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# Energy from Swine Manure

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Abstract

This paper discusses results of anaerobically digesting swine manure. Facts and figures are given on utilization of the energy from the anaerobic digester. Design parameters and some of the biochemical changes that occur during digestion are also given.

Digestion of swine manure for the production of energy is a relatively new concept in the United States. Most of the information on the subject has been published in the past 5 years. At the University of Missouri, research on the digestion of swine manure began in 1973. This paper is a compilation of the results of these studies and some of the results from other research institutions.

Figure 1 summarizes our research on digester loading rates for swine waste (Fischer et al., 1975a). Four g (VS)/liter/day is the highest loading rate we have achieved while maintaining long-term stable digestion. This value appears to be the highest achieved for research studies (Fischer, 1975a, van Velsen, 1977). In comparison, Lapp et al. (1975) operated a digester for a short time at a loading rate of 2.7 g VS/liter/day. The VS destruction calculated from the data of one of Lapp's most efficient, short-term experiments was the same as that of this experiment, about 62 . Schmid and Lipper (1969) had difficulty operating digesters on swine waste at loading rates above 3.2 g VS/liter/day. Robertson et al. (1975) reported a loading rate of 3.27 g total solids (TS)/liter/day and Hobson and Shaw (1973) reported a loading rate of 3.49 g TS/liter/day. These TS loading rates were less than the 4.87 g TS/liter/day of this study. However, in both studies (Robertson et al. and Hobson and Shaw), difficulty in maintaining digester stability was experienced, and only 45 and 26%, respectively, of the TS were destroyed.

We have consistently achieved 53% reduction of the TS (62% of VS) Fischer, 1977a). The biogas produced by our digester has averaged 2.2 $m^3/m^3$ of digester liquid per day (at 4 g VS/liter/day and 15-day retention time). Gas production values of 1.0 to 1.7 $m^3/m^3d$ have been reported (Lapp et al., 1975; Van Velsen, 1977; Hobson and Shaw, 1973).

Ammonia plays an important role in anaerobic digestion. McCarty and McKinney (1961) pointed out that ammonia is one of the important buffers in digesters, yet can become toxic if concentrations exceed 3000 mg/liter $NH_3$-N and pH exceeds 7.4. These guidelines, normally applied to municipal sewage digesters, do not hold for swine waste. Our digesters have successfully operated with $NH_3$-N levels exceeding 3400 mg/liter and pH levels greater than 7.9. van Velsen (1977) successfully operated swine digesters with $NH_3$-N concentrations greater than 4000 mg/liter and a pH of 7.9. Kroeker et al. (1976) reported operating at $NH_3$-N levels of 3450/liter.

The reason for successful digestion at $NH_3$-N concentrations exceeding 3000 mg/liter is not known. It may be that the bacterial population can adapt to high nitrogen levels if acclimated slowly. Part of the answer may also be in the buffering systems associated with anaerobic digestion. Sievers and Brune (1978) reported that swine digesters high in nitrogen content reduced gas production but tended to be more stable environmentally than digesters low in nitrogen. This stability appeared to be associated with the buffering capacity. They recommended that swine digesters be operated near a carbon/nitrogen ratio of 16/1.

The following list summarizes the characteristics of digester operation:

| Parameter | Value |
|---|---|
| Loading rate | 4 g VS/liter/day |
| Retention time | 15-20 days |
| Temperature | 35°C |
| Carbon/nitrogen ratio | 16:1 |
| pH | 7.2-7.6 |
| Alkalinity | 10-12,000 mg/liter |
| Volatile Fatty Acids (effluent) | less than 400 mg/liter |
| Methane/Carbon Dioxide | 60/40 |
| Biogas | 2.0 $m^3/m^3$/day |

Our experiences with the anaerobic digestion of swine manure has not been totally without problems. We have found that sudden shifts in animal feed rations or the large-scale use of antibiotics can cause disruptions to the digester microflors. For the most part these disruptions have been short term; however, changing feed rations from a corn base to a wheat base resulted in the formation of a large, gummy scum layer in the digester, reducing gas production and plugging mechanical parts. Also, manure from hogs that had been given intermuscular shots of some antibiotics resulted in severe upset. The digester had to be emptied and restarted.

