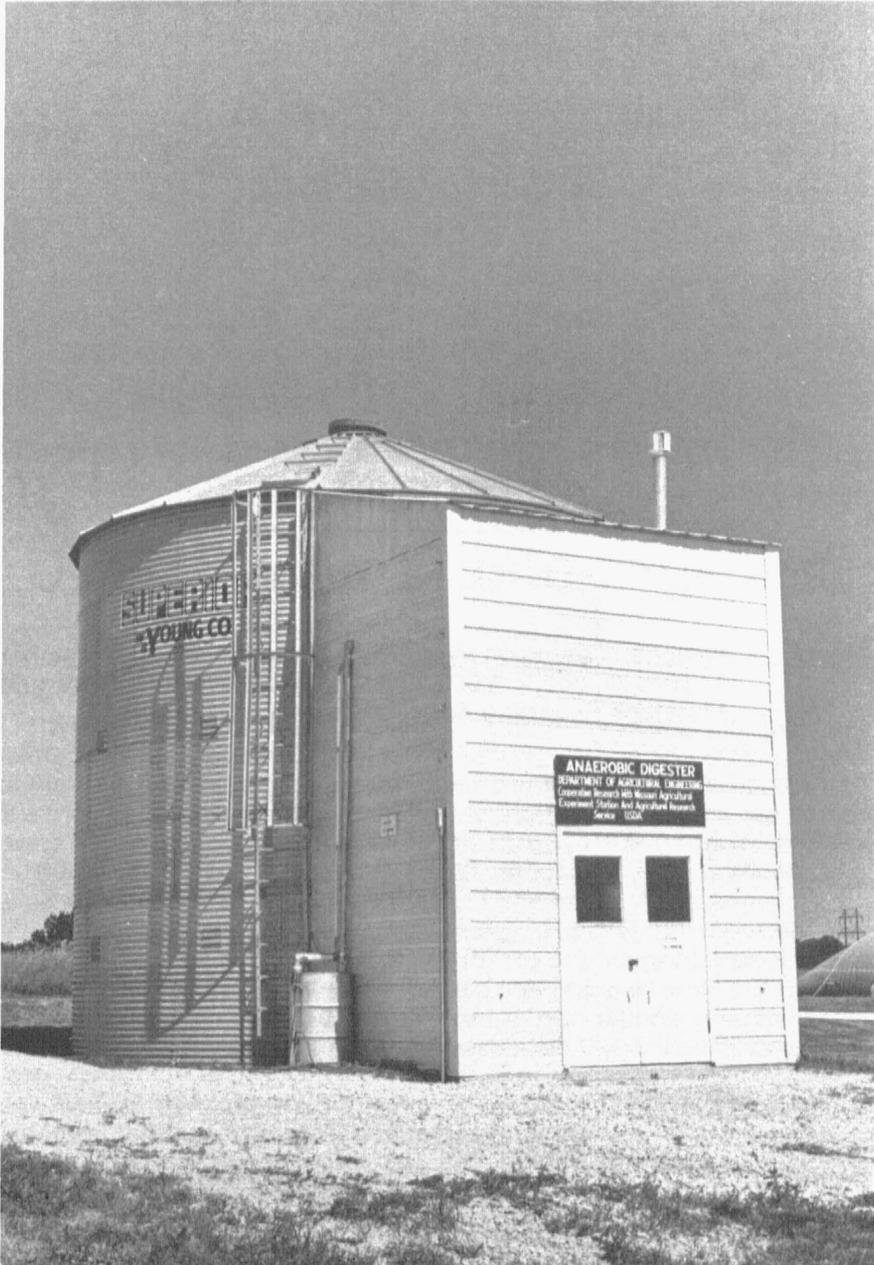


# Swine Waste Digester at the University of Missouri-Columbia



Dennis M. Sievers, James R. Fischer and Charles D. Fulhage

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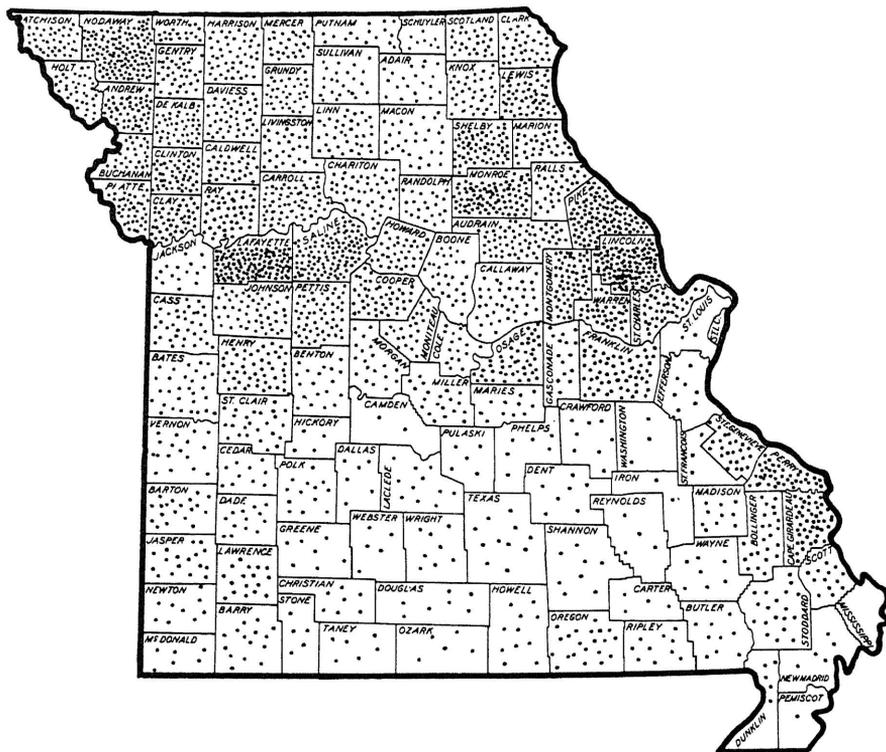
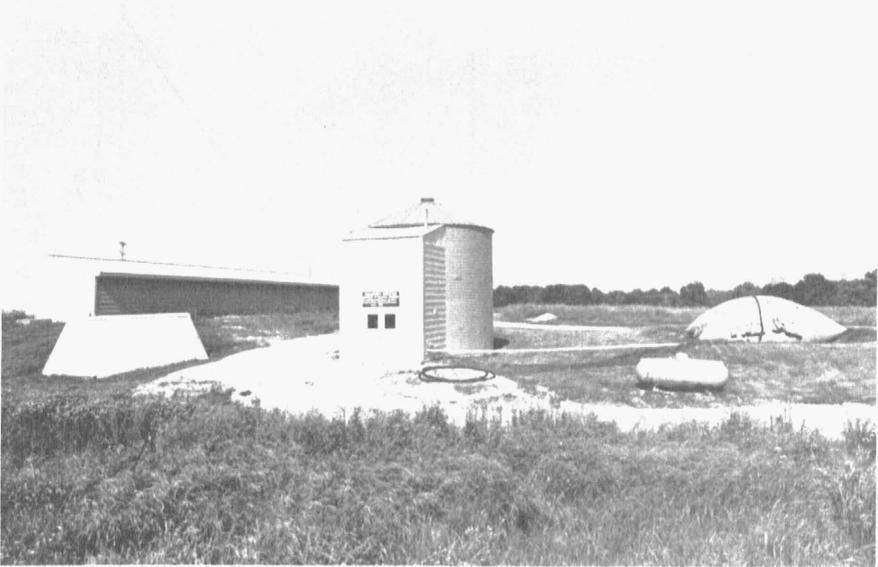


