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Methane Generation from Livestock Waste

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The energy shortage, coupled with concern for the management of livestock wastes, has revived an interest in methane generation from livestock manures.

The conversion of organic materials, such as animal wastes, to an easily utilizable form of energy can be accomplished by a number of methods. The process which appears to hold the greatest immediate potential is anaerobic fermentation or digestion which converts organic materials to methane and other gases. The extraction of energy from wastes using anaerobic digestion to produce bio-gas is not new and the general technology is well known. Bio-gas, which is methane and other gases, has been known as swamp gas, sewer gas or fuel gas. Sewage treatment plants constantly generate bio-gas from the sewage sludge as part of the sewage treatment processes. Many small units were used in Europe after World War II. The World Health Organization assisted in the development of bio-gas production for energy purposes in India.

On the other hand, methane production requires closely controlled production facilities. One feasibility study indicated that methane could be economically produced only if the cattle herd numbered at least 10,000 head. Another study estimated that the physical plant to produce methane with a 60-head cow lot would cost $20,000 (prior to recent price increases).

The newness lies in the application of the technology to energy extraction from agricultural wastes, primarily livestock manures. Until only recently, energy has been cheap and abundant and there was little need to be concerned with alternative energy production sources.

Basic Elements in Digester System

Figure 1 shows the basic elements of a single-stage anaerobic digester. Submerged inflow and outflow lines are needed to prevent gas from escaping. Either a mechanical mixer can be used or the liquid or gas can be recirculated for mixing.

A heat exchanger and thermostat are used to maintain the proper temperature. The heat exchanger can be either internal or external.

A method is needed to transport the wastes from the animal to the digester. Flushing or scraping systems are well adapted because they can provide frequent waste removal for feeding. Lagoon storage is generally the most practical for the waste removed from the digester.

Methane is drawn off the top in the digester. For gas utilization, a compressor and storage tank are used along with the hardware to provide flame traps, regulators, pressure gauges, hydrogen sulfide scrub-

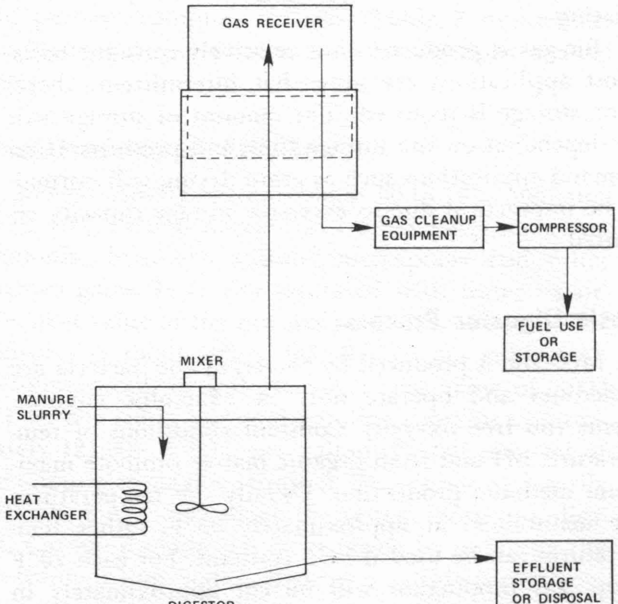

Fig. 1.—Basic components of anaerobic digester for bio-gas generation.

ber, carbon dioxide removal and pressure relief valves. A common facility for gas storage is the floating cover which floats upward while maintaining essentially constant pressure.

Methane or bio-gas cannot be converted to a liquid under normal temperatures as can LP gas (LP gas liquifies at 160 psi). Under constant temperature, volume reduction is inversely proportional to the pressure; that is, as the pressure doubles the volume becomes half as large. The more the gas is compressed the more energy it takes to compress it. Liquification of methane requires pressures of nearly 5,000 psi and is not practical. If the gas is compressed to only 1,000 psi, it requires about 1,320 B.T.U. of energy to put 6,350 B.T.U. into a storage container.

Since bio-gas cannot be liquified, it is best suited for such stationary uses as cooking, heating water and buildings, air conditioning, grain drying or operating stationary engines. It is not feasible for use as a tractor fuel. One cubic foot of compressed bio-gas at 3,000 psi would run a 100 horsepower tractor approximately 7½ minutes. Most tractor fuel tanks occupy about 8 cubic feet. A special high-pressure tank with 8 cubic feet of gas and 3,000 psi would run the tractor approximately 1 hour. A 3,000 psi tank bouncing around on a tractor would present a serious safety hazard. The tractor would run 6 minutes on 8 cubic feet of gas compressed to 300 psi, a more realistic pressure.