The chemical changes in the swine manure and the percentage of destruction of the major constituents are given in Table 1 (Iannotti et al., 1978). Carbohydrates (28.7% hemicellulose, cellulose, and starch) formed the largest group of compounds in the manure, TS, followed by proteins (17.4%), lipids (12.3%), and total acids (8.7%). Starch was most readily degradable; and protein, the least. The difference between the lignin in the influent and effluent was not significant. The data from the chemical analysis was used to calculate the following daily mass balance for the prediction of biogas production: 215 g hemicellulose + 126 g cellulose + 23.5 g starch + 159 g protein + 164 g lipids + 65.2 g acetic acid + 28.0 g butyric acid + 25.1 g lactic acid + 17.8 g propionic acid + 8.5 g succinic acid + 4.7 g formic acid + 215 g unknowns + 246 g water 382 g methane and 857 g carbon dioxide. The calculated total biogas was 965 liters/day, of which 55% (moles) was methane and 43% was carbon dioxide. The experimental values were 960 liters of total biogas/day and 59% and 39%, respectively, for methane and carbon dioxide.

Swine, poultry and domestic waste apparently has a greater potential for anaerobic digestion (WPCF, 1959; Miner and Smith, 1975) than does cattle waste. The material in cattle waste already has undergone anaerobic digestion in the rumen that would remove fibers that are relatively easy to degrade. During studies of thermophyllic digestion, Wohlt et al. (1978) and Varel et al. (1977) found that cattle waste contained 36% hemicellulose and cellulose, which was higher than the 27% in swine manure; however the hemicellulose in cattle waste was degraded 31% to 65%; and the cellulose, 12 to 28%. For swine manure, the hemicellulose was reduced 65%; and the cellulose, 64%. Cattle waste contains high levels of lignin, which we assume binds the celluloses that retard degradation. Rumen digestibility is inversely proportionate to lignin content in the same species of grass but the relationship is less obvious with different species of grass. Although the experimental design for cattle and swine studies differed, results of the studies indicated an apparent relationship between lignin content and VS destruction. The waste from dairy cattle, finishing cattle, and swine contained 10%, 6.8%, and 3.7% lignin, and the reduction in volatile solids was 26-35%, 53%, and 60% (Wohlt et al., Varel et al. and Iannotti et al.).

Swine manure in our study contained 12% lipids, a value between that for lipids in domestic sewage and cattle manure (Iannotti et al., 1978, Varel et al., 177, and Chynoweth and Mah, 1971). Since the lipids are readily degraded (69% reduction in swine digester and 65 to 90% in domestic digester), the presence of higher level of lipids in swine manure compared to cattle manure further increases the digestibility of the swine manure.

Forty percent of the VS added to the digester was not degraded during the anaerobic process. We feel that it would be reasonable to expect that half of that amount could be economically converted to methane with further study. Up to 85% of domestic waste can be digested by increasing the retention time (WPCF, 1959). The lignin content of the effluent is still relatively low (7.5% of TS).

To increase the amount of material converted to methane, we are studying the requirements of the microbial population and the interactions of substances that are toxic for that population. The methods for the enumeration and isolation of an appreciable portion of the microbial population have been reported (Iannotti et al., 1978a), and the nutritional requirements of these organisms are being studied. Preliminary results indicate that many of the swine digester bacteria have complex nutritional requirements. Almost all are stimulated under laboratory conditions by unknown factors in the digester effluent that are not replaced by common microbial growth factors. Many are also stimulated by mixtures of growth factors such as vitamins. Perhaps an understanding of the requirements and interactions will permit manipulation of the anaerobic process for greater conversion to methane.

In 1975, design began on a farm-size anaerobic digester for the University of Missouri-Columbia (UMC) Swine Farm. The swine farm is a 40-sow, farrow-to-finish, totally confined system, and the sows farrow twice a year. An overall schematic of this farm and the digester is shown in Figure 2. Manure is transported from the farrowing house and finishing houses by hydraulic flushing to a settling basin. The gestation and nursery houses have a continuous overflow pit system. A manhole in the sewer line ahead of the settling basin provides a means by which the total stream of manure coming from the buildings can be diverted from the settling basin to an anaerobic lagoon if appropriate for some reason. Manure is automatically diverted from the digester when the farrowing house is sanitized after each farrowing.

The settling basin collects the 1% TS slurry coming from the buildings and concentrates it to 7% or 8% solids for loading into the digester. The settling basin also acts as a solids storage basin since the manure is removed several times a day and the digester is loaded once a day. The design of the settling basin was based on settling column tests conducted in the laboratory. Results of these tests indicated that a settling time of 1 hour was sufficient to remove 70% to 80% of the solids in the manure (Fischer et al., 1975b). The basin is large enough to hold the volume of water and manure from each flush. After the flush volume settles for 1 hour, a pump in the basin is energized and pumps the excess liquid above the settled solids to the lagoon. A schematic of the settling basin is given in Figure 3. Two brooms that move back and forth across the floor of the basin are used to agitate the settled solids in the basin before pumping the manure into the digester.