Figure 1. All hogs: Number on Missouri Farms by Counties, December 1, 1975 (1 dot = 1,000 head). Source: Missouri Crop and Livestock Reporting Service, Columbia, Missouri.

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# UMC Swine Waste Digester

The production of livestock and associated products is an important agricultural enterprise in Missouri.

State farm income in 1976 resulting from the sale of livestock and related products amounted to \$1.71 billion [1]. This represents 62 percent of the total cash receipts from agriculture in 1976. Twenty-six percent of the \$1.7 billion resulted from the swine industry, indicating the importance of pork production in Missouri. In 1976, 6,019,000 pigs were raised in the state, ranking Missouri fourth nationally! Hog production is widespread across Missouri as Figure 1 shows.

Production of pork requires energy. Heichel [2] reported that Americans consumed 30.4 kilograms (67 lb) of pork per person in 1972 which required the energy input of 18.2 liter (4.8 gal) of oil per person. While this is a small amount compared to our national energy needs, every individual must share in the responsibility to conserve energy resources.

Manure generated from swine production facilities represents a resource that can and should be utilized on the farm to help conserve energy and fertilizer nutrients. The process of anaerobic digestion is a means by which these resources can be conserved. Anaerobic digestion is a biological process whereby bacteria utilize the organic solids (fats, carbohydrates and proteins) in manure for growth and reproduction.

The anaerobic digestion process occurs in two stages. Initially the volatile solids in manure are broken down to a series of fatty acids. This

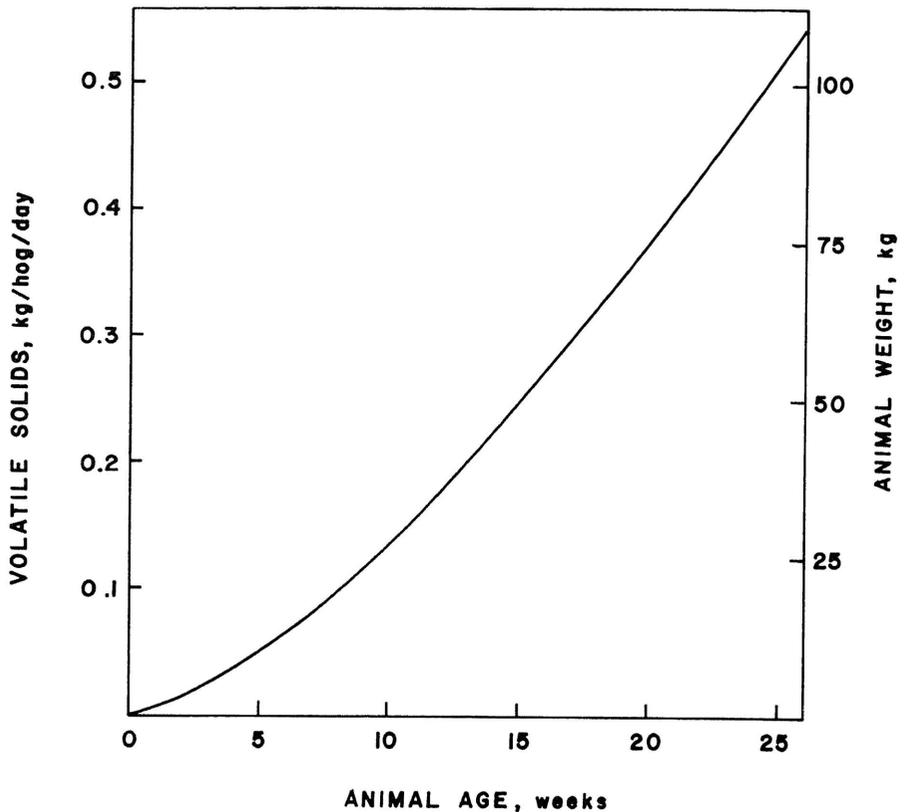


Figure 2. Amount of volatile solids produced by a hog over a 26-week life span.

step is the acid-forming stage, and is carried out by a particular group of bacteria, called acid formers. In the second stage, a highly specialized group of bacteria, methane formers, convert the acids to methane gas and carbon dioxide. The methane or natural gas is the energy bearing material resulting from digestion.

