pork industry handbook

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Methane Gas From Swine Manure

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The concept of methane production has appeal to many swine producers as a means of reducing escalating fuel bills. From the estimated 9 million tons of swine manure (dry basis) produced annually in the United States, roughly 75 billion cu. ft. of methane could be produced every year. For this potential to be realized, however, economical methane production units must be developed and demonstrated.

Anaerobic digestion, the process used to produce methane, also stabilizes the swine manure, thereby reducing its odor and fly breeding potential. Essentially all the original nutrients in raw manure are present in the digested slurry and can be recovered by land fertilization. Another possibility for nutrient recovery is centrifugation of the digested slurry to reclaim edible protein feedstuffs.

There are drawbacks, too, however. Since commercial prototype digesters are not widely available, farmers and their consultants may have to design their own methane production systems. Methane is explosive at concentrations of 5-15% in air. Mechanical aspects of manure handling (grinding, mixing, screening and pumping) and general plumbing problems (gas leakage, corrosion of pipes and valves, etc.) have been the major source of problems in methane production, rather than the chemical and biochemical processes. These problems could be overcome by adequate financing and competent engineering design.

Methane is difficult to store, requiring a pressure of 5,000 psi for liquefication, or 30 times the pressure needed to produce liquefied petroleum gas (LPG). Thus, use of methane is limited to continuous, stationary sources such as heating or operation of electric generators near the site of methane production. On a swine farm it may be difficult to satisfy energy needs through methane production alone, and a large swine feeding operation may yield more methane than can be used at that site on a continuous basis.

Sale of methane through a natural gas pipeline system will be practical only in rare circumstances. This is because it would normally take as many as 50,000 hogs to produce 100,000 cu. ft. of methane daily, which is considered the smallest marketable gas quantity. In a typical confinement swine operation, most of the gas should be usable on the farm.

Some of the principles of methane or biogas production together with yields and uses of the product gases on a swine farm are explained in this fact sheet.

Basic Process

Methane (CH_4) is the primary component of natural gas. Like natural gas, pure methane has an energy content of 1,000 BTUs per cu. ft. Bacterial degradation of manure under anaerobic conditions (without oxygen) releases a mixture of gases (biogas) which usually consists of 50-60% methane, 40-50% carbon dioxide, and about 1% by volume of hydrogen sulfide, ammonia and other trace gases. Raw biogas has an energy content of only 500-600 BTUs per cu. ft. Carbon dioxide, trace gases and water vapor can be removed by chemical means, yielding pipeline quality gas.

In anaerobic digestion of manure, bacteria degrade organic solids into organic acids and then into methane, carbon dioxide and water. Changes in the manure loading rate, temperature fluctuations and the presence of oxygen or toxic elements frequently cause problems in the functioning of the digester. The methane-producing bacteria are most sensitive to improper operating conditions, and when they are inhibited, organic acids will accumulate.

The amount of methane obtainable from swine manure varies depending upon the feed ration, manure collection procedures, digester design and operating conditions. The amount of wet manure (feces and urine) produced daily by swine amounts to 4-7% of their body weight. For a 150 lb.

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hog, wet manure production is about 10 lbs. per day, of which about 9 lbs. is water and only 0.7 lb. per day is biodegradable (or volatile) solids.

Usually only 40-60% of the volatile solids is converted within a practical digestion time of 12-18 days. As a general rule, 8 cu. ft. of methane gas is released for every pound of volatile solids converted in the digestion process. Gas yields are discussed later in this fact sheet.

Manure Quality

Ideally, manure for methane production should be collected daily. Biodegradation of volatile solids begins as soon as manure is excreted. Delays in collecting manure and putting it in the digester reduce methane production potential. The quality of swine manure in terms of moisture content, ash content, age, BTU value and/or absence of residues is an important consideration.

