Many people helped gather the information for and review this bulletin. M. Tamoff and E. Fabian gathered much of the information; R. W. Guest, Cornell University, S. P. E. Pearson, Pennsylvania State University, H. L. Brodie, University of Maryland, and members of the NREA committee spent much time reviewing it. S. MacKay illustrated and did the layout, and B. Cox, USDA Extension Service, arranged much of the funding for publication.

The United States Department of Agriculture (USDA) funded the preparation and publication of this bulletin.

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ON-FARM
BIOGAS PRODUCTION

Over the past decade interest has revived in generating biogas, a mixture of methane and carbon dioxide, from animal manures. Many sewage treatment plants generate methane from sludge, but equipment for this is too costly for the expected return on a farm. So researchers at several universities and colleges, consulting firms, construction companies, and farmers have worked to develop less costly systems to generate and use methane from livestock manure.

This manual includes current ideas on digester design and equipment selection for biogas and methane production and use. On-farm digesters are still experimental, so no best plan or design has been developed. This manual does not cover the design of all components and equipment for a digester, but it does detail the sizing and construction of many of them. With this information, operational problems others have encountered can be avoided.

Anaerobic digestion of manure offers several advantages:
- Biogas produced by the process has significant value as fuel.
- Digested residue is an almost odorless, homogeneous slurry.
- The fertilizing nutrients are conserved.
- Rodents and flies are not attracted to the digested residue.
- The free flowing liquid sludge can be dewatered for other uses.

However, anaerobic digestion has some major disadvantages:
- Equipment is large, expensive, and experimental.
- High standards of maintenance and management are required.
- Process is sensitive to temperature, pH, loading rates, and changes in input materials.
- Few cost effective uses have been found for biogas.

In addition:
- Digestion systems will not significantly reduce the volume of manure to handle, although the solids content will be significantly reduced.
- Digested liquid slurry remains a pollutant, even though its pollution potential is less than that of raw manure.
- The anaerobic digestion process produces no heat.

Figure 1. Schematic of Digestion Process
I—The Digestion Process

A digester biologically converts or 'digests' waste and agricultural by-products into biogas—a combination of methane ($\text{CH}_4$) and carbon dioxide ($\text{CO}_2$) gases. Because this process takes place without oxygen, it is called 'anaerobic' or 'digestion'. The residue which remains after digestion contains little volatile organic matter so it has little odor. (Figure 1)

Anaerobic treatment of organic matter occurs in two phases: In the first phase, acid forming bacteria convert fats, proteins, and carbohydrates in the organic material to simple acids — primarily acetic and propionic acids. In the second phase, the organic acids are converted by methane forming bacteria to methane and carbon dioxide. Small amounts of ammonia and hydrogen sulfide are also produced. (Figure 2)

The acid forming bacteria reproduce rapidly and are not sensitive to the environment. The methane formers are extremely sensitive to oxygen, temperature, pH and the manure loading rate. These factors must be controlled so the methane formers are in balance with the acid formers. The most important methane forming bacteria are slow-growing and require acetic and propionic acids. These bacteria require 4 days or more and for this reason may be the growth limiting step of a digester operation. The process does not create or consume a measurable amount of heat.

These bacteria exist naturally in the manure; digesters simply provide conditions suitable for growth. The most suitable bacteria are determined by the ingredients of the slurry, although research is underway to find more efficient bacteria. A change in the input slurry, such as that resulting from a change in the animal diet, may cause a readjustment in the bacteria population and temporary reduction or increase in gas production.

Types of Digesters

A digester is an airtight container and a major component of a biogas system. Other major components include manure handling and gas utilization equipment. Digesters may be batch loaded or continuously loaded. In the batch system the digester is filled with slurry that remains in the digester until treatment is finished. The biodegradable slurry is then removed and replaced with a new batch. Batch digesters have advantages where the availability of raw materials is sporadic or limited to coarse material requiring handling by special equipment that may need to be scheduled at a specific time. (Figure 3)

Batch-type digesters require little daily attention. However, the rate of gas production is uneven; it increases slowly after start-up and decreases gradually after a brief period of peak production. Gas production can be evened out by using additional batch digesters charged at specific intervals.

The most desirable microbial environment can be achieved by continuous feeding and a discharge system. On a practical basis this is modified by feeding the digester frequently (one or more times daily). A continuously loaded digester is well suited to continuous animal production and is more efficient than the batch digester. It can be operated as a continuously mixed, plug flow, or periodically mixed reactor.

Continuous mixing (Figure 4) is thought to distribute bacteria uniformly for better contact with the slurry, to keep scum from forming on the surface, to reduce solids settling, and to distribute heat evenly through the slurry.

In the plug flow (Figure 4) design material is fed in at one end of a long horizontal digester. It displaces material along its length until it overflows at the other end. Ideally no intermixing occurs during passage of wastes through the reactor. The biodegradable organics decrease along the digester while the microbial mass increases. In reality some mixing occurs. The plug flow digester is less expensive than mixed digesters to construct, is mechanically simpler and requires no energy for mixing.
The periodic mix concept is a compromise between complete mix and plug flow designs. The contents are mixed at regular intervals, depending on size and shape of the digester (for example, two hours every four or five days). The concept allows shaping the digester to minimize heat loss and construction costs, and at the same time it reduces mixing requirements. Due to the microbial process occurring in two definite steps (the acid-forming and the methane-forming stages), a two-stage digester (Figure 4) has been suggested as being more efficient than a single-stage unit. In this way, each stage is controlled for maximum efficiency of each group of bacteria. Two-stage digesters are common in municipal sewage-digestion systems where the main interest is to have low solids content in the effluent rather than to produce the maximum amount of methane gas. However, work has shown that the two-stage method is not superior to the single-stage method in biogas production.

### Operational Requirements

Numerous factors influence the bacteria’s ability to produce steady quantities of high quality biogas.  

**Temperature**

The rate of digestion and gas production is closely related to temperature. Under optimum environmental temperature, gas production will begin to occur in about 4 days and will continue for several weeks. Two temperature ranges are optimum for anaerobic digestion, the mesophilic range, from 85°F to 104°F, and the thermophilic from 120°F to 140°F. (Figure 5)

![Figure 5. Effect of Temperature on Gas Production Rate](image)

**Retention Time**

In fifteen to twenty days microbial activity breaks down the organic material and converts it to gas. In continuous flow digesters new substrate is added at frequent intervals (one or more times daily) in amounts related to the retention time. As an example, one-tenth of the digester liquid volume should be added daily for a 10-day retention time. Additional of small amounts avoids the danger of loading shock, such as occurs when cold input reduces digester temperature or when the composition of the input material changes.

**Loading Rate**

The capacity of a digester to convert organic material into methane is related to its loading rate, which is 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 present in the feedstock. A high loading rate is desirable because a digester of a given size can handle a larger amount of manure in relation to its size. Different loading rates can be obtained by changing the rate of material flow through the digester or by altering the solids concentration of the influent.

**Retention time and loading rate are interrelated.** Table 1 lists the recommended retention time and loading rate for maximum heat-energy recovery in relation to digester capital outlay and for adequate stabilization of the slurry. Longer retention times may be needed for slurries with higher volatile solids concentration, for other types of agricultural residue and for lower operating temperature.

<table>
<thead>
<tr>
<th>Manure Source</th>
<th>Retention Time, days</th>
<th>Digester Volume, ft³ per 1,000 lb of dry solids</th>
<th>Volatile Solids Loading Rate, lb per day per cu ft of digester volume</th>
<th>Biogas Yield, ft³ per 1,000 lb of dry solids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy Cow (Holstein)</td>
<td>20</td>
<td>26</td>
<td>6.3</td>
<td>62</td>
</tr>
<tr>
<td>Beef (Feeder)</td>
<td>15</td>
<td>20</td>
<td>0.3</td>
<td>31</td>
</tr>
<tr>
<td>Swine (Feeder)</td>
<td>15</td>
<td>10</td>
<td>0.25</td>
<td>43</td>
</tr>
<tr>
<td>Poultry (Layer)</td>
<td>22</td>
<td>79</td>
<td>0.13</td>
<td>75</td>
</tr>
</tbody>
</table>

**Manure Feedstock Characteristics**

**Composition and Volume.** A farm digester benefits from the reasonably uniform material from animal production. The amount and composition of manure produced by different animals is listed in Table 2. As much as 50 percent variation from these values may be expected from farm to farm and season to season, depending on type of feed, amount of pasturing, type of manure collection system and type and amount of bedding material used.

<table>
<thead>
<tr>
<th>Manure Source</th>
<th>Average Animal Weight, pounds</th>
<th>No. of Animals</th>
<th>Manure Production per day, ft³ per 1000 pounds live weight</th>
<th>Feed</th>
<th>Manure</th>
<th>Volatile Solids, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy Cow (Holstein)</td>
<td>1250</td>
<td>0.8</td>
<td>0.5</td>
<td>1.4</td>
<td>0.6</td>
<td>22.5</td>
</tr>
<tr>
<td>Beef (Feeder)</td>
<td>900</td>
<td>1.2</td>
<td>0.6</td>
<td>1.0</td>
<td>0.4</td>
<td>11.6</td>
</tr>
<tr>
<td>Swine (Feeder)</td>
<td>130</td>
<td>7.7</td>
<td>0.7</td>
<td>1.0</td>
<td>0.5</td>
<td>9.2</td>
</tr>
<tr>
<td>Poultry (Layer)</td>
<td>4</td>
<td>250</td>
<td>5.3</td>
<td>0.8</td>
<td>9.4</td>
<td>25.2</td>
</tr>
</tbody>
</table>

**Dilution.** Some livestock operations dilute the manure with water for pumping. Large centrifugal pumps with 4 inch or larger pipelines can handle liquid manure with a solids content of up to 12 percent. Smaller pumps require a lower solids content to avoid blockage. A ram pump can handle a mixture of cow manure and sawdust bedding with solids content up to 22 percent. Diluted manure has several disadvantages, though. A larger digester and storage must be built to handle the greater volume of manure. In addition the manure must be mixed, at least periodically, to keep it from settling and reducing gas production. (Figure 7)
Dairy manure as produced in a free stall barn needs no dilution. It normally contains between 10 and 13 percent solids. Manure from stall barns or barns that use heavy bedding require additional digester volume and may require dilution water to form a pumpable slurry. Wash water from milking may be added for dilution or disposal purposes. Excess dilution below 8 percent solids is not recommended to reduce the material to be handled and to maintain a reasonable size digester.