The digester at the UMC swine complex is a 6-m concrete stave silo with a hoppered concrete base and a solid concrete roof. The silo is plastered and epoxy coated on the inside wall, and painted with a rubber-based paint on the outside. One vertical section of staves from the top to the bottom of the silo was omitted and a 0.64-cm-thick steel plate was placed there. All piping and modifications to the digester pass through and are welded to this plate. A 6.4-m-diam steel grain bin was constructed around the silo, and the space between the bin and the silo walls was filled with insulation. A small equipment shed for housing the gas measuring devices and the boiler was attached to the side of the silo (Figure 4) (Fischer et al., 1977b).

The digester is loaded by a submersible liquid manure pump in the settling basin. As manure is pumped into the digester, digester manure is forced out through a gravity overflow tube (Figure 5). The contents of the digester are agitated by gas recirculation. Part of the gas produced is used to maintain the digester temperature and the remaining gas is presently not being utilized. The digester is heated by circulating hot water that is heated by the gas produced. The water flows through 127 mm. black iron pipe arranged in six 21m-diam coils. A mixing valve prevents water having a temperature greater than 130° from entering the heating coils.

The electrical control system automatically controls manure removal from the buildings, settling basin operation, and digester operation (Fischer et al., 1978a). This sytem permits complete automation of the digester operations and thus produces the manpower required to operate the unit. Unlike municipal digesters, for which operation is a major portion of one man's time, the digester for a swine farm must be an integral part of the pork production system so that it will require minimum management and labor time by the pork producer.

The challenge in desinging anaerobic digesters for pork production systems is to assure that the system will be reliable, economical, and labor free. The cost of the digester to a pork producer must be offset by the energy produced or the pollution abatement benefits of the system or both. Utilization of the methane gas on a farm is an integral part of the design of a swine farm anaerobic digester system. Since methane cannot be economically stored except under high pressure and at low temperature, the most efficient method of utilizing the gas is to use it as it is produced. Two forms of energy continuously required in pork production are heat and electricity. Electric energy is needed for ventilating and lighting the buildings and for feed conveying. Heat energy is needed for the farrowing and nursery houses, because the temperature environment for baby pigs must be maintained at about 32°C for the first 2 weeks of their lives. Both electric energy and heat energy can be supplied by utilizing the methane gas from the digester in an internal combustion engine. The engine when coupled to a generator will provide the electricity. The heat required can be recovered from the engine cooling water and exhaust gas. Figure 6 illustrates the energy supplied to the engine by the digester and the energy output of the engine in the form of mechanical, electrical, and thermal energy. The peaks and valleys correspond to variations in the amount of manure coming from the buildings.

Maximum energy production (950 watts), immediately followed by minimum energy production (506 watts), occurs six times a year. The maximum and minimum electric-energy values are 150 and 80 watts, respectively. Thermal energy from the engine was calculated based on the following assumptions: that 37% of the energy supplied to the engine would be in the exhaust gas (Obert, 1955) and the efficiency of recovering this energy would be 80%, and that 39% of the energy supplied to the engine would be in the cooling water (Obert, 1955) and the efficiency of recovering this energy would also be 80%. An analysis performed for a farrow-to-finish hog operation indicated that, for an average January day in Missouri, about 340 watts of heat/hour/sow capacity in the farrowing house is required by a pork production system. The energy system should be capable of supplying that amount of heat. The demand for electric energy on a swine farm designed for efficient use of energy is about 80 watts/sow, which is about the amount of electric energy supplied by the engine-generator combination.

Anaerobic digesters have the following three main assets for a pork production system: (1) Energy production, (2) better odor control than is commonly available from existing waste management systems, and (3) conservation of fertilizer nutrients into manure. However, before a pork producer can take advantage of these assets, several factors such as the following should be evaluated. First, what would the management and labor requirements be for digesters used with pork production systems? Some demonstration anaerobic digesters should be established on commercial farms to evaluate these requirements. Second, would an engine operated on the methane gas produced from hog manure be reliable for continuous operation? What would be the effects of antibiotics, if any, from the various disease treatment procedures used in confinement hog operations today?