A "contaminator" often present in manure is excess water, which comes from drinking cups or nipples, fogging systems and washing systems. Swine manure collected in storage pits beneath slotted floors typically contains 3-6% solids, which is more dilute than the desirable solids concentration of 8-12%. Flush water is increasingly used in swine operations to reduce labor requirements for manure removal. Modern hydraulic flush systems dilute the solids content of manure to 1/2% or less. For a 1/2% solids slurry, a digester would have to be 20 times larger to provide the same digestive efficiency than at 10% solids concentration. Energy needed for heating and mixing would also be much larger. Systems are being developed for concentrating solids from flushed swine manure for anaerobic digestion, but to date 30-50% of the volatile solids is never recovered from the flush water. Significant quantities of methane can still be produced from most swine operations despite problems with dilution water.

System Components

A methane production system may consist of some or all of these steps:

1. Manure handling—collection, hauling, storage.
2. Materials preparation—grinding, mixing, pumping.
3. Anaerobic digester, including agitation and heat exchange equipment.
4. Gas scrubbing—removal of carbon dioxide, hydrogen sulfide and moisture.
5. Gas storage, marketing or on-site utilization.
6. Feedstuffs recovery—screening, centrifugation and drying.
7. Fertilizer recovery—storage pit or pond, irrigation system or tank wagon for land application.

Some components of an anaerobic digester are illustrated in Figure 1.

Anaerobic Digester Types

Anaerobic digesters can be classified according to temperature, degree of mixing, loading frequency and construction materials. In general, anaerobic bacteria digest organic matter with increasing efficiency as temperatures increase from 70-140 F. Two marked peaks in terms of gas production have been found to occur at 95 F and 135 F. Digesters that operate at 95 F are said to be "mesophilic," while digesters designed to operate at near 135 F are "thermophilic." Thermophilic digesters provide peak methane yields per volume of digester and can be 1/2-2/3 smaller than mesophilic digesters. However, they suffer higher heat losses and are reportedly more subject to bacterial upset.

Inside the digesters, the slurry should be mixed often to renew bacterial contact with their food and to release gases of decomposition. However, since mixing takes energy, it is desirable to keep it to a minimum. Some researchers have arrived at a mixing frequency of 15 min. per hr. or less. An exceptional case is the so called "plug flow" digester in which no mixing device is used. Plug flow digesters basically consist of a horizontal tube fabricated of synthetic rubber lining material and placed in a deep trench. Manure slurry flows in one end of the horizontal digester and displaces digested material at the other end. The plug flow concept has worked well for dairy manure but has not been tested with swine manure.

Most anaerobic digesters are loaded at least once each day. Equilibrium conditions are established and maintained so that gas production rate and methane concentration are relatively constant unless unforeseen bacterial upset occurs. Some field experiments have been conducted with batch loaded digesters. But these digesters do not substantially improve methane yield and are less cost effective than are continuously loaded digesters.

Digester Design and Operation

Anaerobic digesters usually consist of concrete and/or steel tanks wrapped with heavy insulation or buried to retain heat. Design of anaerobic digesters is based upon several parameters. *Manure characteristics* of major importance include ash content, carbon content, carbon-nitrogen ratio, biodegradability, ultimate methane yield and specific gas production rate. These depend upon ration, animal species, manure age and manure handling practice.

A second major factor is *hydraulic retention time.* The longer manure stays in the digester, the larger the digester volume needs to be. Gas production occurs rapidly at first but begins to level off after 10-15 days. Correct design involves selecting the best trade-off between gas yield and digester construction cost. For mesophilic systems, retention times of 12-18 days are used. For thermophilic systems, retention times of 5-6 days are usually chosen.