Swine manure from flush systems contains 1 to 2 percent solids; recirculated flush water from an anaerobic lagoon has a higher solids content. Swine manure collected in pits beneath slotted floors is 3 to 6 percent solids. The solids need to be concentrated to 8 percent for a plug flow digester. A settling basin will concentrate the solids, but as much as 30 percent of the volatile organic solids for biogas production are retained in the liquid. Manure scraped from pens at 13 percent solids may be introduced directly into the digester. One to two gallons of dilution water for each 1,000 pounds of animal weight may be added to improve manure flow, for washing, or to control pH.

Poultry manure is normally diluted with 14 to 20 gallons of water for each 1,000 pounds of poultry so it will flow through the digester and to control pH. Digesters are uncommon on modern poultry operations since some waste management practices produce a dry manure which is conveniently stored and handled and has significant fertilizer value.

Carbon-nitrogen ratio. Carbon (carbohydrates) and nitrogen (protein) are the principal nutrients for anaerobic bacteria. The carbon is converted to methane in the process. The nitrogen provides food for the bacteria and acts as a catalyst for the process. However, if the nitrogen content is too high, the process is retarded or stopped. Digestion proceeds at an optimum rate when the ratio of carbon to nitrogen is within the range of 20:1 to 30:1. The availability of these elements varies widely in manures from different animal species, with age and diet of the animals, and with manure management. The carbon content in dairy manure is slightly higher than required for an efficient balance. Swine and poultry manures have excess nitrogen that requires dilution with water rather than change in the carbon-nitrogen ratio.

- **Toxic Materials**
  - Small concentrations of sodium, potassium, calcium, and magnesium (up to 200 parts per million) have been found to stimulate the anaerobic process. Concentrations above 5,000 ppm inhibit methane production.
  - Ammonia concentrations in the range of 1,500 to 3,000 ppm (1,500-3,000 mg/liter) are toxic to methane bacteria in the pH range of 7.2 to 7.4. Concentrations in excess of 3,000 ppm are toxic regardless of pH. High concentrations of ammonia inhibit successful anaerobic digestion of swine and poultry wastes. This toxicity can be controlled by reducing the pH to 7.2 to 7.0 through dilution water.

- **Effluent Composition**
  - Biological activity slightly reduces the volume of the input manure by 2 to 5 percent. A smaller percentage of the volatile solids component is reduced with higher loading rates.

- **有毒材料**
  - 低浓度的钠、钾、钙和镁（每升水200个单位以下）对厌氧过程有刺激作用。浓度在1,500至3,000 ppm（1,500-3,000 mg/liter）范围内对甲烷细菌有影响。在pH范围7.2到7.4时，浓度超过3,000 ppm即使在pH值不同的情况下也是有毒的。高浓度的氨会抑制有效的厌氧消化过程。这种毒性可以通过将pH值降低到7.2到7.0来控制通过稀释水。

- **废物组成**
  - 生物活动只会略微降低输入污泥的体积，减少2到5%。固体可挥发物的较小百分比被去除。

However, a high loading rate causes a higher rate of solids conversion per day corresponding to the higher biogas production rate. Approximately one-half of the volatile solids in fresh manure will be converted in a 10-day treatment period.

Most of the nitrogen in the input manure will remain as ammonia after digestion; but as much as 60 percent of it is dissolved ammonia. This form of nitrogen volatilizes readily and will be lost to the air unless it is immediately drowned down or injected into cropland during the spring or early summer when crops grow rapidly. At other times the effluent may be stored, with little nitrogen loss, in a tank or holding pond. Phosphorus and potassium contents of manures are unaffected by digestion. The processed manure has a musty, but not foul odor, and does not attract flies. It can be handled by liquid manure pumps and tank spreaders for distribution on land or for irrigation.

- **Biogas Amounts and Composition**
  - Gas output reported from digesters for various livestock manures is listed in Table 1. Biogas is mainly methane (CH₄) and carbon dioxide (CO₂), with small amounts of water vapor and other gases, including nitrogen and hydrogen sulfide (1000-4000 parts per million). Methane content ranges from 55 to 70 percent.
II—Digester Construction

Site Selection

Incorporating the digester into the existing manure handling system is one of the most important factors in site selection. Methane digesters require that manure be handled as liquid. Will it fit into the existing manure handling system, or will extensive remodeling or a new system be required? A digester may be located close to an animal shelter, however, keep the gas use and handling facilities separate. Avoid covers or buildings over the digester to minimize areas where explosive mixtures of air and gas can collect.

Figure 8. Ventilation Around the Digester

* Topography

A ground slope which allows manure to flow by gravity reduces the need for expensive pumps and piping. Energy and capital costs for pumping can cost as much as the digester itself. Try to select a site that requires little excavation and has good drainage. Many digesters, both plug flow and mixed type, are built below grade to take advantage of the earth as a structural component. In northern climates the earth provides insulation from cold winter air temperatures. Locate a buried digester at least 2 feet above the high water table so it will not:

- float out of the ground when empty due to hydrostatic pressure
- lose excess heat by conduction from the manure to water in the soil
- pollute the ground water
- require more expensive excavation and construction in wet ground.

Select an accessible site. Place the digester convenient to electricity and water. Plan an access for maintenance and manure removal. Plan enough space to fix heating pipes, unclog or empty the digester, remove the top, etc.

Allow for future expansion. Don’t build the digester where it will block a new or expanded building. Leave enough space to expand the digester and gas handling facility.

* Drainage

Divert surface and subsurface water away from the digester. Wet soil exerts much greater pressure on buried walls than dry soil. Poorly drained soil can push in walls of a below-grade digester and cause problems due to frost heaving. In addition, wet soil conducts heat away from the digester much faster than dry soil.

Subsurface drainage. A soil survey will help you decide the degree of drainage required. Build the digester at least 2 above the high water table. As a minimum, place a 4 perforated plastic pipe around the perimeter of the footing. (Figure 9)

Figure 9. Drain System for a Below Grade Digester

Site Selection

The digester itself is one of the most important features of an anaerobic digestion system. A useful design considers the volume, based on the retention time and loading rate, and the kinds of designs and their respective costs of installation, operation, and maintenance. Also consider the digester shape and materials, mixing (if applicable), heating and insulation.

A digester is usually designed for either periodical mixing or plug flow. Recognize the limits of each design before choosing one. Plug flow digesters only work with manure that has little or no dilution water or bedding. The manure presumably flows as a plug of material and does not separate as it goes through the digester. Manure that is 10% to 15% solids will flow and digest properly in a plug flow digester. (Figure 9)

Manure flushed or diluted to less than 10% solids requires mixing to keep it in suspension, otherwise, diluted manure will settle and a scum will form on the surface, inhibiting gas production. The mixed digester allows, therefore, a greater range of material that may be digested.

* Construction Materials

Two types of digester construction are common. The rigid-walled tank is usually a vertical cylinder of coated steel, concrete, or fiberglass. Coated or glass lined steel or fiberglass tanks are strong and durable, although generally more costly than concrete. Concrete is a durable and low cost material, but it requires more labor to erect than other materials. Sulfates and milk acids in a digester may degrade the cement in the concrete, although that has not been a serious problem. The flexible "rubber-type" digester is the second major type of construction. Here a soil-supported flexible liner serves as the main digester and a liner cover collects the gas.

* Plug Flow Digesters

On farms where manure is not diluted, the plug flow design may be simpler and less expensive than the mixed digester. Plug flow digesters have been constructed as covered earthen basins both insulated and uninsulated, or as reinforced concrete tanks both buried and above ground. The design objective is to build a low cost digester that functions properly with minimum maintenance. Length to width ratio of 4:1 seems to maintain good plug flow conditions. Divide wide digesters with a center wall to maintain this ratio. Side slopes are 1:1 or steeper. Typical depth is 0 to 10.

Minimizing the digester’s surface area, to prevent heat loss, benefit the net energy production and reduce the land area needed for a digester.

* Buried Plug Flow Digestor

Forces which may act on a buried tank are shown in Figure 10 and include:

- soil pressure which pushes inward.
- manure surry pressure which pushes outward.
- inward and uplift forces if a flexible gas cover is attached.
- upward hydrostatic pressure which can lift an empty tank out of the ground, if the surrounding soil is not properly drained.

Figure 10. Forces on a Buried Tank with Flexible Gas Cover

The inwards soil force on an empty tank is most critical; the tank walls must be reinforced to withstand this pressure. Outward manure pressure is carried by the soil surrounding a properly backfilled tank. An almost flat or low profile flexible cover can exert a very high inward pull which must be checked in the design. A buried concrete tank design is shown in Figure 11.
**Earthen Basin Plug Flow Digester**

A plastic lined and insulated earthen trench may be used as a digester (Figure 12). In warm areas, an uninsulated, covered earthen manure storage may work. When designing a trench digester, the absence of a rigid shell implies that the soil must be stable enough to maintain the desired shape during construction and after the digester is filled.

As with any buried digester, the area around the basin must be well drained. Any backfill over the gravel and tile drains must be free of stones or any objects that might damage the lining or insulation. After the backfill is compacted, rigid board insulation may be laid in place. Tape the boards so the liner will not be pinched.

The plastic or rubber liner should fit loosely in place. Bury the edges in a trench around the digester to prevent shifting. The manufacturer may have special boots and adhesive to seal around pipes. A hole cut one half the diameter of the pipe will stretch and form an upsprung collar. The collar may then be reinforced with adhesive and additional liner material.