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Table 1. Composition of material entering and leaving a swine manure anaerobic digester.

| Component | Composition (% of Total Solids) Influent | Composition (% of Total Solids) Effluent | Percent Destroyed |
|---|---|---|---|
| Volatile Solids | 82.6 | 69.8 | 60 |
| Hemicellulose | 17.1 | 12.5 | 65 |
| Cellulose | 10.3 | 7.8 | 64 |
| Starch | 1.3 | 0.2 | 94 |
| Protein | 17.4 | 19.4 | 47 |
| Lipids | 12.3 | 8.0 | 69 |
| Total Acids | 8.7 | 2.4 | 87 |
| Lignin | 3.7 | 7.5 | 3 |

## BIOGRAPHY

James R. Fischer is an Agricultural Engineer with the U.S. Department of Agriculture, Science & Education Administration, Agricultural Research, located at the University of Missouri in the Department of Agricultural Engineering-Columbia. Dr. Fischer received his B.S. in 1967, M.S. in 1969, Ph.D. in 1972, all from the University of Missouri-Columbia. He has been employed with the U.S. Department of Agriculture since 1969. He has membership in various professional and honorary societies and is a registered engineer in the State of Missouri. He has authored or co-authored over 45 publications.

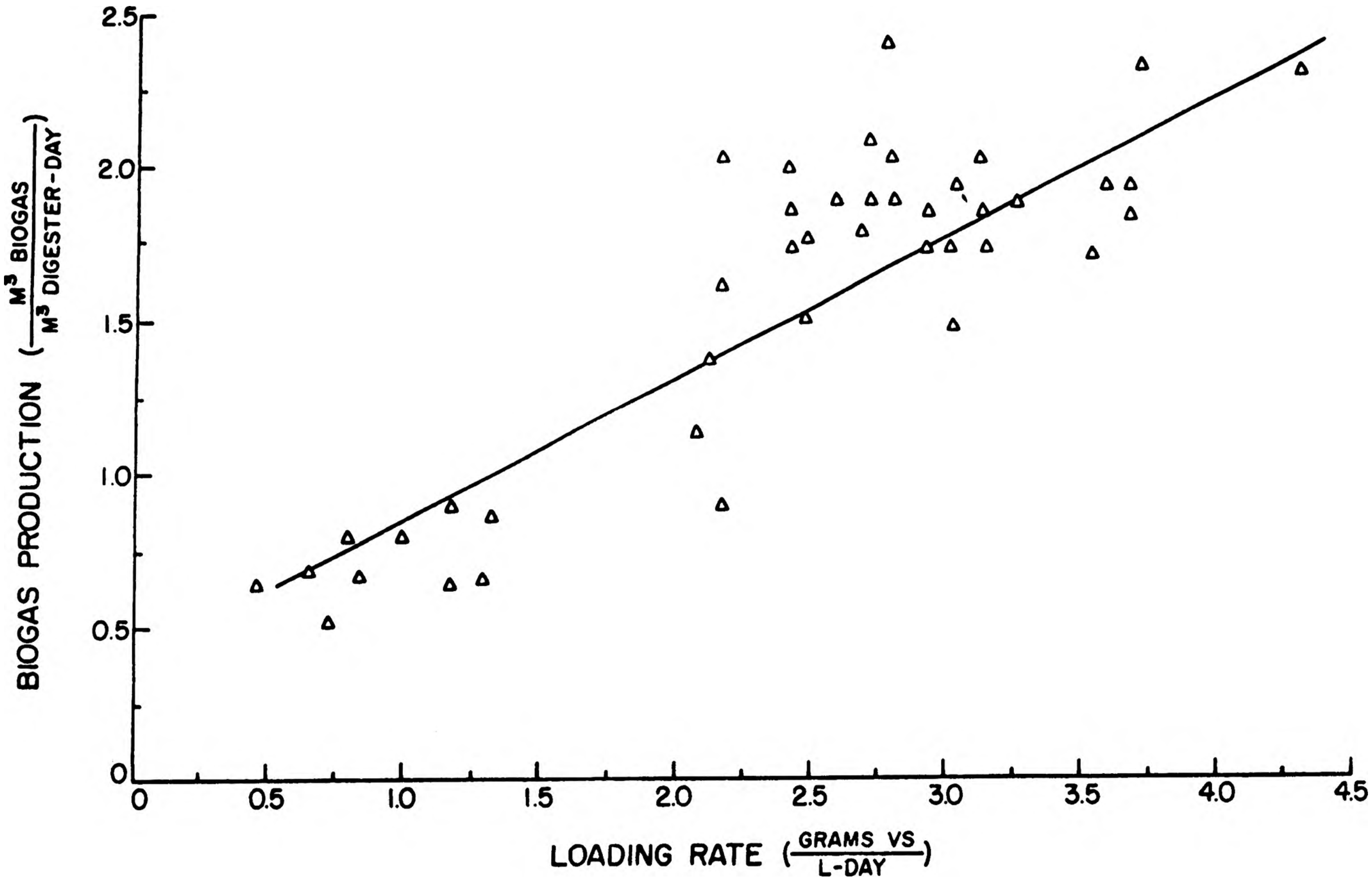


Figure 1. Gas produced by swine waste digester as affected by loading rate.