If we assume a well-insulated three-bedroom home takes about 900,000 B.T.U. per day for heating during cold weather and assuming 50 percent of the bio-gas goes back into maintaining the necessary temperature of the digester, it would take the manure from 50 cows to produce enough bio-gas each day for home heating.

Bio-gas is produced on a relatively constant basis. Most applications are somewhat intermittent; therefore, storage is required. The amount of storage will be dependent on the storage time and pressure. High demand applications such as grain drying will normally be impractical due to excessive storage capacity required.

Basic Digester Process

Methane is produced by bacteria. The bacteria are anaerobes and operate only in anaerobic environments (no free oxygen). Constant conditions of temperature, pH and fresh organic matter promote maximum methane production. Usually the temperatures are maintained at approximately 95°F. Other temperatures can be used if held constant. For each 20°F drop, gas production will be cut approximately in half or will take twice as long. Likewise, for each 20°F rise activity will double (up to 135°F maximum). The factors to be considered are the energy requirements to maintain the digester temperature and the gas production. A constant temperature is very critical. Temperature variations of as little as 5°F can inhibit the methane-formers enough to cause acid accumulation and possible digester failure.

Anaerobic digestion is a two-part process and each part is performed by a specific group of organisms. The first part is the breakdown of complex organic matter (manure) into simple organic compounds by acid-forming bacteria. Several species of acid-forming bacteria grow and reproduce rapidly and are not very sensitive to their environment. They essentially break down complex organics and produce primarily acetic acid and propionic acid.

The second group of microorganisms, the methane formers, break down the acids into methane and carbon dioxide. This group is composed of a relatively few species of bacteria that grow and reproduce slowly and are quite sensitive to their environment.

In a properly functioning digester, the two groups of bacteria must be balanced so that the methane-formers just use the acids produced by the acid-formers. If the acid-formers get ahead of the methane-formers, acids begin to accumulate, the pH drops, the methane-formers are inhibited and ultimately digestion ceases. The balance of the two groups of bacteria is affected by several factors, including loading quantity, quality and frequency, as well as temperature, toxic elements and pH.

A simple apparatus can produce bio-gas. The amount of the gas and the reliability desired have a great influence on cost and complexity of the system. A simple batch-loaded digester requires an oxygen-free container, relatively constant temperature, a means of collecting gas and some mixing. Since methane gas is explosive, appropriate safety precautions are needed.

You can simply place a mixture of organic matter and water in the digester and allow it to decompose completely. However, this is inefficient for producing methane, as production goes from no methane to a peak and back to none. Feeding at least once a day is necessary to insure good conversion to methane. Under the use of a batch system, it may take two weeks to a month before gas production begins; therefore, the maintenance of the most desirable microbial environment will make the system more efficient and reduce the required detention time. For maximum efficiency, continuous feeding and removal of digested manure is desirable.

Tank size is controlled by the number, size and type of animals served, dilution water added and detention time. The factor that can be most easily changed with regard to tank size is detention time. Ten days is the minimum, but a longer period can be used. The longer the detention time the larger the tank must be. Longer detention times allow more complete decomposition of the wastes. Fifteen days is a frequently used detention time. Table 1 shows some recommended sizes, dilution ratios and loading rates for different types animals.

Table 1. Loading rate guidelines for heated, mixed anaerobic digesters at 95°F being fed fresh livestock manures (From R. J. Smith, The Anaerobic Digestion of Livestock Wastes and The Prospects for Methane Production, Midwest Livestock Waste Management Conference, ISU, Ames, Ia., November 27-29, 1973).

Factor	*Swine Growing-Finishing*	*Dairy*	*Beef Under 700 lbs.*	*Poultry Layer*	*Poultry Broiler*
Dilution ratio manure: (manure and water)	1:2.9	Undiluted	1:2.5	1:8.3	1:10.2
Estimated dilution water, gal. water/1,000 lbs. body weight	15	0	11	47	79
Hydraulic detention time, days	12.5	17.5	12.5	10	10
Loading rate, lb. volatile solids/cubic foot/day	0.14	0.37	0.37	0.13	0.1
Digester volume, cubic feet/1,000 lb. animal weight	30	24	14	72	120

Very little volume reduction occurs in an anaerobic digester. Waste fed into the digester will be more than 90 to 95 percent water. The only part that can be reduced is a portion (about 50 to 60 percent) of the solids. The percent reduction is dependent upon the detention time in the digester. Therefore, the maximum volume reduction to be expected may run 5 percent, with 1 to 3 percent more common. The carbon content will be reduced, thus giving a more stable material. The processed material will have less odor. Since it still contains most of the original nitrogen, phosphorus and potassium, and is still highly polluted, the waste cannot enter a stream after it leaves the digester. Lagoons are commonly used to hold the waste until it can be disposed of with final disposal being either hauling or pumping onto agricultural land. Pumping is generally preferred because of the high volume of waste due to dilution. Sludge must be periodically removed and disposed of.