### Mixed Digesters

Generally manure diluted below 8% solids requires a mixed digester to:

- keep light material from forming a floating scum.
- minimize settling.
- improve heat exchange from the heating pipes to the manure.
- maintain a more uniform temperature throughout the digester.
- distribute bacteria and fresh influent throughout the digester for maximum contact which may increase gas production.

In practice, mixing carries some manure from the digester before it is completely digested so gas production may be less than from a plug flow digester. In addition, mixing is expensive, requiring additional equipment and maintenance, as well as additional energy. Manure in all digesters mixes to a certain degree. Mixing will occur by a variety of natural mechanisms including: daily loading of fresh manure; gas bubble movement to the surface; thermal convection; chemical dispersion and diffusion.
Mechanical Agitation may be done by internal paddles, or propellers generally driven externally by electric motors. Two to four bladed paddles with a diameter 0.2 to 0.4 times the digester diameter are typical. Baffles along the side promote mixing. Propeller mixers rarely exceed 18" in diameter and are mounted off center at an angle for good mixing (Figure 14).

**Mixed Digester Construction**

The shape of mixed digesters may be either square, rectangular, or cylindrical. Liquid depths range from 10’ to 25’, at greater depths the liquid manure pressure becomes too large for economical construction. Allow at least one foot of freeboard to provide a safety margin in case of foaming or the outlet gets blocked.

Wall materials must be strong, liquid tight, and resist corrosion and weather. Cast-in-place reinforced concrete requires individual design by a qualified engineer or contractor. The recommended minimum compressive strength is 3500 psi. Specify air-entrained concrete as it resists sulfates, acids, and freezing weather.

Precast concrete silo staves are widely available and allow great flexibility in selecting the diameter and height. Hoops resist the liquid pressure and keep the staves in place. A suggested spacing schedule is listed in Table 4. Install at least 3 connecting lugs per hoop on 10” to 16” diameter digesters and at least 4 on 16” to 22” diameters. Tighten the hoops before applying insulation, gunite plaster or other sealant. Then retighten the hoops before filling, particularly those on the lower 2/3 of the digester.

Extend the footing at least 18” deep into undisturbed soil. It need not extend below frostline because soil is well drained. The footing distributes the weight of the walls, roof and any snow that accumulates on the roof. Run tests to determine the soil bearing capacity, so the footing width may be calculated. Typical soil bearing strengths are listed in Table 5. The normal footing thickness equals half the footing width and is at least 8”. Generally when digester walls are 8’ tall or less, they may be supported by the floor instead of a footing.

**Digester Inlets and Outlets**

Manure may be pumped or flow by gravity to the digester. The manure handling system requires:

- An easily cleaned grate or slats over the inlet to help screen out large material.
- Corrosion resistant pipe, such as heavy steel, PVC plastic, concrete and cement asbestos.

The floor may be a 4” thick flooring concrete slab over a 6” gravel base. It should be reinforced with 6” x 6” 10 gauge welded wire mesh. Install a perimeter drain (4” diameter) which drains to an outlet that does not drain directly to a stream or other water source, (Figure 16)
Minimal turns and joints to decrease plugging.
- Protection from freezing, yet accessibility in case of plugging when service is necessary.
- Valve and bypass around the digester when service is necessary.
- Where manure is pumped at less than 8% solids, at least 4" diameter pipe is common; 6" is better. (Figure 17)

Figure 17. Inlet Pipes

- Single Feed
- Split Feed
- Dual Feed
- Between Two Barns
- Counterflow

In addition, gravity flow systems require:
- A 4" to 6" elevation drop between the barn floor and the full digestion level for manure flow up to about 200' away.
- For dairy barns a 24" to 36" diameter pipe to prevent clogging. A 15" to 20" diameter pipe may be used if bedding is not, and never will be used. (Figures 18 and 19)

Figure 18. Gravity Flow Inlet to a Dairy Digester

- For swine barns, where manure is flushed or washed to either a deep narrow or gravity drain gutter, a 6" to 8" diameter drain.

Regardless of the size pipe or the method of moving manure, the digester inlets and outlets must:
- Be air and gas tight without over pressurization. (Figures 20 and 21)
- Maintain correct liquid level and prevent accidental emptying. Place the digester so the manure level is below the barn floor or install a check valve to prevent backflow of manure.
- Promote plug flow in plug flow digesters.
- Permit cleaning and sampling.

Figure 19. Pipe Diameter Guide for Dairy Cattle Manure Flow

- Sludge Removal

Sand, lime, dirt, and undigested solids settle to the bottom of a digester and will reduce its active volume unless removed occasionally such as once a year. A built-in or portable auger, bucket loader, or vacuum tank manure spreader have been used to remove sludge from digesters. Do not bed dairy free stalls with sand to reduce the amount of sludge.

Figure 20. Inlet and Outlet for a Simple Gas Seal

Collecting the Gas

The cover or roof seals out air and collects the biogas produced (Figure 22). Include some reliable means for biogas escape for safe operation. If the digester is used for short term gas storage, a floating or flexible cover adjusts the gas storage volume while maintaining a constant pressure on the biogas being produced.

Figure 21. Digester Outlets that Limit Gas Pressure

- Digester Pressure

Design a digester, particularly the cover, to withstand the operating pressure. The higher the operating pressure, the stronger the digester components must be. Most agricultural digesters operate at a maximum pressure of
The maximum pressure is not the operating pressure, but is an upper limit determined by the design of the vessel. The minimum pressure in the digester must be above atmospheric, preferably 0.5大气压 or more. The pressure may be kept to as little as 0.1大气压 above atmospheric, but good controls are needed to prevent a vacuum. Air enters the digester, it may cause explosive conditions as well as interfere with the anaerobic digestion.

If the digester cover is gas supported, maintain enough pressure to support the cover as well as anything placed on top of it such as insulation or snow. An outdoor flexible cover must also be pressurized enough (or protected) so it will not nutter in the wind because the resulting shock wave reduces the life of the material. A pressure of 1 to 1.5 will withstand winds up to 70 mph.

Most agricultural digesters operate at 2 to 4大气压 of water gauge. This pressure is sufficient to operate most biogas-fired equipment without expensive blowers or compressors. Rigid wall digesters and digesters inside buildings with flexible covers may operate at less than 1大气压 of water pressure. In heavy snow areas a low profile, outdoor digester with a flexible cover may need to operate some of the time at more than 4大气压.

**Fixed Covers**

This cover or roof may be an integral part of the digestion chamber. It must have sufficient weight or be designed to withstand the gas pressure. Excessive pressure buildup increases the danger of explosion. A University of Missouri digester was constructed with a thick concrete roof. A large expandable flexible bag then stored the gas. The interior of a concrete gas chamber is sealed with paint, a mastic compound or a membrane impermeable to gas.

**Floating Covers**

A gas seal allowing free vertical movement between the cover and the main digester walls may be difficult to achieve. The lower edge of the cover may be submerged in the slurry or in a more elaborate water seal, but a floating cover will likely freeze in cold weather. Metal, even when galvanized, corrodes rapidly at the slurry seal; fiberglass sidewalls are corrosion resistant. A slurry seal also allows heat and gas to escape between the cover and wall. The weight and surface area of a floating cover controls the pressure and volume of the biogas contained beneath it.

**Flexible Covers**

A flexible cover is subjected to considerable tension, corrosive atmosphere in the digester, and weathering if it is not sheltered. In addition it may be difficult to seal the digester and anchor the cover. These conditions will cause an improperly or hastily chosen material to fail much earlier than expected.

**Cover Reinforcement**

Many plastic or synthetic rubber films are relatively impermeable to air and biogas. However, because they are not very resistant to stretching and/or tearing they are often reinforced with polyester, nylon or fiberglass strands. The reinforcing is generally a scrim or a woven fabric. A scrim reinforcing is a very loose weaving (or mesh) of reinforcing strands, generally 4 to 10 years per inch. (Figure 23)

![Figure 23. Scrim Reinforcement of Synthetic Rubber or Plastic Films](image)

Woven fabrics contain more yarn per inch and have very little space between yarns. Plastic or synthetic rubber is laminated or coated corresponding to the type of reinforcement. In laminated fabrics a scrim is sandwiched between two sheets of plastic under heat and pressure. The thickness of the sheets are exploded in mills (1/1000 in.). Thus two 15 mil sheets laminated to a scrim layer compose a single 30 mil nominal thickness sheet. Other common sizes are 20, 35 and 45 mil sheets.

The bond between the two sheets depends on the mechanical joining in the spaces between the yarns. The space between the yarns in woven fabrics is too small for the mechanical bonding of laminates to be effective.

Instead fabric is coated with a hot melted plastic which tightly adheres to the reinforcing. Coated fabrics are generally more expensive, but stronger than laminated materials. Common coated fabrics have finished weights between 14 and 30 ounces per square yard.

**Polyester fabrics** are best for reinforcing digester covers. Although polyester is not as strong as nylon, it has good resistance to acid, sunlight, water solutions, and microbial attack.

Fiberglass reinforcement is not recommended because it is water sensitive and subject to breakdown by soil microbes. Nylon reinforcement is resistive to both water and soil organisms. However, nylon is readily attacked by acid solutions. Any exposed fibers will wick in acid and destroy it. Nylon is also degraded by sunlight. The rate of degradation depends upon the thickness of the plastic coating and its ultraviolet inhibiting properties.

**Cover Materials**

Table 6 lists many plastic or synthetic rubbers available. Important characteristics include impermeability, durability (against sunlight and ozone if the cover is not sheltered), cold weather flexibility, and chemical resistance against attack from the manure and biogas. All of the plastics listed are impermeable to air and biogas soaking any imperfections such as pin holes or small cuts. Ask for a written guarantee from the manufacturer supported by lab results.

Durable or how long the material will last when exposed to sunlight and ozone (present in the atmosphere) is quite variable among the different plastics. The life of some plastic can be increased by a coating (e.g. acrylic or polymeric on PVC) or by painting the surface with hypalon (e.g. hypalon paint on Neoprene). Ask the supplier about coating, especially when considering polyvinylchloride (PVC), chlorinated polyethylene (CPE) or Neoprene membranes.