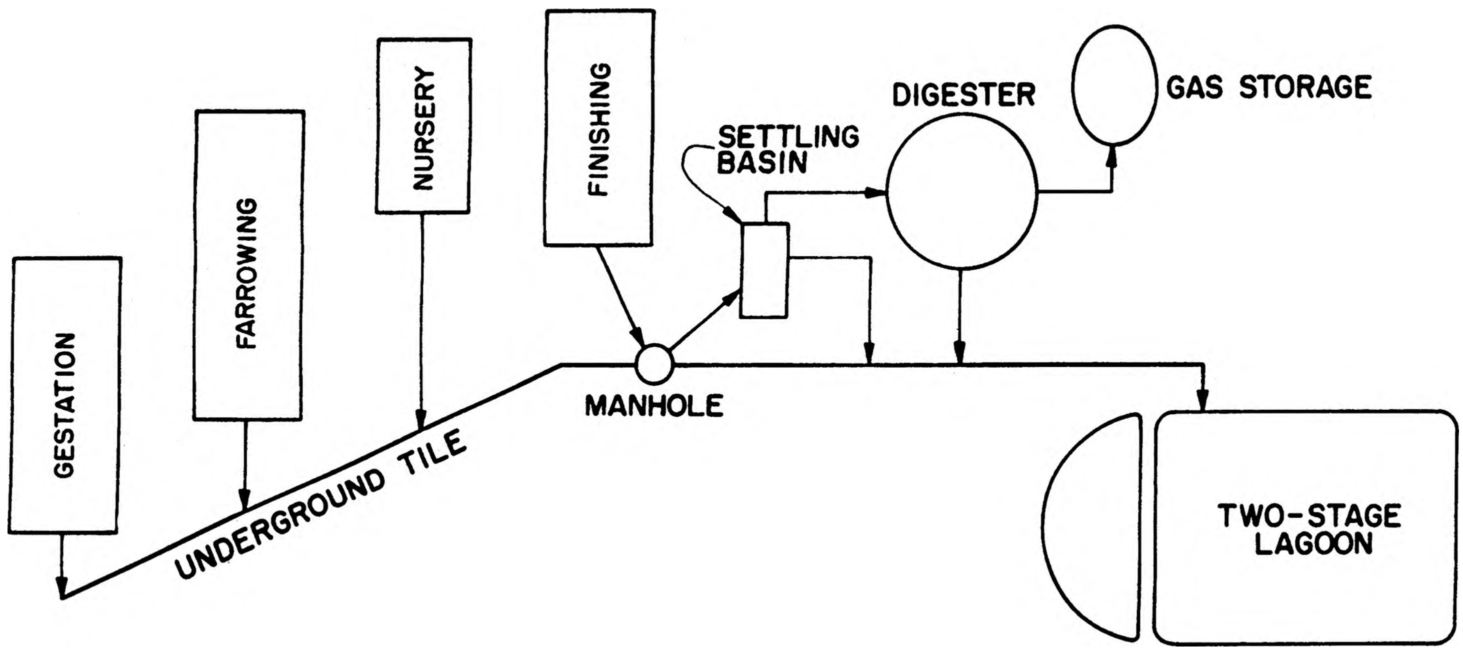


Figure 2. Schematic representation of swine waste digester, swine farm, settling basin and two-stage lagoon.