## How Much Energy

Figure 2 is a plot of the weight of volatile solids (VS) voided daily by a pig as it grows from birth to 26 weeks of age. The sum of volatile solids produced over the 26 weeks is 40.4 kg VS per animal. Research at UMC has shown that 60 percent of swine waste volatile solids placed in a digester will be broken down within a 15-day detention time and 0.9 liters of biogas produced per gram VS destroyed [3]. Applying these figures to the 40.4 kg VS produced per animal results in 21 cubic meters (cu.m) of biogas produced per animal in 26 weeks. Biogas produced from swine waste is 60 percent methane. Therefore, each animal will produce 12.6 cu.m. of methane during his 26-week stay on the farm.

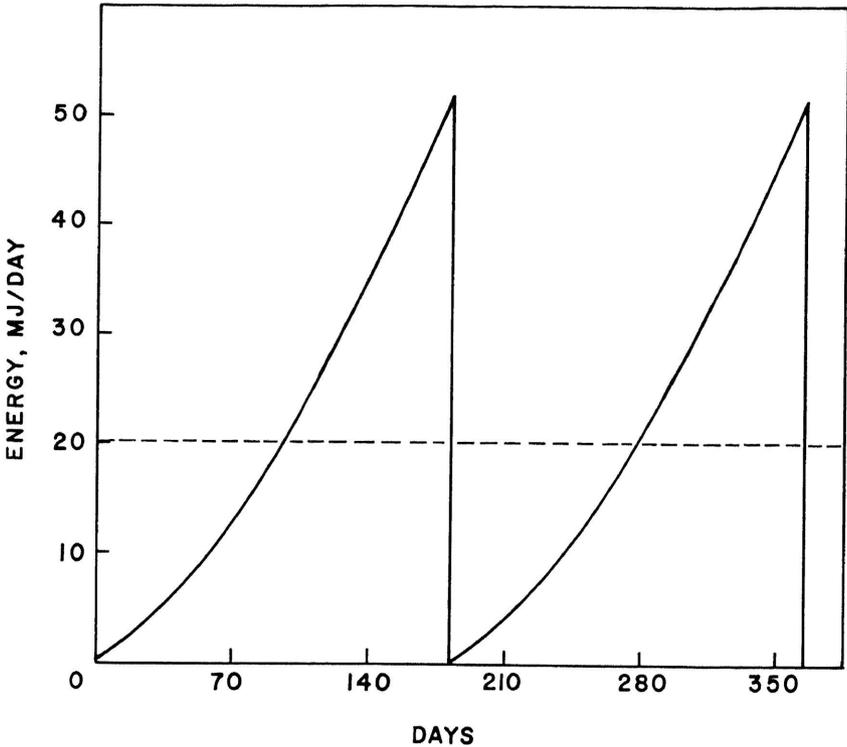


Figure 3. Yearly energy production and distribution (gross) for a sow-unit (one sow and two litters of 8 pigs each).

Potential gas production can be expressed on a sow-unit (SU) basis. A SU is defined as a sow plus 16 pigs (two farrowing of 8 pigs each year) that are raised to market weight. Summing the daily gas production for one SU over 52 weeks results in 395 cu.m. biogas per year. Biogas has an energy value of approximately 22.4 megajoules (MJ) per cu.m. (600 Btu/cu. ft). A SU then has the potential to produce 8850 MJ per year (2460 kW-hr/yr).

Two important points must be made concerning this potential energy.

1. Not all of it will be available for use because some must be used to maintain the digester at a constant temperature (more will be said later).
2. The distribution of the energy will vary over the year according to VS production (Figure 2).

The maximum amount of gas will coincide with maximum VS production which is a function of animal age. The amount of available energy at any one time on a swine farm is tied directly to the frequency of farrowing.

Figure 3 is the potential (gross) yearly energy production for a SU. Peak energy production occurs twice a year. The average daily energy production is 21 MJ per SU. Figure 4 is the potential energy for 3 SU's (6