Cold weather flexibility and cold crack resistance depend on the particular compound. All of the materials listed in Table 6 may be compounded for crack resistance at very low temperatures where flexing isn’t a major concern; many will also remain flexible. Specify how cold it gets in the area and if the membrane will be subjected to repeated flexure (continual inflating and deflating) at low temperatures. The plastic manufacturer will assure satisfactory service under those conditions, especially with PVC membranes.

**Resistance to attack** from micro-organisms in the manure, fungus and mildew, hydrogen sulfide, and possibly dilute sulfuric acid forming in the condensate must be considered.

<table>
<thead>
<tr>
<th>Material</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypalon45</td>
<td>Moderately priced synthetic rubber. Easily repaired in field. Excellent weathering characteristics.</td>
<td>Not readily available in small orders. Failed on at least one outdoor digester.</td>
</tr>
<tr>
<td>PVC (polyvinylchloride)</td>
<td>Relatively inexpensive. Excellent chemical resistance. Life expectancy 4 to 10 years when protected from sun.</td>
<td>Poor flexibility in cold weather. Decomposes under sunlight in 1 to 2 years.</td>
</tr>
<tr>
<td>PVC coated with acrylic or Hypalon</td>
<td>Good weathering characteristics. Moderately priced. Life expectancy 3 years.</td>
<td>Same as PVC.</td>
</tr>
<tr>
<td>Etonne Polyurethane</td>
<td>Moderately priced (more than Hypalon). Easily repaired in field. Excellent cold weather performance.</td>
<td>Subject to delamination.</td>
</tr>
<tr>
<td>Etonne Polyethylene</td>
<td>Synthetic rubber. Good performance over wide temperature range.</td>
<td></td>
</tr>
<tr>
<td>Polyethylene</td>
<td>Low cost. Life expectancy when sheltered 3 to 5 years.</td>
<td>Poor resistance to abrasion and moisture. Poor adhesion prevents adequate sealing.</td>
</tr>
<tr>
<td>CPME (cycloprene polyethylene) flexible member</td>
<td>Good low cost flexible liner.</td>
<td>Poor resistance to heat and sunlight.</td>
</tr>
<tr>
<td>Neoprene (polychloroprene polymer resistant to ozone)</td>
<td>Medium to high price. Performs well at high temperatures.</td>
<td>Poor aging quality. Decomposes under sunlight. Difficult to repair.</td>
</tr>
</tbody>
</table>

[Material used on top on the Cornell University plug-flow unit.](image)
Joining Methods and Sheet Construction

Reinforced flexible membranes are made in standard widths up to about 72”. Join standard widths by sewing, heat sealing or welding, cementing, and solvent sealing. The method used doesn’t matter as long as the seam strength, under a continuous load, is as strong as the reinforced membrane itself and there are no exposed reinforcing fibers. Fabrics with exposed fibers at the seams will in solution that weakens the fabric at the joints. (Figure 23)

Some coated or laminated fabrics arrive in an unvulcanized condition to facilitate field seamming, (e. g., hypalon). They require time to fully cure, and, until they do, seam strength is seriously reduced.

Sewn seams are the least desirable because they are less strong than others, the needle holes have to be sealed to prevent gas leakage, and the thread is weakened by weathering unless properly coated. The orientation of the seams is very important. Stress in the cover is always greatest across a rectangular digester than along it. Therefore stress is minimized by running the seams across the digester, because the lengthwise force has less ability to pull the seam apart (Figure 24). Most standards specify testing in both the warp (lengthwise) and weft (crosswise) direction because strength may vary in the two directions. Typical values for these strengths appear in Table 7.

Fabric Specifications

Many reinforced flexible materials have been tried, and many have failed. Some delaminated because exposed fibers at the seams allowed moisture and gas between the laminates. Some were over pressurized and tore at or near seams. Membranes that have worked successfully at low pressures include relatively inexpensive ones such as a 30 mil, 6 x 6 threads per inch, 1000 denier polyester scrim reinforced pond liner operated at a maximum pressure of 1/2" of water. Higher pressures (6" water gauge) require higher priced coated fabrics such as 16 oz/yd PVC coated polyester fabric. The actual plastic or synthetic rubber finally chosen is a compromise between life, cost and availability. A letter explaining an anaerobic digester and a sketch should accompany the specifications sent to the supplier or manufacturer. Also include a specification sheet listing the mechanical properties with the appropriate test method and values — pounds per square inch for the tensile test, pounds for the tear test, etc. Include any notes on the application. For example, will the flexible reinforced membrane be continually inflating and defating (flexing) or will it remain relatively rigid? Note construction features such as cover size and seam characteristics.

Loads on Flexible Covers

The maximum loads or stresses that a flexible cover experiences depend on the maximum digester pressure, cover width, and the cover profile. Cover width may be calculated by multiplying the distance between the cover anchors by the multiplier listed in Table 8. Typical tension per foot of cover fabric for a long cylinder is listed in Table 9. Note that fabric tension becomes very large with low profile digesters.
Fastening a Flexible Cover

A flexible cover may be fastened in many ways. Consider the following when choosing a fastening method:

- Fabrics are very sensitive to tearing; anchor them uniformly so stress is distributed and not concentrated at any point.
- Make the seal gas-tight and strong enough to restrain the cover under the worst conditions of high wind and high gas pressure.
- An easily removed cover makes repairs or maintenance easier. This feature is particularly important at startup.

Methods of fastening may be separated by sealing method – liquid seal, dry seal and dry-liquid seal.

Liquid seals are formed by placing the edge of the flexible cover beneath the manure surface (Figure 27). Dangerous over pressure may be controlled by the depth the cover edge is placed below the manure surface; the deeper the edge is placed, the greater the pressure required before the gas escapes. This type of seal may be difficult and messy to work with if repairs are needed.

Dry-liquid seals are fastened above the manure; a flap projects below the manure to form a liquid seal (Figure 29). Dry seals (Figure 29) allow easy removal of the cover, but are difficult to seal tightly, particularly at corner folds. Burying the edges in a trench forms one type of dry seal. Gaskets or sealing compounds seal surface irregularities. Many dry seals extend a flap into the manure slurry to form a dry-wet seal.

Ballast anchors (Figure 30) rely on the weight of the anchor to resist the vertical component of the fabric tension, and passive soil pressure or friction to resist the horizontal force. Table 10 lists the weight needed to hold down typical semi-cylindrical digester covers.

Table 10. Ballast Weight Needed to Hold Down a Semi-Cylindrical Shaped Digester Cover

<table>
<thead>
<tr>
<th>Diameter Width</th>
<th>Anchor Weight, lb</th>
<th>Cover Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>3'</td>
<td>250</td>
<td>310</td>
</tr>
<tr>
<td>4'</td>
<td>360</td>
<td>340</td>
</tr>
<tr>
<td>5'</td>
<td>460</td>
<td>410</td>
</tr>
<tr>
<td>6'</td>
<td>560</td>
<td>460</td>
</tr>
<tr>
<td>7'</td>
<td>630</td>
<td>510</td>
</tr>
<tr>
<td>8'</td>
<td>750</td>
<td>630</td>
</tr>
<tr>
<td>10'</td>
<td>720</td>
<td>670</td>
</tr>
</tbody>
</table>

Positive Screw Anchors: The uplift capacity of a screw anchor depends on the shear strength of the soil. Anchors must be positioned below the layer of ground affected by seasonal changes and the soaking and drying of soil. Manufacturers publish the typical holding power of their various anchors. Be careful when positioning anchors so they lay at the same angle as the edge of the fabric. This orientation keeps the shaft in straight tension rather than bending (Figure 31).

Cable restraint reduces tension in the fabric by reducing the span between supports (Figure 32).

- Coatings and Liners

Normally concrete digesters are not lined, although they may be sealed with cement, vinyl or rubber based silo coatings. As an alternative, digesters walls may be formed by placing a pond liner directly over insulation laid in a trench. When the sides are steep (greater than 2:1 slope) use a polyester or nylon scrim reinforced hypalon or EPDM pond liners with a minimum tensile strength of 95 lb and a minimum tear strength of 20 lb (ASTM D761). Silo seal coatings will normally seal the roof of concrete tanks, although some designers recommend installing a 30 mil hypalon or plastic liner. Steel tanks with properly sealed joints are gas tight.

When ordering a liner, include a sketch and description of the application. Include an allowance for 1° of vertical treeboard and for anchoring the material.
Insulation

Normally the digester is maintained at a temperature of about 95°F for optimum (mesophilic) gas production. During winter in northern areas even a moderately well insulated digester may use 50% or more of its total gas production to keep warm. Insulation makes more biogas available for use because:

- it reduces heat loss from the digester, and
- it makes it possible to run the digester at the high temperatures needed to generate more gas.

Three important properties of insulation are:

1. **Insulation or R-value.** An insulation’s ability to resist the heat flow is commonly rated by R-value. A high R-value at low cost is preferred.

2. **Moisture permeability.** Moisture absorbed by insulation decreases its insulation value and will ruin blanket or batt insulation. The perm is a measure of resistance to moisture penetration. Insulation with a perm rating less than one will absorb very little moisture. Protect insulation that has a perm value greater than one with a vapor barrier of 6 mil polyethylene film or aluminum foil.

3. **Compressive strength.** As an insulation is compressed it loses its insulating value. Fiberglass batts may be easily compressed and must be protected. Rigid foam has a 10 to 30 psi compressive strength; cellular glass insulation has a compressive strength of 100 psi and may be carefully walked on without damage.

**Types of Insulation**

Fiberglass batts or blankets, rigid plastic foam board, spray-on polyurethane foam, and cellular glass are used to insulate digesters. Table 11 lists physical and thermal properties of various insulations.

**Where to Insulate**

The top cover over the manure is the single most important area to insulate. If the insulation is placed on top of a flexible cover, it must conform to the curved surface, yet stay in place. Fiberglass blankets taped together work well. A plastic cover over the top keeps the insulation dry.