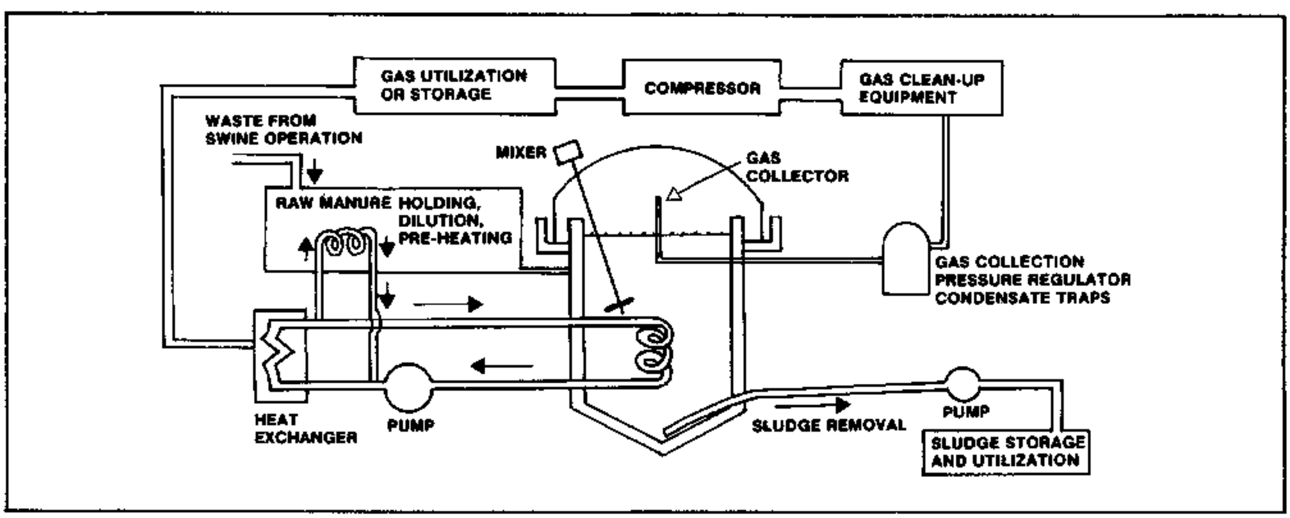

Figure 1. Anaerobic digester.

A third design factor is waste *slurry concentration*, which dictates digester size, performance and cost. To minimize digester size, concentrations should be as high as possible without causing mixing problems or inhibition of bacteria. Desirable concentrations of total solids (ash plus organic matter) are 8-12% total solids. Concentrations are often specified in terms of volatile solids (organic solids) since the ash fraction cannot be digested. The optimum concentration for thermophilic digesters is approximately 8% volatile solids (VS), while 7-8% VS is the proper concentration range for mesophilic digesters.

A fourth factor is *loading rate*, which is usually specified in terms of the weight of volatile solids added to the digester daily per unit of digester volume. Typical volatile solids loading rates are 0.2-0.3 lbs. VS per day per cu. ft. for mesophilic digesters, and 1.0 lb. VS per day per cu. ft. for thermophilic digesters.

The approximate sizes of anaerobic digesters for swine feedlots of different sizes are given in Table 1. These figures are based on the design assumptions outlined above.

Digester Start-up and Operation

Starting with the digester filled with water, only 20% of the normal daily manure loading rate should be applied during the first week of digester operation. Then, the daily manure loading rate should be raised by 20% each week until the full loading rate is reached. It usually takes 60-90 days for a mesophilic anaerobic digester to reach equilibrium conditions. Indications of a stable digester are as follows:

1. pH—proper range is 7-7.8.
2. Methane yield—should exceed 6 cu. ft. methane per lb. of volatile solids fed into the digester.
3. Methane concentration—should reach 55-65% methane on a volume basis.
4. Volatile solids destruction—should level off at about 50% organic matter destruction (40-60% range, depending upon retention time) as determined by inflow and effluent sampling.
5. Alkalinity—an indicator of buffering capacity. It should always exceed 1,000 mg/ l, and many digesters operate above 5,000 mg/ l.
6. Volatile acids—digester slurry should plateau at a volatile acids concentration of about 500-1,000 mg/ l for mesophilic systems and 1,000-2,000 mg/ l for thermophilic systems. Propionic acid should constitute only a small amount of the volatile acids.

After equilibrium conditions are reached, it is important to maintain the correct slurry temperature within a degree or two of accuracy. A sudden change in animal ration can cause temporary decrease in gas production. Some feed additives in a swine ration and some disinfectants can cause digester upset. The best indicators of digester upset are decrease in biogas production and a pH drop.

It may be necessary to shut down a digester periodically to remove the settled manure solids and sand that interfere with mixing and reduce the retention time and effective solids load. When the digester is to be shut down for solids removal, the slurry can first be pumped into a covered holding tank and reloaded after cleanout.