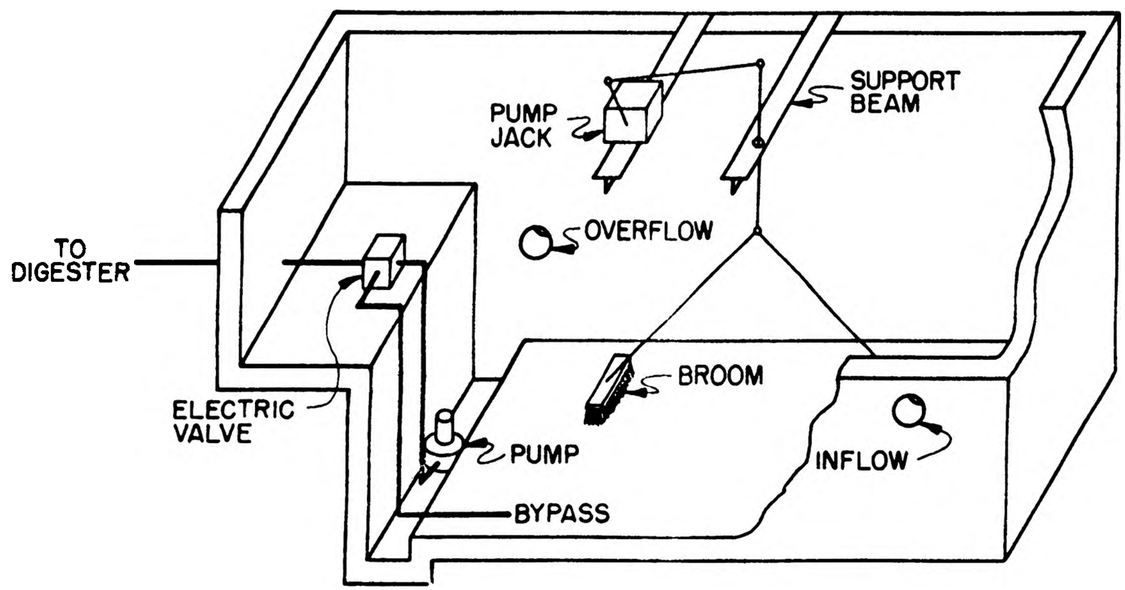


Figure 3. Schematic of settling basin.