Insulation placed inside a flexible cover must be unaffected by moisture and the harsh biogas environment and be rigid enough to hold in place. Closed-cell rigid polyisotere or polyurethane plastics and foam-glass insulation have been used. Closed cell extruded polyisotere has been floated on manure, but may make it difficult to empty the digester if the manure must ever be agitated to pump it out. The closed cell rigid plastics are preferable to cellular glass because of their light weight, lower cost, and superior insulating properties.

<table>
<thead>
<tr>
<th>Table 11. Insulation Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>fiberglass blanket or batt</td>
</tr>
<tr>
<td>Expanded polystyrene board</td>
</tr>
<tr>
<td>Extruded, smooth skin</td>
</tr>
<tr>
<td>Extruded, cut cells</td>
</tr>
<tr>
<td>Molded beads</td>
</tr>
<tr>
<td>Cellular glass board</td>
</tr>
<tr>
<td>Expanded polyurethane board or spray-on</td>
</tr>
<tr>
<td>Insulation board</td>
</tr>
<tr>
<td>Polyurethane</td>
</tr>
</tbody>
</table>

**Heating System**

Heating is added to warm the cold incoming manure and to replace heat lost to the atmosphere. Normally heat is transferred from hot water (130°F to 140°F) circulated through pipe placed either in the digester, or in a separate heating tank ahead of the digester, or in both. The hot water circulates in a closed loop.

Hot water or steam may also be injected directly into a mixed digester. However, hot water substantially dilutes the manure, so it requires a mixed digester to keep solids from settling and larger storage and equipment to handle the greater volume. In addition, during winter, more hot water must be added, which lowers gas production per unit of digester volume, just when heat is needed most.

Steam injection may be a promising heating method, although it has not been investigated in this country. Steam stores more heat than the same volume of hot water, so less dilution occurs. In addition, a steam boiler generates the pressure needed both to inject the steam and mix the slurry without additional pumps.

Figure 33 diagrams a typical boiler-heat circulation system. A remote sensor thermostat is well protected (Figure 34) and located to assure quick response to changes in temperature, such as where the slurry is actively agitated, controls the heater. Manure may cake on heat exchanger pipes when water temperatures exceed 140°F. An automatic mixing value mixes cool return line water with the hot feed water to keep the water temperature at 140°F.

**Hot Water Piping**

Many digesters have heating pipes divided into two circuits. The first or inlet circuit, sometimes placed in a separate tank, heats the cold incoming manure up to digestion temperature (Figure 35). The second circuit replaces heat lost by the manure in the digester. With
Piping placed low in a plug flow digester, approximately 1" to 1 1/2" from the bottom, may enhance convective heat transfer. The piping is supported by concrete blocks or a metal or pressure treated wood frame. Securely fasten supports to prevent heating grid movement. Heater pipes in a plug flow digester normally run lengthwise or from top to bottom to decrease the likelihood of material catching in the pipework.

Wrought iron, black or galvanized steel and high temperature plastic (CPVC) pipe are used with little concern about corrosion—as long as the pipe is totally submerged in the manure. Rapid corrosion occurs when metal is partly submerged. Aluminum, copper and brass corrode rapidly due to the sulphur in the biogas. Regular or cold water PVC plastic cannot withstand the high temperature in the digester. Nominal 2" or 2 1/2" diameter steel or wrought iron pipe is preferred over plastic because of its rigidity and resistance to damage.

**Amount of Piping**

In hot water recirculation systems the amount of piping needed depends on:

- Rate of heat transfer from the pipes.
- Temperature difference between the hot water, the pipes and the manure.
- Heat needed to raise the temperature of the incoming manure.
- Heat losses from the digester.

Heat transfer through the pipe, whether plastic or steel, is largely impeded by a thin film of manure around the piping. Table 12 lists heat transfer coefficients based on studies with thick municipal sewage (which closely resembles manure of about 12% solids).

**Table 12. Heat Transfer Coefficients of Piping Materials**

<table>
<thead>
<tr>
<th>Piping Material</th>
<th>Transfer Coefficient (MRT/°F/hr-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare Steel Pipe</td>
<td>8 to 15</td>
</tr>
<tr>
<td>Bare Plastic Pipe</td>
<td>6 to 12</td>
</tr>
<tr>
<td>Insulated (3&quot;) polyethylene pipe</td>
<td>4&quot; to 35,000</td>
</tr>
</tbody>
</table>

**Water Temperature**

Keep below 140°F to minimize manure caking on the pipes. Municipal digesters successfully operate with water temperatures of 133°F, while the plug flow digester at Cornell University has operated over 3 years with temperatures of 140°F without caking problems.

**Amount of Heat**

The amount of heat needed to raise the incoming manure to digestion temperature is about:

\[ Q = W(Th - Tc) + 140 Wf \]

Where:

- \( Q \) = Heat to warming incoming manure, Btu/day
- \( W \) = Daily manure input (from Table 2), lb.
- \( Th \) = Digester temperature, °F
- \( Tc \) = Manure temperature, or average air temperature for the coldest 2 week period of the year, or 30°F, whichever is higher.
- \( f \) = fraction of manure that is frozen.

Frozen manure requires a substantial amount of energy to heat. Farms with frozen manure should plan to store most of it rather than load it into the digester. As an alternative, scrape or load frozen manure frequently into the digester so that less than half is frozen. When about half the manure is frozen, the amount of energy required to heat the manure is:

\[ Btu/day = 130 (Pounds of manure/day) \]

A substantial amount of heat is required to warm incoming manure, generally more than half of the total heating requirements during the winter.

**Heat loss** through the walls, floor and top cover depends on digester construction and surrounding temperatures. Estimate digester heat loss using Table 13. Multiply the total wall, floor area and top areas by the appropriate heat loss value to calculate the total heat loss. Thermal resistance values of various components and materials are listed in Table 14.

**Table 13. Typical Digester Heat Loss Values. Digester temperature is 95°F**

<table>
<thead>
<tr>
<th>Surface Insulation</th>
<th>Air or Soil Temp., °F</th>
<th>Heat Loss, Btu/hr sq ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buried concrete wall or floor</td>
<td>60°</td>
<td>3</td>
</tr>
<tr>
<td>Insulated</td>
<td>8-10 fiberglass or 3&quot; polyurethane</td>
<td>6°</td>
</tr>
<tr>
<td>Foam glass</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Fiberglass batt</td>
<td>2.7</td>
<td></td>
</tr>
</tbody>
</table>

Once the heat needed to raise the incoming manure to 95°F and the heat lost during cold weather are known, the actual length of piping may be calculated as:

\[ \text{Feet of pipe} = \frac{Q}{CA(Tw - Tm)} \]
The heat transfer coefficient for this type of concrete panel in a mixed digester is 22 Btu/hr sq ft °F. The size of a concrete heat exchanger panel insulated on one side may be calculated as:

\[ A = \frac{Q}{22 (T_p - T_m)} \]

where

- \( A \) = Panel size, sq ft
- \( Q \) = Heat needed, Btu/hr
- \( T_p \) = Panel surface temperature (110°F = 140°F typical)
- \( T_m \) = Manure temperature (normally 95°F)

Calculate water flow needed to heat manure by:

\[ \text{GPM} = \frac{Q}{500 (T_i - T_o)} \]

where

- \( \text{GPM} \) = Water flow rate, gal/min
- \( Q \) = Heat required to warm the digester, Btu/hr
- \( T_i \) = Inlet Water temperature
- \( T_o \) = Outlet water temperature

The heat exchanger in the Pennsylvania State University mixed digester (Figure 38) consists of four concrete panels. Steel pipe, 3/4" diameter, imbedded 1/2" from the surface and about 4" on center, conducted 140°F hot water through the panel. One side of the panel was insulated so the uninsulated surface reached about 110°F. The panel allowed the use of high temperature water without causing manure to cake on the heat exchanger and reduce its effectiveness.

Figure 38. The Two Stage Digester at The Pennsylvania State University

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### III—USING THE BIOGAS

**Biogas may be:**

- Burned for space heating, drying, cooking, or water heating.
- Used to run an engine-generator to produce both heat and electricity.

In some countries biogas has been used to fuel vehicles. In the U.S., the cost has been too high to consider this option. Gas production from a digester is nearly constant throughout the year. Some of the energy produced is required to heat the incoming manure and replace heat lost to the atmosphere. The heat required varies over the year depending on daily temperature (Figure 39).

### Heating

**Biogas**, being about 60% methane, has a lower energy density than comparable fuels (Table 16). Natural gas and LPG appliances will run on biogas, without modification, but their heat output will be reduced to about half for natural gas and to one third for LPG. To maintain the rated output, the gas metering orifice may be replaced with a larger one drilled to the proper size. For example, converting a natural gas heater to run at rated output on biogas with 55% methane requires increasing the orifice diameter 1.54 times (Table 17).

The pressure regulator and air metering orifices also must be adjusted to an approximate air to fuel ratio of 16 to 1. Since the supply of biogas may be interrupted, plan to install an electric ignition or a separate pilot light supplied by a reliable fuel source such as LPG. In some cases the appliance requires a larger biogas supply pipe. Use Table 18 to size this pipe.

**Table 16. High Heat Value of Various Fuels**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>High Heat Value</th>
<th>Amount Equivalent to 1,000 cu ft of Biogas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td>138,000 Btu/gal</td>
<td>4.4 gal</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>100,000 Btu/1,000 cu ft</td>
<td>6.0 therm</td>
</tr>
<tr>
<td>LPG</td>
<td>92,000 Btu/gal</td>
<td>6.5 gal</td>
</tr>
<tr>
<td>Biogas (60% methane)</td>
<td>580 Btu/ft</td>
<td>1,000 cu ft</td>
</tr>
</tbody>
</table>

**Figure 35. Typical Energy Available from a Northern U.S. Dairy Digester**

[Graph showing energy production per month for a 100 cow dairy]
Table 17. Orifice Diameter Multiplier for Gas Appliances

<table>
<thead>
<tr>
<th>Percent Methane in Biogas</th>
<th>Natural Gas [1,000 Btu/ft³]</th>
<th>Propane [1,000 Btu/ft³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>75%</td>
<td>1.32</td>
<td>1.63</td>
</tr>
<tr>
<td>65%</td>
<td>1.39</td>
<td>1.72</td>
</tr>
<tr>
<td>55%</td>
<td>1.46</td>
<td>1.82</td>
</tr>
<tr>
<td>45%</td>
<td>1.54</td>
<td>1.92</td>
</tr>
<tr>
<td>35%</td>
<td>1.61</td>
<td>2.04</td>
</tr>
</tbody>
</table>

Example: A natural gas appliance with an orifice diameter of 0.12" would have to be drilled to 0.12 x 1.54 = 0.187" diameter for biogas with 55% methane.