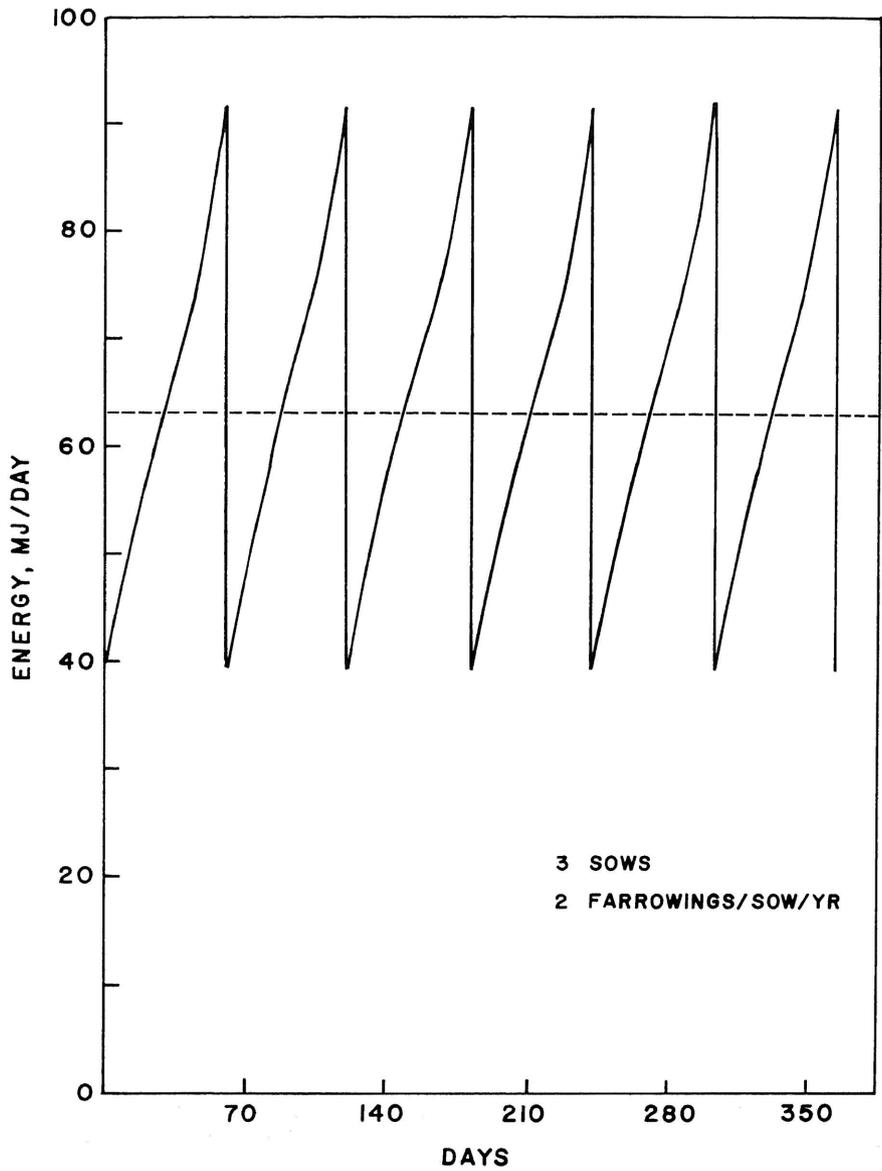


Figure 4. Yearly energy production and distribution (gross) for 3 sow-units.

evenly spaced farrowings/year). The evenly spaced farrowings produce an average energy value of 63 MJ per day, but the energy distribution still contains peaks and valleys.

The greater the number of evenly spaced farrowings per year, the shorter the time between peaks and the more consistent will be the level of available energy. Shortening the time period between energy peaks reduces the necessary gas storage volume to maintain consistent energy levels between peaks. Since storage of methane is expensive, reducing the need for it will lower the cost of the entire energy recovery process.

The greatest amount of energy required for heating the digester in Missouri occurs during January and February. Straggering the sequence of farrowing to achieve maximum energy production (maximum VS production) during this cold period will provide for maximum net energy above digester heating requirement to be used elsewhere on the farm.

## **Conservation of Nutrients**

As organic matter is broken down in the digester, plant nutrients (nitrogen, phosphorus and potassium) are mineralized and released into the digester liquids. The digester, being a closed container, conserves these nutrients so they can be used on crop land. There is one problem—nitrogen is converted to ammonia in the digester and when digested liquids are removed and exposed to the atmosphere, the ammonia escapes. This can be overcome by storing digested liquids in a covered container. Subsurface injection of liquids appears to be the best method of conserving nitrogen in the field.

Anaerobic digestion is a waste management process that recovers energy, conserves fertilizer nutrients, and provides some control of odors. It is a process that utilizes waste materials on the site in which they are produced. The process adapts well to confinement systems where concentrated sources of waste are generated and automatic collection systems are available.

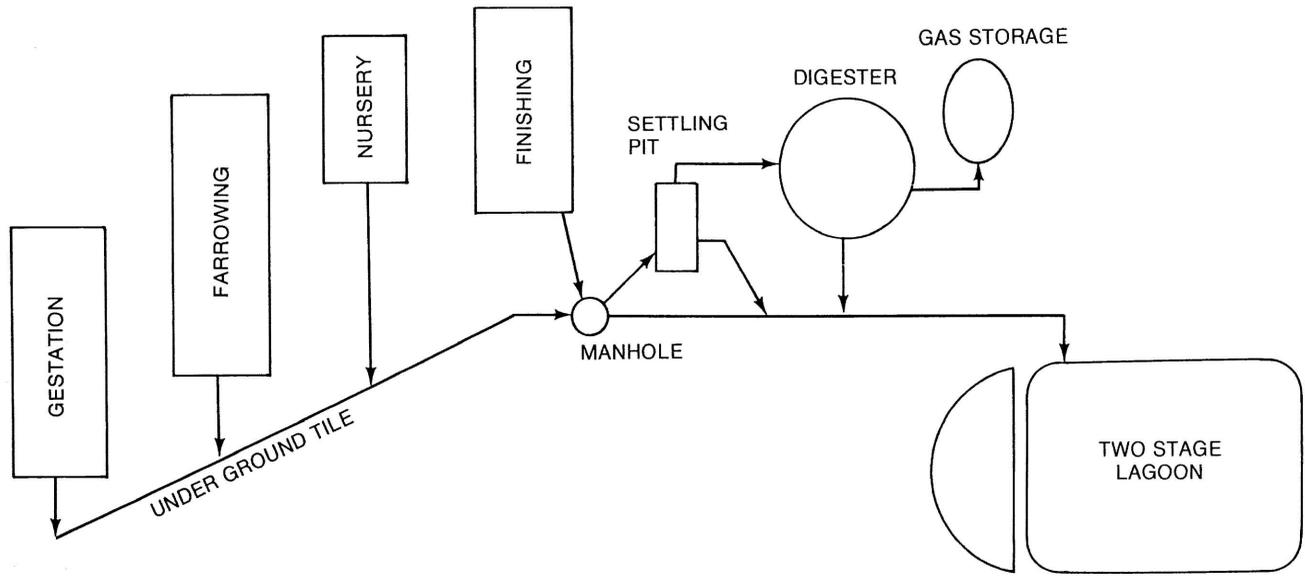


Figure 5. Waste management system for the UMC Swine Research Farm.

## **UMC Swine Farm System**

Figure 5 shows the waste management system for the UMC Swine Research Farm. Wastes are automatically removed from each building and transported through underground tile to a common manhole. A valve in the manhole allows the waste to be directed to an anaerobic lagoon or to a settling basin.

Gutter flushing is used in the farrowing and finishing buildings and produces excess water not needed in the digester. The wastewater is placed in the settling basin where the solids settle to the bottom. Excess water is then removed and directed to the lagoon and the concentrated solids pumped into the digester.

A constant liquid volume is maintained in the digester. When the liquid-solid slurry is pumped into the digester from the settling basin, a similar volume of liquid is discharged from the digester to the lagoon. It is important that the pipe carrying manure solids from the basin to the digester be sloped back to the basin so that slurry remaining in the pipe after pump shut-off can drain back to the basin.

The entire waste management system is automated and controlled from an electrical control panel located in the digester equipment room. Wastes are placed into the digester once a day but could be done more frequently. It is important to collect manure at least daily if it is to be digested. Manure that is allowed to lie around uncollected begins to decay immediately, resulting in loss of potential gas production.