Methane will be produced in time as long as anaerobic conditions are maintained and pH does not fall below about 6.0. Low pH must be neutralized by adding chemicals such as lime or sodium bicarbonate to raise pH to about 7.0. It may take several weeks to produce methane during start-up or following digester upset. Research has demonstrated that good digester stability is achieved if input conditions remain fairly constant.

Gas Yields

Methane yield is a measure both of waste degradability and digester efficiency. It is the amount of gas produced from every pound of organic solids converted to gases and liquids by bacterial action. On the average, about 8 cu. ft. of methane (or 12-13 cu. ft. of raw biogas containing 50-60% methane) is produced for every pound of volatile solids actually destroyed.

This means that gross methane production can amount to 2.2-3.4 cu. ft. per day per 150 lb. hog. About one-third of the energy from methane production is needed to heat the digester and to operate pumps and mixing equipment.

In general, the net methane yield should be approximately 1.5-2.3 cu. ft. (or 1500-2300 BTUs) per day per 150 lb. hog. By comparison, a gallon of diesel fuel has a heating value of 140,000 BTUs. The amount of methane and fertilizer elements expected to be produced from swine operations of different sizes is shown in Table 2.

Gas Scrubbing Systems

The degree of biogas clean-up required depends upon the ultimate use of the gas. Water vapor is removed by frost proof condensers and condensate traps to prevent condensation and excessive corrosion in gas lines. Hydrogen sulfide also presents a corrosion problem. Hydrogen sulfide can be removed using an iron sponge, i.e., column of iron-impregnated wood chips, to a sufficient degree to allow on-site use of biogas in internal combustion engines. Many sewage treatment plants use an iron sponge which can be regenerated or replaced inexpensively.

Carbon dioxide (CO_2) removal will increase the heat value of biogas from an initial level of about 600 BTU per cu. ft. up to a pipeline natural gas level of 1,000 BTU per cu. ft. Carbon dioxide can be removed by water scrubbing, membrane separation, phosphate buffer, or regenerative amine absorption. Water scrubbing is the most economical method. It consists of bubbling the biogas under about 500 psi pressure through water to dissolve the carbon dioxide. A commercial selective membrane process can yield 98%

Table 1. Anaerobic digester size for swine operations (95 F, 16 day detention time).

Size of operation: head*	Volatile solids lbs./day	8% volatile solids concentration: Slurry inflow gal./day	8% volatile solids concentration: Digester size gal.	5% volatile solids concentration: Slurry inflow gal./day	5% volatile solids concentration: Digester size gal.
50	36	54	950	86	1,500
100	72	110	1,900	175	3,100
200	140	220	3,900	345	6,100
500	360	540	9,500	860	15,300
1,000	720	1,100	19,000	1,730	31,000
2,000	1,440	2,200	39,000	3,450	61,000
5,000	3,600	5,400	95,000	8,630	150,000
10,000	7,200	11,000	190,000	17,300	310,000
15,000	10,800	16,100	280,000	25,900	460,000

*150 lb. hog or equivalent liveweight, one-time capacity

Table 2. Estimated production of methane and fertilizer elements from swine manure.

Size operation [1]	Gross yield, cu. ft./day [2,3,4]		Net methane yield cu. ft./day [5]	Fertilizer elements lbs./day [6]		
	Biogas	Methane		N	P_2O_5	K_2O
50	240	144	100	4	3	3
100	480	290	200	7	5	5
200	960	580	400	14	10	11
500	2,400	1,440	1,000	35	25	25
1,000	4,800	2,900	2,000	70	50	50
2,000	9,600	5,800	4,000	140	100	100
5,000	24,000	14,400	10,000	350	250	250
10,000	48,000	29,000	20,000	700	500	500
15,000	72,000	43,000	30,000	1,100	750	750

[1] 150 lb. hog or equivalent liveweight, one-time capacity
Assumptions:
[2] Volatile solids destruction = 50%.
[3] Gross methane yield is 8.0 cu. ft. CH_4 per lb. volatile solids destroyed.
[4] Biogas contains 60% methane and 40% carbon dioxide (volume basis).
[5] Energy requirement for heating and mixing the digester is 30% of gross biogas output.
[6] Recoverable fertilizer amounts are 0.07 lbs. N, 0.05 lbs. P_2O_5, and 0.05 lbs. K_2O per head per day, not including losses during slurry storage.

pure methane after passing the biogas through two or more membrane stages.