Notes: The area multiplier is the diameter multiplier squared. Gas densities @ 68°F and 14.7 psia.
- Lactam displace < 0.344/hr ft².
- Natural gas < 0.006/hr ft².
- Methane < 0.006/hr ft².
- Biogas, 65% methane < 0.070/hr ft².
- Dry air < 0.025/hr ft².

Table 18. Size of Biogas Piping

<table>
<thead>
<tr>
<th>Natural</th>
<th>Internal</th>
<th>Pipe Diameter</th>
<th>Pipe Length, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1/4</td>
<td>0.308</td>
<td>360</td>
<td>600</td>
</tr>
<tr>
<td>1-3/8</td>
<td>0.450</td>
<td>360</td>
<td>600</td>
</tr>
<tr>
<td>1-1/2</td>
<td>0.625</td>
<td>360</td>
<td>600</td>
</tr>
<tr>
<td>2-1/2</td>
<td>0.875</td>
<td>360</td>
<td>600</td>
</tr>
<tr>
<td>3</td>
<td>1.250</td>
<td>360</td>
<td>600</td>
</tr>
</tbody>
</table>

Maximum Capacity in Cubic ft per hour of Standard Iron Pipe Carrying Biogas of 0.95 Specific Gravity. Based on Pressure Drop of 0.5 In. Water Column

Velocity at the left of the vertical line exceed 12 ft/sec.

Electricity Generation

Converting biogas to electrical energy seems convenient, but it requires additional management and capital expenditure. However, electricity represents a convenient form of energy that is required throughout the year. An engine generator converts only 20% to 25% of the biogas energy to electrical energy. The bulk of the energy is converted to heat. Heat exchangers typically recover 40% to 50% of the energy in the biogas as hot water. Thus the production of both heat and electricity from an engine-generater, called cogeneration, is 60% to 70% efficient. Remember, however, that as much as half the available heat may be required to heat the digester in the winter.

• Engine-Generator Size

An engine generator may be the sole source of electrical energy to the farm. But electrical demand varies widely over the day. For example, typical demand for a 200 cow dairy peaks to over 44 kW at each milking, while the average daily demand is only about 18 kW (Figure 40). It is difficult to match electrical production over this range of demand.

Many utilities, however, buy electricity at a lower rate than they sell it to the farm. In this case, it may be best to size the generator to run only during peak demand periods. The electrical savings are balanced against the additional capital costs for gas storage and a larger generator.

A second option is to select the engine generator set to operate at a constant electrical output for part of the day and connect it to the electrical utility grid. The utility then supplies the peak power needs of the farm and buys back electricity from the generator during periods of low farm electrical demand. The amount of biogas produced normally limits the size of the engine generator. Table 19 lists appropriate sizes of engines and generators for various levels of biogas production.

Table 19. Engine-Generator Sizing for Constant Electrical Output

<table>
<thead>
<tr>
<th>Daily Biogas Producing</th>
<th>Operating Hours per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 hours</td>
<td>12 hours</td>
</tr>
<tr>
<td>E</td>
<td>E</td>
</tr>
</tbody>
</table>

It is possible to purchase an engine-generator that will vary output with the farm’s electrical load. This type of unit operates independently from the utility, so it must be sized to handle the largest electrical load. It requires a detailed study of heating and lighting electric loads, electric motor loads, starting power requirements of electric motors, and timing of all electrical loads. Such a detailed study should be performed by an engineering consultant or supplier of electric generator sets. Normally this unit is too complex and costly for on-farm biogas units.

• Engines

Biogas has a lower energy density than most fuels, a high octane rating, and a low cetane rating (Table 20). It operates high compression spark ignition engines well, but the low cetane rating requires it be combined with a pilot fuel to initiate combustion in compression ignition (diesel) engines. Power output of a biogas fueled engine is about 80% of the same engine operating on gasoline.

Table 20. Properties of Selected Fuels

<table>
<thead>
<tr>
<th>Properties</th>
<th>Methane</th>
<th>Biogas</th>
</tr>
</thead>
<tbody>
<tr>
<td>E = Engine horsepower rating on biogas based on engine energy use efficiency of 20% E = Gas Production from energy efficiency 11% G = Electrical output of generator in kilowatts.</td>
<td>Nat. Gas</td>
<td>1,000</td>
</tr>
<tr>
<td></td>
<td>Oil</td>
<td>100-110</td>
</tr>
<tr>
<td>Octane Rating</td>
<td>11 to 12</td>
<td>10 to 12:1</td>
</tr>
<tr>
<td>Engine Compression Ratio</td>
<td>12 to 1:1</td>
<td>10 to 14:1</td>
</tr>
</tbody>
</table>

• Modifications - Spark Ignition Engines

In most situations, the spark ignition engine will be designed and rated for gasoline use. Biogas requires a large spark advance, typically 30° to 40° BTDC for an 1800 rpm engine.

The fuel-air mixture critically affects engine efficiency; peak efficiency occurs with a slightly lean mixture. A gasoline carburetor must be modified or have a high-speed metering value added to it to meter more biogas to the engine. A natural gas carburetor designed to supply one pound of natural gas for every 17 pounds of air, must also be modified to supply one pound of biogas for every 6 pounds of air. Biogas may be supplied at 4:1 to 12:1 of water pressure, depending upon design.

The high octane rating of methane allows the biogas to be run in an engine with a high compression ratio for greater fuel efficiency. The engine should have a compression ratio between 12 and 14 to 1 (see Figure 41). At 15 to 1 audible knocking reduces engine life. Below 12 to 1, fuel efficiency drops rapidly. Most stock gasoline and LP-gas engines have compression ratios of only 8 to 10 and 1 to 1 respectively, so some sacrifice in fuel economy may be necessary.
Generators

An induction generator will always synchronize without controls because the utility powers the generator's electric field which controls its output. When an induction machine runs as a motor, its rotor turns at a speed slightly less than its synchronous speed (generally 1800 R.P.M.). If the same machine is coupled to an engine that turns at slightly greater than synchronous speed and an exciting voltage is applied, power will be generated. The faster the induction generator is driven above synchronous speed, the greater the electrical power output.

A synchronous generator generates its own electrical field; thus it needs special controls to match its power production to the utility. Manual synchronization is not acceptable, especially with an inexperienced operator. An automatic synchronizer eliminates errors which may damage a generator or engine. It may also be necessary to include special voltage regulators for paralleling operations and a power factor controller. Often the extra controls needed by a synchronous generator may exceed the cost of the generator. All control systems should be planned with the cooperation of the electric power and engine-generator suppliers.

Waste Heat Recovery

Properly sized cooling water and exhaust gas heat exchangers will capture about 45% of the total energy in the biogas as hot water. For example, an exhaust gas heat exchanger may be purchased as part of the engine silencer. All surfaces exposed to the coolant water in an open (non-pressurized) system should be stainless steel to prevent scaling and降低 corrosion.

A temperature mismatch between that required by the digester heat exchanger and the engine may occur, however. The engine operates best with a coolant temperature of about 190°F. Most studies recommend that the temperature of the digester's heat exchanger not exceed 140°F to prevent buildup of manure residue on the exchanger surface which lowers heat transfer, and to maintain a uniform temperature throughout the digester. Studies at Cornell University, however, measured no reduction in heat transfer when 170°F-180°F water was circulated through a digester's heat exchanger for over 500 hours.

Gas Scrubbing

Gas scrubbers remove various components from biogas, such as carbon dioxide, water vapor, hydrogen sulfide, and mercaptans.

Carbon dioxide by itself is an inert gas; however when it mixes with water, it forms a mild carbonic acid which can corrode some equipment. More importantly, carbon dioxide reduces the energy density of biogas. Removal of carbon dioxide leaves mostly methane which requires 40% less storage volume for the same energy level. Unfortunately, carbon dioxide scrubbing is very expensive and requires large amounts of scrubbing medium or energy to regenerate the scrubbing medium.

Each 1000 cu ft of biogas coming from the digester contains about 0.3 gallon of water vapor. Most of this water will condense out as the gas cools and must be collected in traps and drained regularly (Figure 43).

Hydrogen sulfide, a corrosive and highly toxic gas, smells like rotten eggs in low concentrations. At higher concentrations or after prolonged exposure, the gas paralyzes the odor sensing nerves. Hydrogen sulfide is found in biogas at a concentration of 0.2% or more. At this concentration, especially with water vapor present, hydrogen sulfide seriously corrodes pipes, valves, burners, compressors and engine bearings. It is particularly detrimental to copper and its alloys; in fact, standard brass gas valves often become inoperative after one year of contact with unscrubbed biogas. Engine and compressor manufacturers generally recommend that the level of hydrogen sulfide for wet gas be kept below 0.1%.

Emergency Fuels

During start-up and in emergencies, the digester may not produce enough biogas to run the engine. Many times it will be essential to run the engine with a substitute fuel. A low compression spark ignition engine may be switched to gasoline. Timing and the fuel supply metering value needs readjusting for peak performance.

A diesel engine that has been converted to spark ignition will not run on gasoline because of its high compression ratio. It will run on alcohol, if a carburetor is added. The biogas-diesel fueled engine will still run on diesel alone, but timing should be changed.