## **The Digester**

The digester was constructed using commonly available materials and construction techniques and can serve as a reproducible unit. Many types of tanks were investigated for use as a digester, including fiberglass, concrete, and glasslined steel [4]. All of these would appear to work depending upon size of tank required, availability of materials and cost. A concrete stave silo was chosen for the Missouri digester due to its availability and reasonable cost.

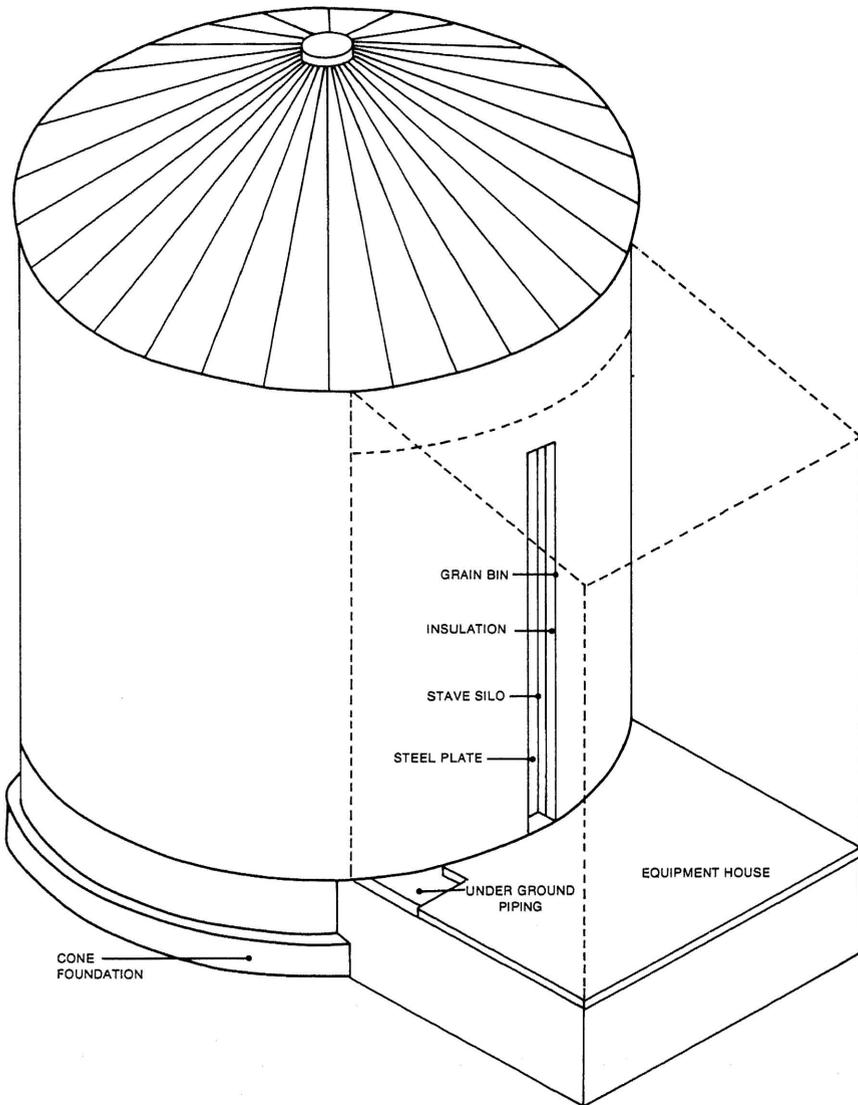


Figure 6. Concrete stave silo digester illustrating the insulation, grain bin cover and steel plate.

The stave silo is 6 m (19 ft - 9 in) in diameter and 4.9 m (16 ft) high with a hoppers concrete base and fixed concrete roof. Two manholes in the roof provide access. Liquid depth is 3.7 m (12 ft) as measured from the base of the wall, leaving 9.2 cu. m (2430 cu. ft) of gas storage volume above the liquid surface. Water tightness in the silo was achieved by placing butyl rubber material between the interlocking staves and tightening the staves together with tension bands. Additional tension bands above those normally required for a stave silo are needed due to the increased pressure caused by storing water. The inside walls of the silo were plastered and coated with a tar-type compound containing fiber material.

The digester must be gas-tight to conserve the methane produced and to maintain safe operating conditions. Gas leaks around the roof where the concrete joined the stave walls were stopped by spraying the inside of the roof area with a butyl rubber compound. An excellent method of leak detection has been reported in an earlier publication [5].

A 6.4 m (21 ft) steel grain bin was set around the silo and the space between the bin and silo wall filled with foam insulation (Figure 6). Since the digester is heated to 35°C (95°F), insulation is needed to conserve heat energy. The grain bin provides an aesthetically pleasing structure and protects the insulation. The diameter of the grain bin must be sufficiently large to allow space for enough insulation to achieve a minimum R-factor

$$of \ 2,064 \ \frac{\text{sec-m}^2\text{-}^\circ\text{C}}{\text{kJ}} \left[ \frac{(12 \text{ hr-ft}^2\text{-}^\circ\text{F})}{\text{Btu}} \right]$$