The volume of effluent may actually be greater than the volume of manure prior to digestion. This increase is due to the dilution water added to liquify the manure to the desired solid content for the digester.

There is no increase in the amount of nitrogen, phosphorus or potassium in this material, although it may be in a more available form. A small portion of the nitrogen may be lost to the gas portion of the system, thus reducing the amount of nitrogen initially available.

Gas Production

Total bio-gas production will vary depending on the organic material being digested, the digester loading rate and the environmental conditions in the digester. Under ideal conditions (95°F temperature and proper pH), it is possible to produce about 45 cubic feet of gas at atmospheric pressure from one day's manure from a 1,000 pound cow, or about 60 cubic feet of gas at atmospheric pressure per day from a 1,400 pound cow. Not all of the bio-gas energy is available for utilization. Energy is required to heat and mix the digester, pump the influent and effluent and perhaps compress the gas. Table 2 summarizes the estimated gas production from various animal wastes.

Table 2. Bio-gas production (60% CH_4 and 40% CO_2) from animal wastes per 1,000 pounds body weight.

Animal	*Volatile Solids lb./anim. day*	*Probable Volatile[1] Solids Destruction percent*	*Gas cu. ft/ day*	*BTU[2] per day*
Beef	5.9	45	30	18,000
Dairy	8.6	48	44	26,000
Poultry, layers	9.4	60	72	43,000
Poultry, broilers	12.0	60	92	55,000
Swine (growing-finishing)	4.8	50	29	17,400

[1] Percent destruction of volatile solids will vary depending primarily on detention time and digester temperature.

[2] Calculated at 600 BTU/ft^3 (heat content will vary depending on quality of gas). For comparison some other heating values are: gasoline, 124,000 BTU/gal; diesel fuel, 133,000 BTU/gal; natural gas, 850 to 1,000 BTU/ft^3; propane, 92,000 BTU/gal.

Characteristics of BIO-Gas

Bio-gas usually contains about 60 to 70% methane, 30 to 40% carbon dioxide and other gases including ammonia, hydrogen sulfide, mercaptans and other noxious gases. It is also saturated with water vapor. The heat value of the raw gas at sea level atmospheric pressures is about 500 to 600 B.T.U. per cubic foot. In comparison, natural gas has a heat value of 1,000 B.T.U. per cubic foot and gasoline contains approximately 124,000 B.T.U. per gallon. Partial removal of the impurities may be required. This is not necessarily difficult, but it does make the system more complicated. Carbon dioxide can be removed by bubbling the gas through lime water. Hydrogen sulfide is commonly removed from the bio-gas at municipal anaerobic digesters by the use of iron impregnated wood chips. Wood chips are regenerated by removing them from the gas stream and exposing them to the atmosphere.

Hazards

Methane in a concentration of 6 to 15% with air is an explosive mixture. Since it is lighter than air, it will collect in rooftops and other enclosed areas. It is relatively odorless and detection of its presence may be difficult. Extreme caution and special safety features are necessary in the digester design and storage tank, especially if the gas is compressed.

Summary

The combination of concerns for the energy crisis, environmental pollution control and the fact that agricultural organic wastes account for a major portion of our waste materials have created renewed interest in the processing of these wastes for energy recovery. Of the several types of energy capturing processes available, anaerobic digestion appears to be the most feasible for the majority of agricultural operations. Anaerobic digestion is capable of stabilizing most agricultural wastes while producing bio-gas or methane gas. This concept has been extensively applied in Europe and India during energy shortages. Similar equipment has been used for gas production with domestic wastes.

Primarily, disadvantages are the amount of management required due to the sensitivity of the digesters, the high initial investment required for equipment, and the fact that the wastes still must be disposed of after digestion.

Research is in progress to make the process more practical for energy production. Bacteriologists are investigating new strains of bacteria and culturing techniques for producing methane. Engineers are investigating digester designs and operation to reduce construction and operational requirements and costs.

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