Selection and Maintenance

Engine maintenance is the single largest cost of operating the digester and gas fueled equipment. Some things that can be done to reduce operating and maintenance costs include:

- Purchase a heavy duty stationary industrial engine. Heavy duty engine bearings, crankshaft, pistons and block contribute to longer engine life between overhauls.
- An engine operating 24 hours per day will run more than 8,000 hours each year.
- Install a slow speed engine. Slower engines experience less wear with time. In most situations, the engine must run at 1,800 RPM due to the requirements of the generator. In special circumstances, 1,200 RPM generators may be available.
- Specify that valves and valve seats be hard-faced to withstand the lack of lubrication from gaseous fuels.
- Try to find an engine with aluminum bearings. Copper, bronze and brass based bearings corrode rapidly from the high sulfur content in the biogas.
- Scrubbing the gas to remove sulfur compounds will reduce wear, but it is difficult and expensive. (See section on gas scrubbing.)
- Consult the supplier for proper lubricant selection. Monitor engine lubricant temperature and do not allow it to exceed 200°F. Run oil tests every 100 hours to check engine wear and impurity build up.
- Conventional spark plugs wear rapidly. Install inconel base or platinum or gold plated plug electrodes to prevent rust.
- House the unit in a dry shelter.

Any engine needs regular maintenance. Table 21 suggests typical maintenance intervals for an engine operating on scrubbed (no hydrogen sulfides) biogas. An overhaul includes replacement of valves, rod and main bearings, piston rings and reboring of cylinders. The crankshaft and pistons should also be checked. In some instances valves may need replacing more often. Proper engine selection, good lubrication and clean fuel will greatly reduce the frequency of major overhauls.

Table 21. Typical Engine Maintenance Schedule

<table>
<thead>
<tr>
<th>Interval</th>
<th>Change oil and oil filters</th>
<th>100 - 200 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tareup and change plugs</td>
<td>300 - 500 hours</td>
<td></td>
</tr>
<tr>
<td>Major overhaul</td>
<td>5,000 - 10,000 hours</td>
<td></td>
</tr>
</tbody>
</table>
Table 22. Characteristics of Synchronous and Induction Generators

<table>
<thead>
<tr>
<th>Synchronous</th>
<th>Induction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readily available</td>
<td>Simple, rugged construction.</td>
</tr>
<tr>
<td>Can supply stand alone power</td>
<td>Easily paralleled to the utility; no synchronizing equipment required.</td>
</tr>
<tr>
<td>Requires costly synchronizing controls</td>
<td>Can supply stand by power.</td>
</tr>
</tbody>
</table>

Unscrubbed gas causes more frequent maintenance. Oil may need changing every 50 hours or less and the engine may require an overhaul after 1500 hours.

An oil analysis after every 50 to 100 hours of operation will help to diagnose impending engine problems. The capacity of the oil to neutralize high sulfur fuel is indicated by its Total Base Number (TBN). An oil with a high TBN of 10 helps avoid rapid buildup of acid in the oil, particularly with unscrubbed gas.

• Controls and Safety Devices

Because the engine will not be monitored closely it should include:
- A governor to regulate engine speed. Precise control of engine speed is possible with an electric governor. Less control may be obtained with a mechanical or hydraulic governor.
- Automatic controls that stop the engine for high coolant temperature, low oil pressure and engine overspeed; and
- Controls for low gas pressure and low voltage output are also desirable.

Most farms with biogas digesters generate electricity in parallel with the electric utility. The farm may then purchase electricity from the utility during peak loads and sell electricity during off-peak periods. The utility must be consulted about connecting generating equipment to their lines. Parallel generation requires a manual disconnect switch between the main circuit breaker and the generator. The switch must be lockable and located outside any building, so that utility personnel may have access to it at all times. This switch allows the utility to disconnect from the farm generator for line repair or in case the generator becomes a safety hazard.

• Removing hydrogen sulfide

Both high pressure and low pressure hydrogen sulfide scrubbers are available. High pressure (20-25 psig) scrubbers for farm use are not recommended because the unscrubbed, corrosive gas must be compressed.

Compressors that can handle wet, corrosive gas with reasonable life are extremely expensive ($20,000).

Low pressure scrubbers operate at the same pressure as the digester, or a few inches of water pressure. Chemically active filters, molecular sieves, and iron sponge will all remove hydrogen sulfide. Few scrubbers have operated well for long periods on the farm. Estimated costs for typical dairies are listed in Table 23.

Table 23. Hydrogen Sulfide Scrubbing Costs for Typical Dairies

<table>
<thead>
<tr>
<th>Size (cow/day)</th>
<th>Active Filter Cost</th>
<th>Iron Sponge Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 Cow Dairy</td>
<td>Initial Cost 275</td>
<td>$84</td>
</tr>
<tr>
<td></td>
<td>Yearly Cost 76</td>
<td></td>
</tr>
<tr>
<td>100 Cow Dairy</td>
<td>Initial Cost 275</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>Yearly Cost 76</td>
<td></td>
</tr>
<tr>
<td>200 Cow Dairy</td>
<td>Initial Cost 550</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>Yearly Cost 156</td>
<td></td>
</tr>
<tr>
<td>500 Cow Dairy</td>
<td>Initial Cost 895</td>
<td>382</td>
</tr>
<tr>
<td></td>
<td>Yearly Cost 234</td>
<td></td>
</tr>
</tbody>
</table>

The amount of sponge needed depends on flow rate and the amount of hydrogen sulfide in the gas. Iron sponge becomes black when completely fouled with hydrogen sulfide and mercaptans. It may be regenerated by exposure to air which returns it to its original brown color. The life decreases by about 30% after each fouling regeneration cycle; for the most economical operation, the sponge should be regenerated only twice before placement. Take care to keep the sponge damp during regeneration, or the heat generated by the chemical reaction could burn the sponge.

On-farm experience with gas scrubbers is limited, but generally has not been good. Most scrubbers, such as an iron sponge, must be moist, but not wet, to work effectively. Wet gas eventually saturates and fouls a sponge, and gas with little or no moisture, dries it so much it will not work.

Figure 45. Variable Volume Low Pressure Storages

Gas Compression and Storage

• Storage Options

Gas storage evens out the mismatch between gas production and its use. Gas compression and storage also acts as a buffer allowing components to operate efficiently at a constant pressure. Options to consider include:
- Store in the space between the manure and a flexible top cover. The cover then deflates as gas is used. But the digester must be sheltered to protect the cover from wind damage when it deflates.
- Store at low pressure in a flexible storage bag or rigid tanks. (Figure 45.)

Figure 44. Dual Chamber Iron Sponge Scrubber
- Compress to medium pressure (200 psi) into rigid tanks such as propane tanks. (Figure 46)

**Figure 46. Medium Pressure Storage of Biogas**

- Compress to high pressure (2000 psi or more). High pressure storage requires an expensive compressor that has a high energy demand. In addition the carbon dioxide and water vapor must be removed from the biogas. This technology has not been economical for general storage. (Figure 47)

**Figure 47. High Pressure Storage of Biogas**

- Provide no storage. Use only as much gas as is produced during low production periods and let the excess gas escape (flare off).

**Compression**

Gas compression requires a substantial energy input disproportionate to the degree of compression (final pressure) and quantity (cubic feet of gas to be compressed per minute). In addition, an oversized compressor starts and stops more frequently than a properly sized one. The start-up energy demand is two to four times more than needed for continuous running and can become the major cost for operation. Table 24 lists the approximate energy needed to compress all the biogas produced on several farm sizes.

**Flammable gas compressors**, rather than standard air compressors are best for long and safe operation. The differences between the two are important. In a flammable gas compressor:

- The cylinder end is farther from the crankcase
- Higher quality packings and hardened connecting rods are used.
- Special passageway vents leak to prevent explosive mixtures from forming in the crankcase.

**Table 24. Energy Required for Medium Pressure Storage at 150 psi**

<table>
<thead>
<tr>
<th>Biogas Cubic Yards</th>
<th>50</th>
<th>2.2 scf</th>
<th>100</th>
<th>4.4 scf</th>
<th>150</th>
<th>13 scf</th>
<th>200</th>
<th>32 scf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min. N Required</td>
<td>3/4</td>
<td>1.1/2</td>
<td>5</td>
<td>1/2</td>
<td>7</td>
<td>1/2</td>
<td>9</td>
<td>1/2</td>
</tr>
<tr>
<td>Energy Required</td>
<td>15.8</td>
<td>21.4</td>
<td>105.3</td>
<td>157.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generator Efficiency Required</td>
<td>155</td>
<td>155</td>
<td>178</td>
<td>195</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yearly Cost $7 cent/kWh</td>
<td>$223</td>
<td>$448</td>
<td>$1,136</td>
<td>$2,228</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

100 psi absolute pressure, energy values based on all the gas produced going through compressor. Energy required to generate 1 kW-hr slightly higher because the electric motor available is 5 hp.

**Table 25. Volume required to hold 2,000 cu ft of Methane at a Given Pressure**

<table>
<thead>
<tr>
<th>Pressure, in Scf in</th>
<th>Volume, in Scf</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>1,087</td>
</tr>
<tr>
<td>100</td>
<td>679</td>
</tr>
<tr>
<td>200</td>
<td>421</td>
</tr>
<tr>
<td>500</td>
<td>100</td>
</tr>
<tr>
<td>1,000</td>
<td>10</td>
</tr>
</tbody>
</table>

1,000 cubic feet of methane at atmospheric pressure is equal to 25 gallons of gasoline. Assumes adiabatic compression.