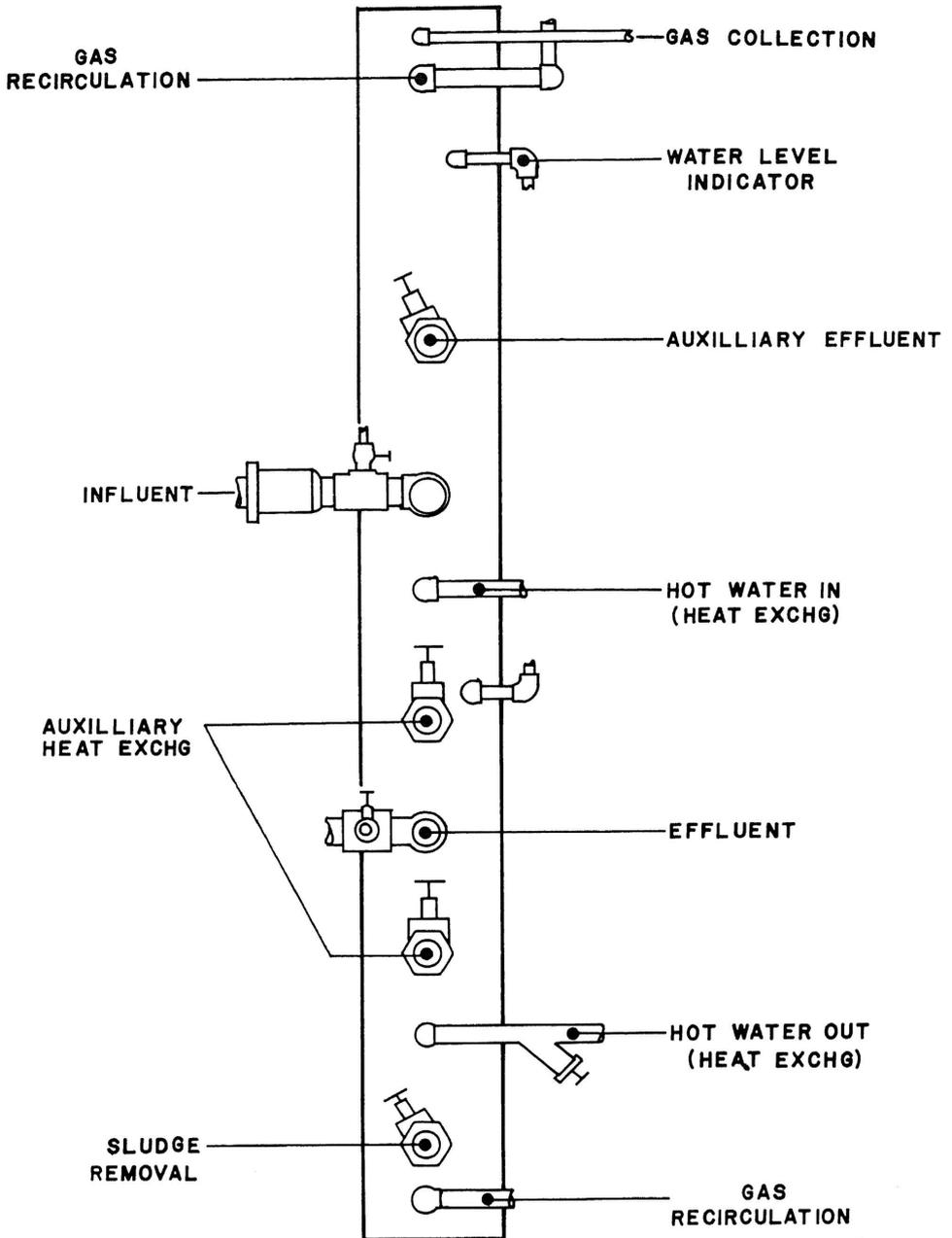


Figure 7. Plumbing entrances through the steel plate into the digester.

A place for plumbing to enter into the digester was provided in the stove silo by replacing one vertical section of staves with a 0.64 cm (0.25 in) thick steel plate. All piping (metal) was passed through appropriately sized openings in the metal plate and welded into place. This provided a gas and water tight seal and a structurally sound connection point. All piping on the inside of the digester is connected by unions to pipes welded into the metal plate so that removal of interior piping is possible. Figure 7 illustrates the various plumbing openings provided through the metal plate. Some additional openings were provided for research purposes.

## The Heating System

The digester is heated by circulating hot water through internally located steel coils. The heating system consists of four components: (1) the boiler, (2) the mixing valve, (3) heat exchanger, and (4) temperature controls.

The heating system capacity was based on

1. calculated heat loss through the exterior walls of the digester, 12,660 kilojoules (KJ) per hr (12,000 Btu's per hour) for a -6.7°C (20°F) day and
2. the heat required to raise the temperature of the influent to 35°C (95°F), 13,715 kJ per hr (13,000 Btu's per hour). Assuming a boiler efficiency of 70 percent, a minimum of 39,000 kJ (37,000 Btu's) of energy per hour would be required on a -6.7°C (20°F) day.

The boiler selected was a Triad Model G-60JX twin-burner. One burner was designed to burn propane and the other burner was specially designed to burn biogas as it comes from the digester. Each burner utilizes 60,135 kJ (57,000 Btu's) per hour. The digester gas burner is designed to operate at 10.2 cm (4 in) of water column. The boiler has a secondary heating unit with boiler capacity at 21.6 liters (5.7 gal).

Each burner is controlled by an individual aquastat which is regulated by the temperature of the boiler water. The propane aquastat is set at a lower temperature (approximately 54°C [130°F]) than that of the digester gas aquastat (approximately 71°C [160°F]). This individual setting of the aquastat permits the digester gas burner to do most of the heating with the propane burner used only in emergencies.

The thermostatically controlled mixing valve, located on the outside of the boiler, regulates the temperature of the water flowing through the heat exchanger coil. The valve mixes the 71°C (160°F) boiler water and 35°C (95°F) water returning from the heat exchanger coils to achieve a temperature of 49°C (120°F) water flowing into the heat exchanger. The coil temperature is held at 49°C to reduce the caking of digester slurry on the heat exchange coils. Caking is reported to occur when the water temperature exceeds 54°C (130°F).