Biogas scrubbing equipment may account for up to 30% of the total cost of the methane production system if carbon dioxide, hydrogen sulfide and water vapor are all removed. But if only hydrogen sulfide and water vapor are removed, about 10% of the total system cost would be required for biogas scrubbing.

Gas Use Strategies

Economical success of methane production usually requires on-site use of gas and digested slurry. Methane produced can be used at the swine farm to heat farrowing and nursery buildings and to generate electricity. When methane is burned in an internal combustion engine to drive an electric generator, the conversion efficiency is only about 20%.

The remaining 80% of the energy is waste heat, much of which can be recovered from the water jacket of the engine or from exhaust gases. This waste heat can be used to preheat the incoming slurry or to heat the digester contents.

Some of the strategies for on-site use of methane are:

1. Electricity generation after gas scrubbing (carbon dioxide, hydrogen sulfide and moisture removal); gas compression to 125 psi and one-day storage.
2. Electricity generation after removal of only hydrogen sulfide and moisture, with or without gas compression or storage.
3. Boiler fuel, after hydrogen sulfide and moisture removal; compression to 125 psi; and one-day storage.

Nutrient Recovery and Use

Essentially all the plant nutrients originally present in swine manure are still present in slurry from the digester. Thus, the amount of land needed for disposal or use as crop fertilizer is about the same as with fresh or pit-stored swine manure. There is increased potential for nitrogen loss through volatilization because the organic nitrogen is converted to ammonia. Research has shown that half the nitrogen is lost from digested slurry after 72 days of storage in a holding pond.

There appears to be some economic potential for recovery of high-protein feedstuffs from the digested slurry. Feedstuffs can be recovered from digested slurry by centrifugation, sometimes with chemical flocculating agents added to improve recovery percentage. The yield and feeding value of residues that can be recovered from digested swine manure slurry needs further research.

Economics of Methane Production Systems

For methane production to be practical, a low cost yet reliable digester is a necessity. Economic projections of capital and operating costs for methane production plants are uncertain at the present time. The size and design of systems, and the opportunity for use of methane, fertilizer and feedstuffs, will have an enormous bearing on the capital costs, operating costs, revenue and net profit or loss. Energy tax incentives also affect economics.

Larger-scale methane systems appear more economically feasible than small farm-sized units because of lower unit costs, higher process control and greater potential for total usage of the methane gas and by-products produced.

Using 1980 prices, a conventional rigid wall, aboveground mesophilic digester, complete with slurry and gas handling systems, will cost approximately \$22-\$36 per 150 lb. hog to construct. This is equivalent to \$6-\$10 per cu. ft. of digester volume. Thermophilic units cost \$10-\$20 per cu. ft., depending upon their size. Plug-flow, trench digesters fabricated of flexible membrane liners reduce total system cost to about \$3-\$7 per cu. ft. They offer potential for making anaerobic digestion economically attractive for small livestock operations.

The net gas output from a 150 lb. hog would be worth about \$2 per head per year if used to replace natural gas or more than \$5 per head per year if the gas is used to replace propane. It may be worth even more if used to generate electricity and if waste heat is recovered to provide reasonably high conversion efficiency.

Summary and Conclusions

The net output of biogas from anaerobic digestion of swine manure can be expected to be about 3.2 cu. ft. per day per 150 lb. hog. This biogas will contain about 60% methane. Thus, the net heat output should be approximately 2,000 BTUs per day per 150 lb. hog.

Some of the keys to economically feasible production of methane from hog manure appear to be:

1. Collection of high quality manure (8-10% solids) from swine buildings.
2. Efficient manure management.
3. Low cost construction of digester.
4. Efficient use of methane to heat farrowing and nursery buildings and to generate electricity to power ventilation fans and to light the buildings.
5. Efficient recovery and drying of high protein solids from digested slurry for use as a feedstuff.
6. Storage and land application of digested slurry to use plant nutrients.
7. Heat recovery from internal combustion engines used to convert methane into electricity.
8. Large manure tonnage to achieve economics of scale.