**Table 26. Storage Needs for One Half Day Gas Production**

<table>
<thead>
<tr>
<th>Cubic Feet of Storage</th>
<th>50 scf</th>
<th>100 scf</th>
<th>150 scf</th>
<th>200 scf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vol. L/12 day Gas Produced</td>
<td>1,575</td>
<td>3,150</td>
<td>4,950</td>
<td>7,570</td>
</tr>
<tr>
<td>Low Pressure (6&quot; 80)</td>
<td>1,983</td>
<td>3,105</td>
<td>4,113</td>
<td>5,812</td>
</tr>
<tr>
<td>Med. Pressure (100 psi)</td>
<td>232</td>
<td>446</td>
<td>1,390</td>
<td>2,315</td>
</tr>
<tr>
<td>Med. Pressure (150 psi)</td>
<td>195</td>
<td>309</td>
<td>927</td>
<td>1,144</td>
</tr>
<tr>
<td>Med. Pressure (200 psi)</td>
<td>136</td>
<td>232</td>
<td>695</td>
<td>1,198</td>
</tr>
</tbody>
</table>

**Gas Pipeline**

**Materials**. Plastic gas lines may be used inside the digester. Exposed gas piping is generally standard weight galvanized steel because the National Gas Code prohibits plastic pipe for above ground use. Where gas lines contact the manure, cast iron is preferred for its high corrosion resistance. Copper is not suitable because it corrodes rapidly. Buried galvanized steel requires a protective coating, particularly in highly acid or alkaline soils.

**Size**. Table 18 lists maximum flow rate for various sizes of iron or steel pipe. The National Gas Code recommends that the pressure drop in low pressure (less than 0.5 psi) gas lines not exceed 0.5 inches of water. Sulfur and other material tend to collect on metal pipe and reduce its effective diameter. To reduce the effect of clogging, plan to install 1/4" diameter pipe as a minimum. After the gas is cleaned, or where pipe is easily accessible, 3/4" pipe is available.

**Gas Velocities** less than 12 feet per second prevent carry over of water from condensate traps.

**Installation**. Let gas pipes enter the digester below the manure surface. It is easier to form a manure tight seal around the pipe when the digestor wall than a gas tight seal above the manure surface. Cement plaster or silicone rubber caulking will form a tight seal. Extend the gas outlet at least a foot above the manure. An overloaded digester may form and flood or clog the gas line unless its inlet is well above the manure surface.

**Slope** all gas lines to drain any moisture to condensate traps. Support pipes sufficiently to keep them from sagging. Low points in a sagging pipeline may collect enough condensate to stop gas flow and overpressurize the digester. Support horizontal runs of iron pipe every 8 to 10 feet and plastic pipe every 4 feet. Slope gas lines 1/4 inch per foot of run; where this much slope is not possible, slope at least 1/8 inch per foot.

When installing the pipe, reel it to remove burrs and use factory fittings. Apply pipe dope to pipe threads, teflon tape is not gas tight. On completion test the gas piping by putting in under gas pressure at least 10 psi for 15 minutes. The pressure should not drop in that time.

**Gas Equipment**

**Condensate Traps**. One thousand cubic feet of biogas at 80°F contains 0.3 gallon of water. Upon cooling to 60°F, 0.2 gallon will condense. Condensate traps at all low points or changes in vertical direction are needed to collect from 0.6 to 3 gallons of water a day. Positive traps which do not allow gas to escape while they are emptied keep hazardous accumulations of gas from forming. Manual traps are preferred to float operated traps which sometimes stick open and allow gas to escape.

**Flame traps** protect the digester from flash back from engines or burners. A metal gauze trap or water trap through which the gas bubbles (.Figure 48) will work. Install the trap as close to the point of ignition as practical.

**Figure 48. Combination Flame and Condensate Trap**

**Gas meters** which measure gas production are an important indicator of whether the digester is operating properly. Conventional diaphragm type, natural gas meters do not operate satisfactorily with the wet, dirty corrosive biogas. Rotameters, Venturi-meter tubes, orifice type, and rotary displacement flow meters may be used instead.

**Pressure controls**. Gas pressure may be controlled with a pressure relief device. Either a weighted device or liquid-level device (Figure 49) may be set to relieve gas pressure. The device should be 6 to 8 inches above the liquid level, depending on the design of the gas system and digester roof. The relief must be properly vented to avoid gas accumulations.

Equipment may consume the biogas faster than it is generated and form a vacuum that draws in air. An explosive methane-air mix could result. (The explosive range is from 9 - 20% by volume biogas in air.) Install a low pressure or vacuum cutout switch in rigid digester tubing to stop the equipment when a low pressure occurs.
Digester Startup and Operation

**Startup**
Before adding manure, test as many digester components as possible. For example:
- Pressurize the heating pipes overnight with water to about 50 psi and check for leaks.
- Check the accuracy of temperature sensors with a known accurate thermometer by immersing both in a pan of hot water.
- Pressurize the gas pipelines with air and check for leaks by pouring soapy water over the joints and watching for gas bubbles.
- Check pressure relief devices. Once the components have been checked, the digester may be started in one of several ways. Filling or seeding with recently anaerobically digested sewage sludge or effluent from another farm digester starts production quicker and more surely than only adding manure. Seed from 10% to 80% of the digester volume; the more seed added, the faster the system will reach full gas production. Once the seed is added, heat it to 90°F before adding manure. Then slowly feed the digester. Start by adding manure at half of the normal feed rate each day for a week. Gradually increase the amount of manure added over a two to four week period depending on the amount of the initial seed. During the startup, monitor pH, volatile acid level, and gas composition. The pH should move toward 7 or just above. Volatile fatty acid concentration is a good indicator of bacterial activity. It may increase initially, but it will decrease as gas production increases. Carbon dioxide concentration in the biogas is also a good indicator of the digester status.

If anaerobically digested seed is not available, the digester may be slowly filled with raw manure. If possible, store some manure for 2 to 3 weeks in an anaerobic lagoon or tank. Anaerobic bacteria will grow as seed to speed the startup. Start at one quarter the loading rate, keep the manure temperature at 95°F, monitor volatile acid level, pH and gas composition, and slowly increase the feed rate over 2 or 3 months. If the pH drops or the volatile acid level increases, stop feeding for a few days until conditions become stable and the rate can be increased.

**Operation**
Feeding. Uniform frequent feeding works best. Add manure to the digester at least once a day and more often if desired.

Temperature. Bring the manure quickly up to an operating temperature of 95°F. Temporary foaming and higher gas output may occur as the digester stabilizes.

Gas Purging. Startup can form an explosive gas mix if the digester is started without a seed so that biogas develops slowly and mixes with air in the enclosed digester. To avoid the danger of an explosion, vent a digester that is started without a seed for a week or more to purge the air. In a seeded digester, fermentation begins quickly and consumers the oxygen so purging is not necessary.

Safety. Do not smoke or use an open flame around the digester, particularly when venting it. Never enter a digester unless it is open, empty, well ventilated, and, preferably, hosed down. Even then, wear a safety harness attached to a rope and have one or two people outside ready to pull you out with the rope in case you are overcome by toxic gases.

Restarting. Restart a digester that has been emptied the same way as the original startup. If possible, store some of the emptied contents as seed. Refill with the seed, heat it to 95°F, and gradually increase the feedrate.

**Troubleshooting**
Keep a daily log of performance to help spot trouble early. A log such as the example in Figure 51 gives a record of changes due to variations in the manure or the operation of the digester. Use it to record:
- Daily biogas production
- Digester temperature and pressure
- Daily electrical production
- Influent and effluent pH
- Carbon dioxide content of the gas

A decrease in biogas production over a day or two indicates such problems as overloading, toxic materials, poor temperature control, reduced feed rate, or leaks. Changes in digester temperature, gas pressure and electrical output indicate possible need for repairs to the digester or engine-generator. Stop or slow the feeding of the digester if the temperature drops.

The pH normally ranges from 7 to 8. If the pH drops below 7 for more than a day, stop feeding the digester for a day or two to allow the methane bacteria to convert the excess acid to biogas. Electronic pH meters accurately measure pH, but paper which changes color in acid gives an acceptable test.

The carbon dioxide content in biogas ranges from 30% to 48% in an operating digester. It will be higher during startup. Simply burning the gas gives some indication of methane content as it only burns when it has 50% or more methane. A sudden increase in the carbon dioxide level gives an early indication of trouble.

**Figure 51: Sample Log for Digester Record Keeping.**

<table>
<thead>
<tr>
<th>DATE</th>
<th>TIME</th>
<th>GAS METER READING</th>
<th>DIGESTER TEMPERATURE</th>
<th>AIR TEMPERATURE</th>
<th>DIGESTER GAS PRESSURE</th>
<th>GENERATOR OUTPUT (Electric Meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Approximate time/weight contributing wastes to digester:

Additional comments: (pH of influent or effluent, CO2 level, maintenance notes, etc.)
APPENDIX A. Estimating Digester Volume and Yield

The volume of a digester and its biogas output may be estimated from Table 23. The estimates are only valid for undiluted manure or manure that is only slightly diluted with about 15% added water. Increase the digester volume if a greater amount of dilution water is added.

Table 23. Manure Production from Various Livestock and Biogas Yield from a Properly Functioning Anaerobic Digester

<table>
<thead>
<tr>
<th>Animal Unit</th>
<th>Average Animal Production (wt/lbs)</th>
<th>Dairy Manure Size (cu ft)</th>
<th>Expected Daily Biogas Yield (cu ft/animal)</th>
<th>Recommended Retention Time (days)</th>
<th>Electricity Production (kWh/day/animal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holstein milking cow b</td>
<td>1050</td>
<td>1.25d</td>
<td>54</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>Beef</td>
<td>800</td>
<td>1.0</td>
<td>25</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Feeder pigs</td>
<td>130</td>
<td>0.16</td>
<td>5.6</td>
<td>15</td>
<td>0.2</td>
</tr>
<tr>
<td>Sow unit c</td>
<td>Farrow to Finish</td>
<td>1300</td>
<td>1.75</td>
<td>56</td>
<td>2</td>
</tr>
</tbody>
</table>

a Solids, liquids and 15% extra volume from waterers and wash water.

b Increase digester volume by 50% if manure from dry cows and replacement stock is added.

c Assumes average weight of pig and sow at any time in an operation per productive sow. A sow produces an average of 16 pigs per year.

d Assumes biogas has an energy value of 500 BTU/cu ft and the generator operates at 21% overall efficiency.

Generator Size (kW) = (No. Animals x Electricity Production (Operating hours per day per Animal)

Selected References


Research Results in Manure Digestion. Rumpf, Refeeding, Odors. NRPS-25. Midwest Plan Service, Iowa State University, Ames, IA.