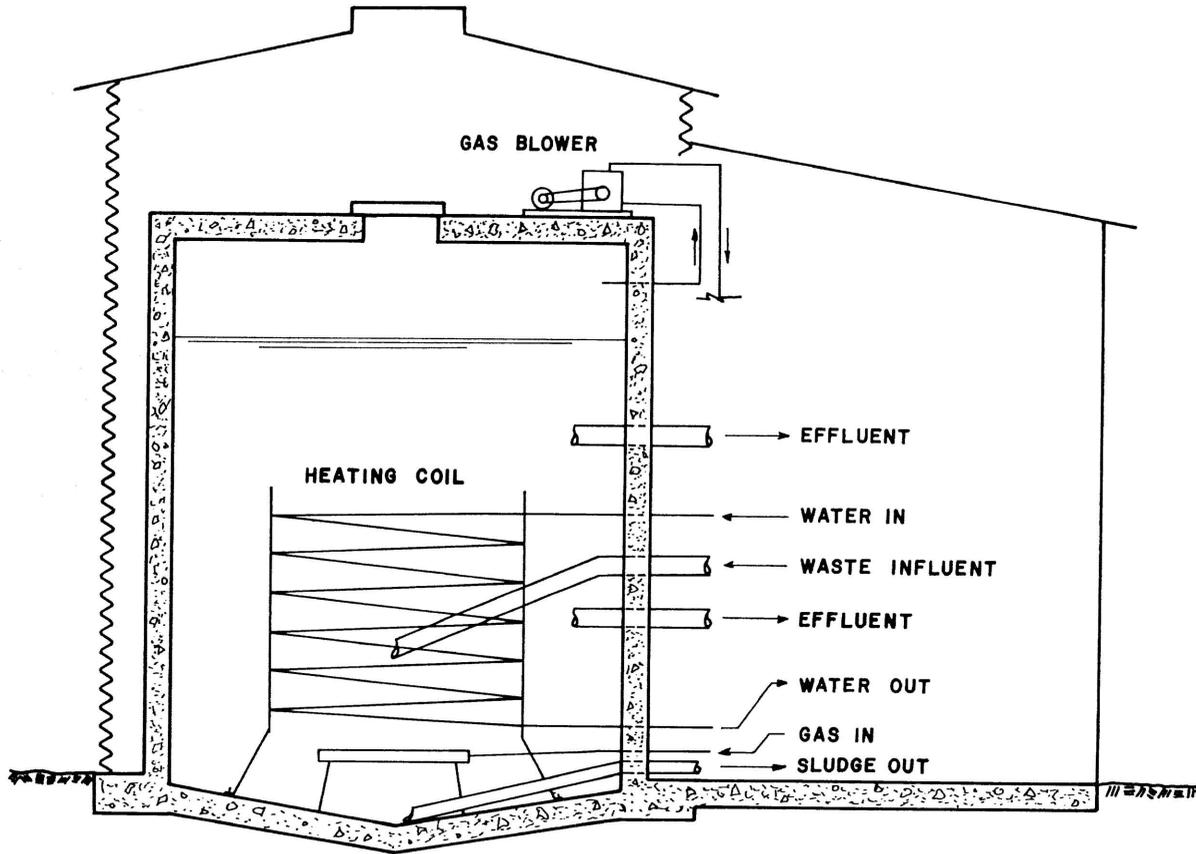


Figure 8. Side view of digester and equipment house illustrating placement of various components.

The heat exchanger consists of six 2.1 m (7 ft)-diameter coils made in an octagon shape with 45° elbows and 5.1 cm (2 in) black iron pipe. The coils are spaced 20.3 cm (8 in) above each other and placed in the lower half of the digester liquid volume (Figure 8).

The temperature of the digester is controlled by a Fenwal temperature controller. The sensing bulb is located halfway between the outer wall of the digester and the outer diameter of the heat exchanger. If the temperature in the digester falls below 35°C (95°F), the temperature controller energizes a water pump which circulates hot water through the heat exchanger coils. When the temperature reaches 37°C (98°F), the temperature controller deenergizes the water pump. The water pump is a 124-watt (1/6hp), 110-v Bell and Gossett Model No 2.54 cm (1 in)-PR centrifugal pump. The pump delivers 37.8 liters (10 gal) per minute at 4.9 m (16 ft) of head.

## **The Gas System**

The gas system for the digester includes two parts: the agitation system and the production system. For agitation, gas is drawn off the top of the digester by a gas pump and returned to the bottom of the digester where it is released through four 2.54 cm (1 in) nozzles (Figure 9). The upward movement of the gas produces the necessary agitation of the digester contents for scum layer breakup and efficient heat transfer.

The quantity of gas recirculated for agitation was based on the design parameter of 28.23 liters (L) per minute (1 cfm) of gas per 30.5 cm (1 ft) of diameter of digester [5]. For the 20-ft diameter Missouri digester, a 565 L per min (20 cfm) pump is required. The gas pump is a rotary lobe type pump manufactured by Roots Blower Company (Model No. 42XA). This pump has a gas capacity of 565 L per min (20 cfm) at 41.3 kilopascal (6 psig). The motor for the pump is a 2.24 kilowatt (3-hp), three-phase, 208-v motor.

The gas production system consists of manometers, meters, and storage (Figure 10). All piping in the gas production system is 2.54 cm (1 in) PVC pipe. A U-tube, water-filled manometer is connected to the PVC pipe immediately outside the digester. This manometer is used as a safety pressure relief valve. If gas pressure in the system exceeds 25.4 cm (10 in) of water column, water in the manometer is expelled, relieving pressure in the digester. Condensate traps were placed in the gas line at all low places where condensate would collect. A red ink manometer is connected to the gas line to record the pressure in the system.

The quantity of gas produced is measured by an AL 250 diaphragm displacement meter manufactured by American Meter Company. Condensate build-up in the meter was a problem, but was eliminated by directing the gas from the digester to a 208 liter (55 gal) drum located on the north side of the equipment house. The drum serves as a condensa-