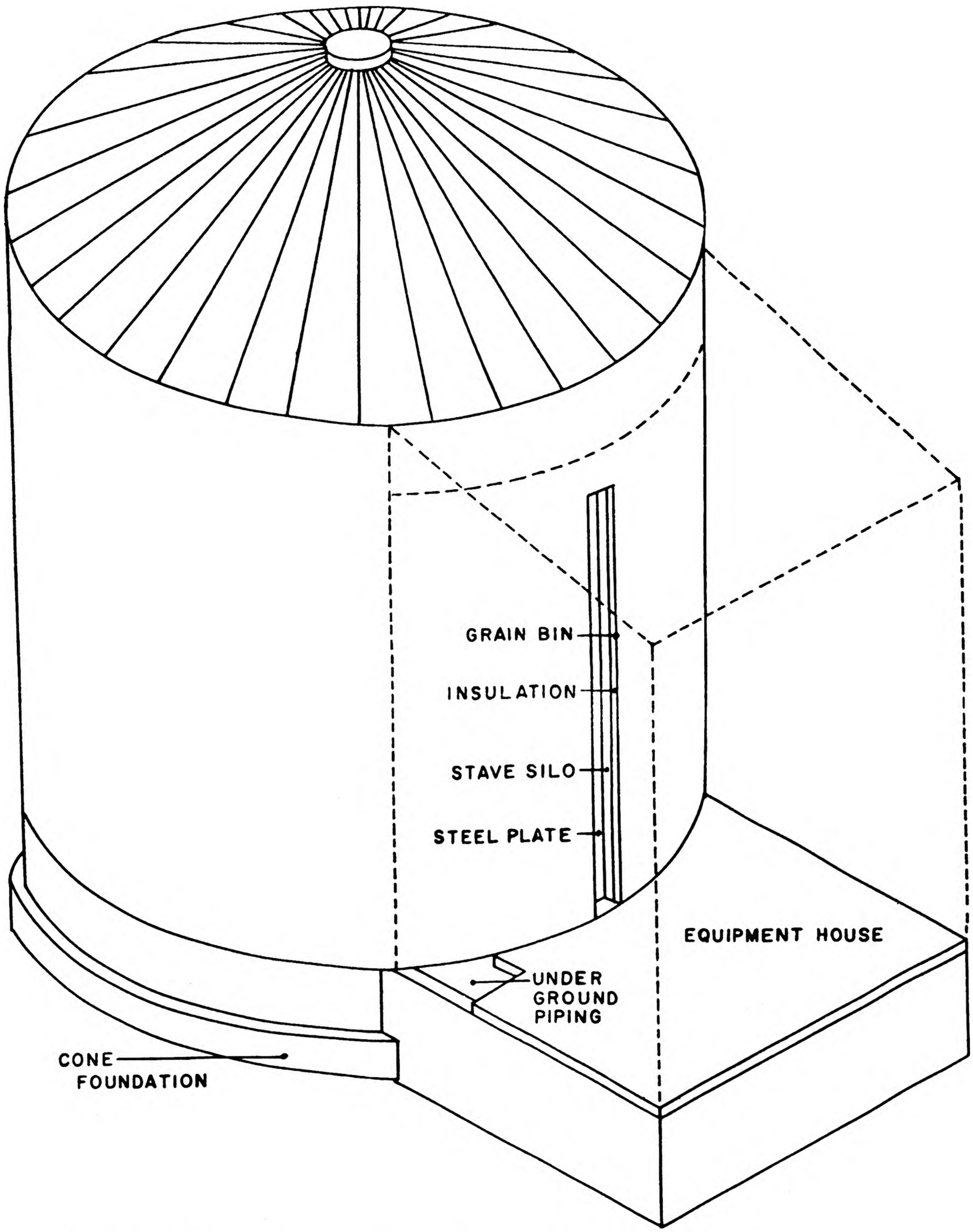


Figure 4. The anaerobic swine waste digester and equipment house.