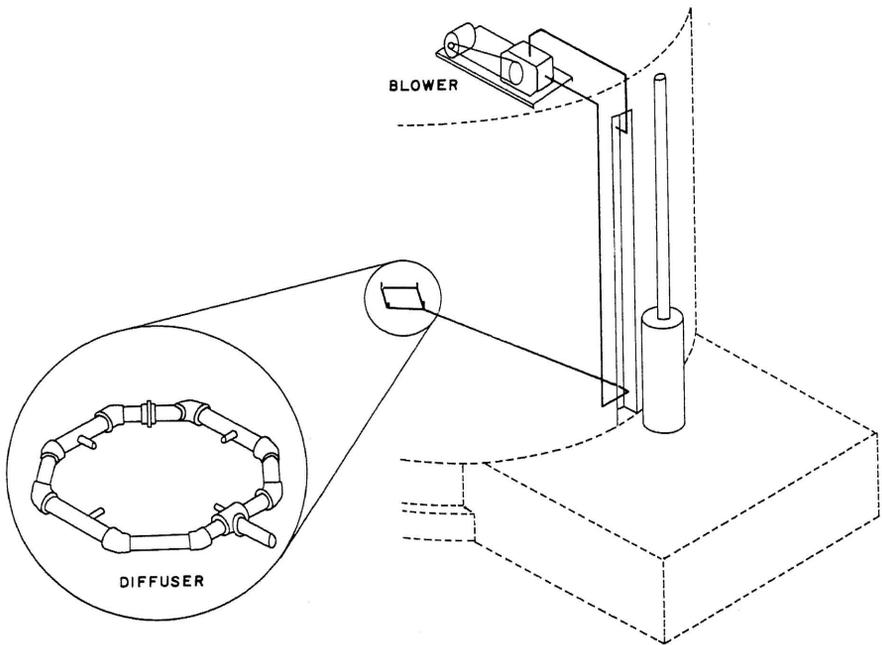


Figure 9. The gas agitation system.

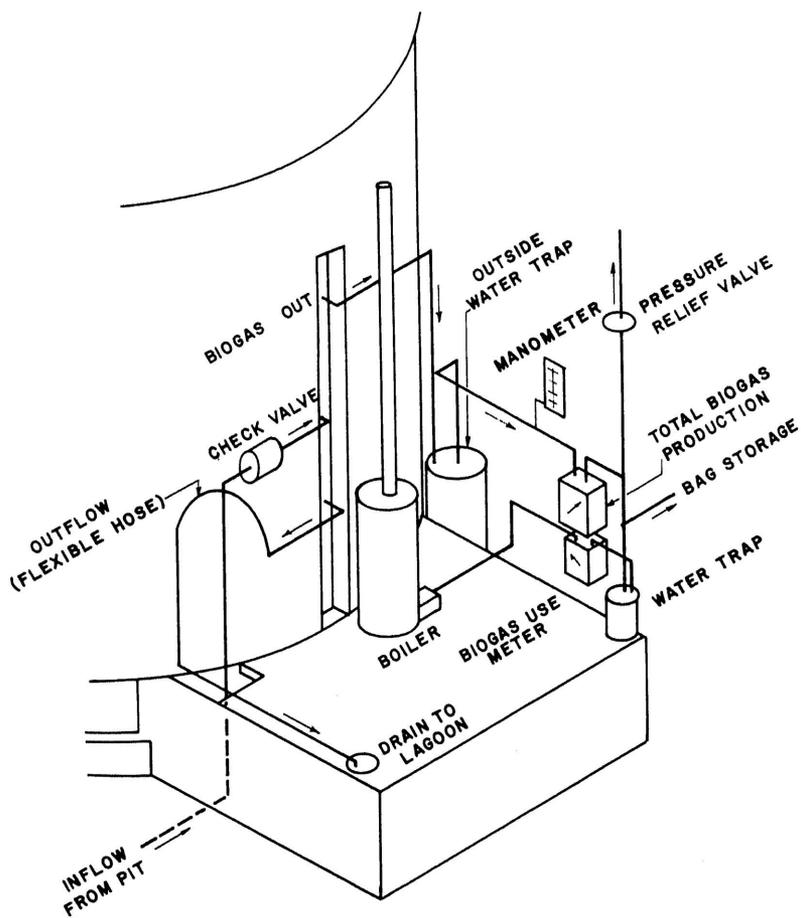


Figure 10. Placement of gas and liquid handling components in the equipment house.

tion trap and has served well even during warm summer months. The gas pipes on the outside of the building should be insulated to prevent freezing during extremely cold temperatures.

After flowing through the meter, the gas can flow to three different places depending upon the demands of the system. The gas can flow through a second meter and to the burner in the boiler or to an inflatable 36 cu. m (1300 cu. ft) gas storage bag. Or, if the boiler does not require heat and the gas storage bag is filled, the gas can flow through the pressure regulator to the atmosphere or to a potential energy use.

The inflatable gas storage bag serves as a pressure damping regulator when material is placed into or removed from the digester and as temporary storage to supply the boiler with biogas. Storage of large volumes of biogas is not economically feasible at this time. Methane cannot be liquified at reasonable temperatures and pressures. In fact, methane will not liquify at any pressure if the temperature is greater than  $-32^{\circ}\text{C}$  ( $-116^{\circ}\text{F}$ ). Current technology dictates that the methane be used as it is produced or converted to another form of energy such as electricity.

Cost of the digester was \$153.50 per cu. m of digester volume (\$4.30 per cu. ft). This cost figure includes labor for construction of the concrete base, stave silo, metal bin and insulation, but does not include all labor costs associated with plumbing and electrical wiring.

Methane becomes explosive when combined with air in a 5-15 (by volume) mixture. Proper safety devices and procedures must be designed into any anaerobic digester. It is recommended that anyone desiring to construct an anaerobic digester seek the advice of a competent engineer experienced in this area.

The digester is an integral part of a multidisciplinary research project at the University to study various aspects of anaerobic digestion on individual farms. This research involves a variety of area including improving the anaerobic process through a study of the bacteriology and biochemistry, the storage and use of methane on the farm, the use of fertilizer nutrients contained in digested material, and the simplification and cost reduction of digester equipment.

If more detailed information concerning this research is desired, contact the following people at the University of Missouri-Columbia:

Dr. Dennis M. Sievers	Dr. James R. Fischer
Assistant Professor	SEA, USDA
Agric. Engr. Dept.	Agric. Engr. Dept.
UMC	UMC

Additional information concerning the digestion of animal wastes can be found in UMC Guide 1881 [6].

## Metric Conversions

1055 Joules (J) = 1 BTU

1 Mega Joule (MJ) =  $10^6$  Joules

1 Mega Joule = 947 BTU

3.6 Mega Joule = 1 kilo Watt-hour (kW-hr) = 3409 BTU

2.54 cm = 1 inch

1 meter = 3.28 feet

1 cubic meter = 35.3 cubic feet

1 liter = 0.035 cubic feet = 0.26 gallon

1 kilogram (kg) = 2.2 pounds (lbs)

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