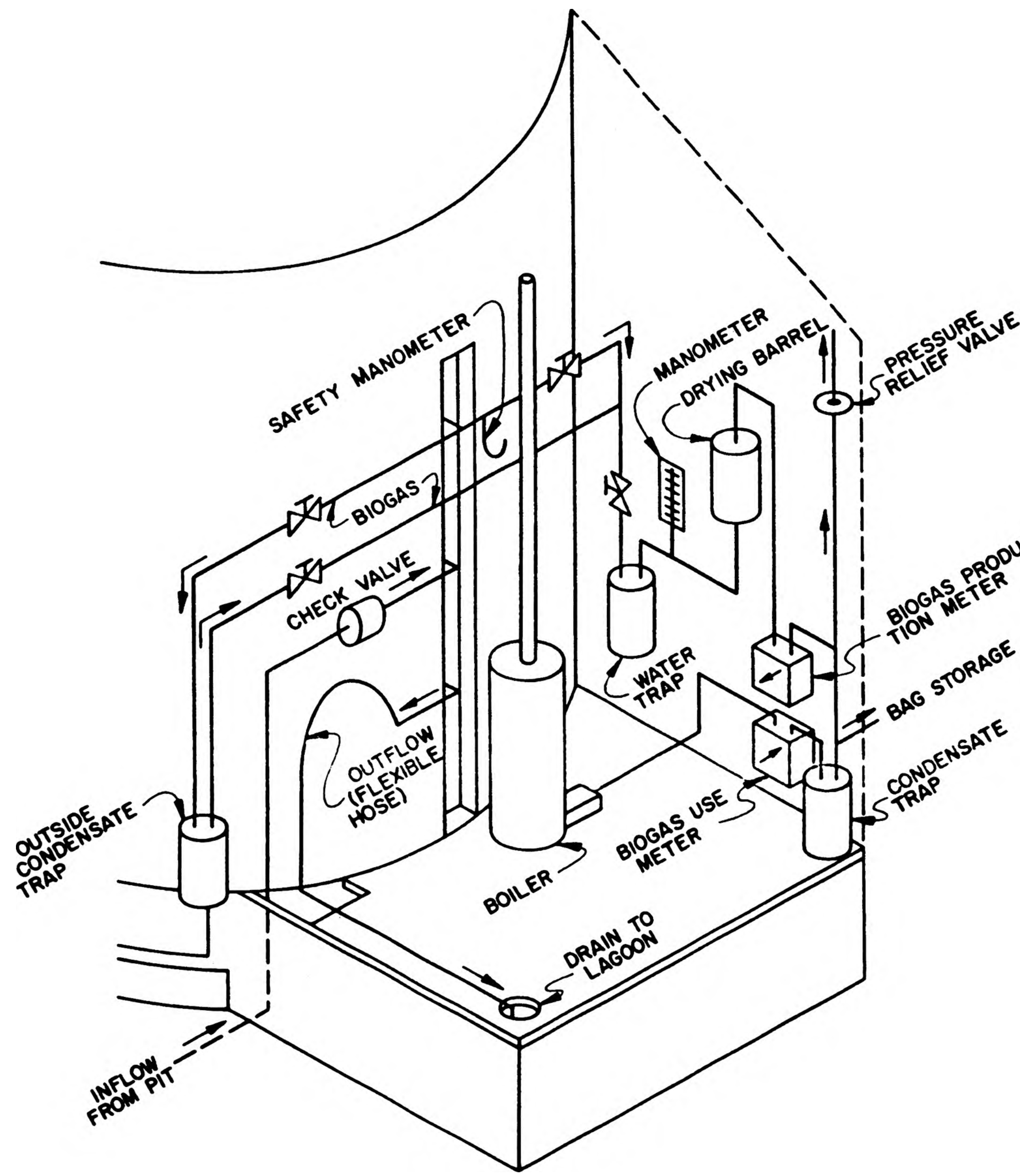


Figure 5. Schematic representatation of anaerobic swine waste digester.

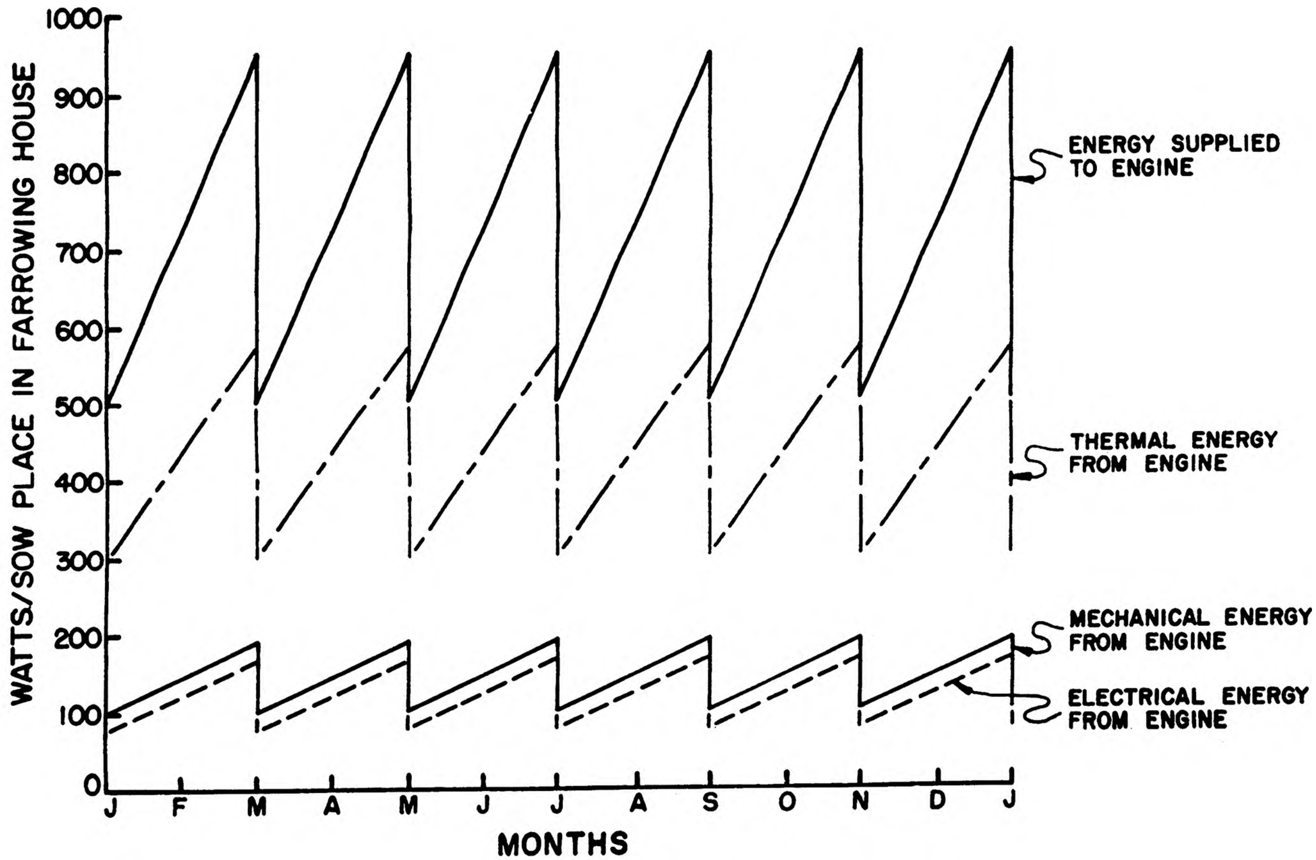


Figure 6. Energy supplied to engine and thermal, mechanical, and electrical energy output of engine/sow.