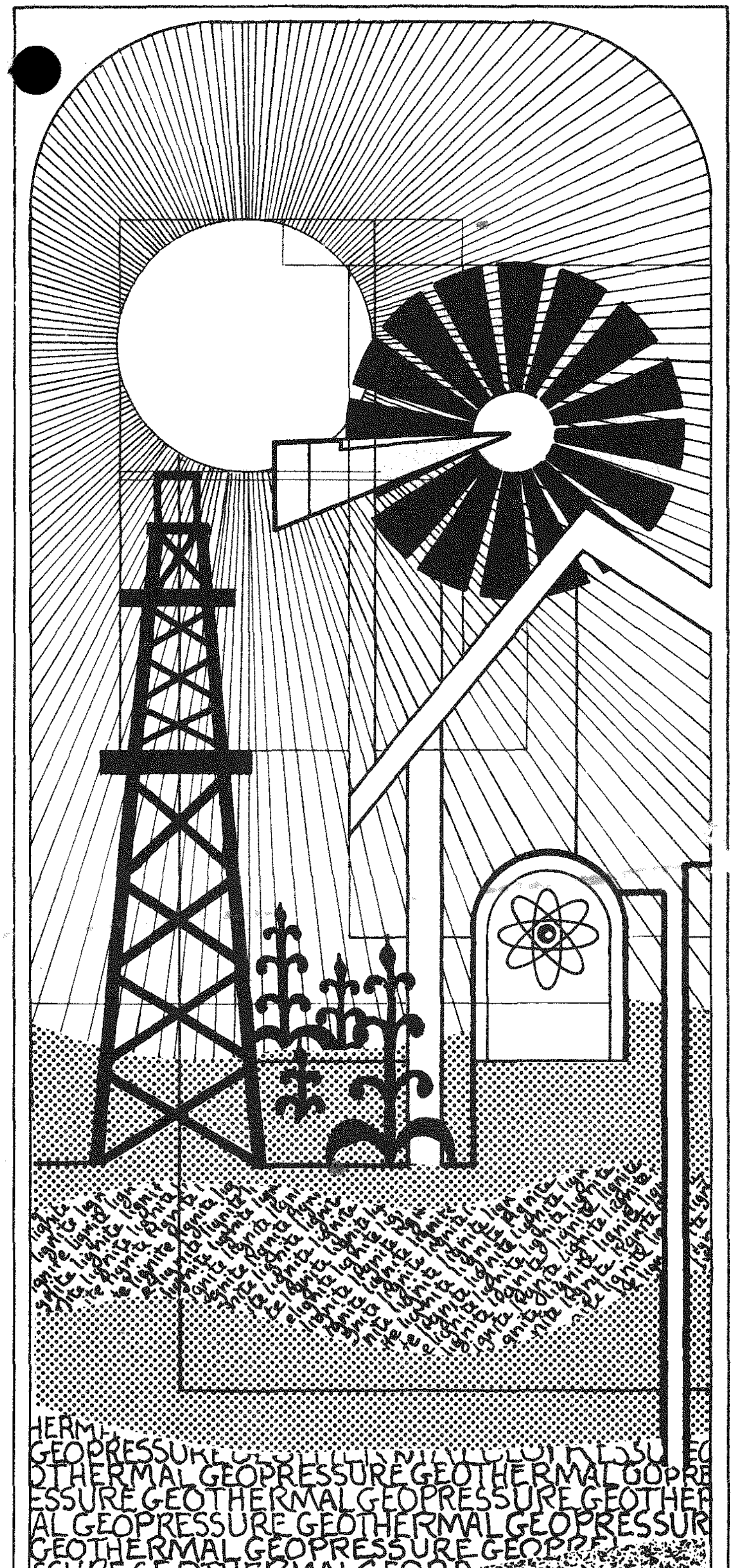


Texas Energy Development Fund

TENRAC/EDF--052

DE83 900874

DEMONSTRATION OF BIOMASS-DERIVED FUELS FOR INTEGRATED ENERGY FARM

TENRAC/
EDF-052

TEXAS ENERGY & NATURAL RESOURCES ADVISORY COUNCIL

OCTOBER, 1981

DEMONSTRATION OF BIOMASS-DERIVED FUELS

FOR INTEGRATED ENERGY FARM

SumX Corporation
P.O. Box 14864
1300 East Braker Lane
Austin, Texas 78761

FINAL REPORT

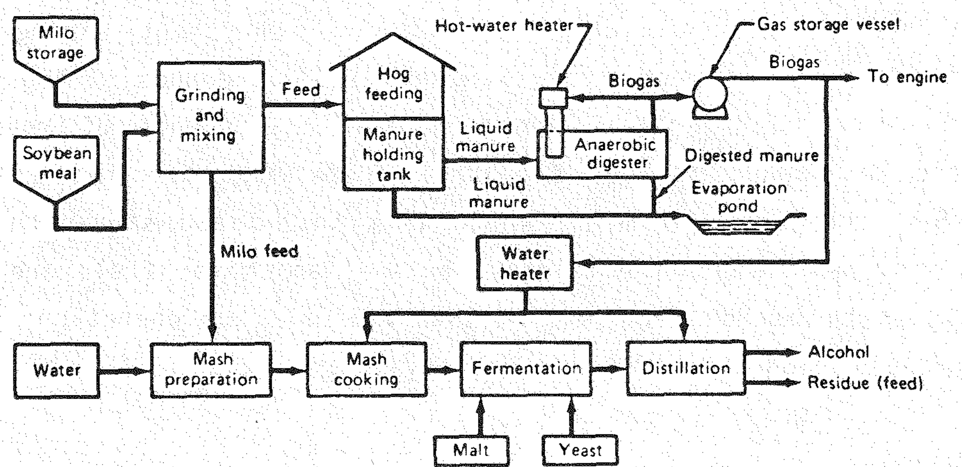
October 20, 1981

Prepared for
Texas Energy and Natural Resources Advisory Council
Energy Development Fund
Project # 80-B-3-1

Report # EDF-052

EXECUTIVE SUMMARY

In October, 1980, SumX Corporation, under direction of the Texas Energy and Natural Resources Advisory Council and the U.S. Department of Energy, initiated a program to design, construct, and demonstrate an Energy Integrated Farm System on the Del Valle Hog Farm in Del Valle, Texas. Specifically, SumX Corporation intends to determine and demonstrate the technical and economical feasibility of methane production derived from the anaerobic digestion of swine manure and the reliability of this process as an alternative energy source for electrical generation and fuel alcohol production. A schematic of the proposed facilities and materials handling is shown in the following figure.



Del Valle Hog Farm
Energy Integrated System

This program is being conducted through a three-phase approach in accordance with the agreement. The three phases are:

Phase I:	Design and Analysis
Phase II:	Fabrication and Installation
Phase III:	Demonstration

It is proposed that the total program be completed over a four-year period. This schedule allows for approximately 2.5 years for demonstration, for disseminating information, and for technology transfer. This report presents the results of the program obtained to date during the first eleven months of the program. During this project period, Phase I was completed and a Design and Analysis Report was submitted in April 1981. A portion of Phase II was also completed.

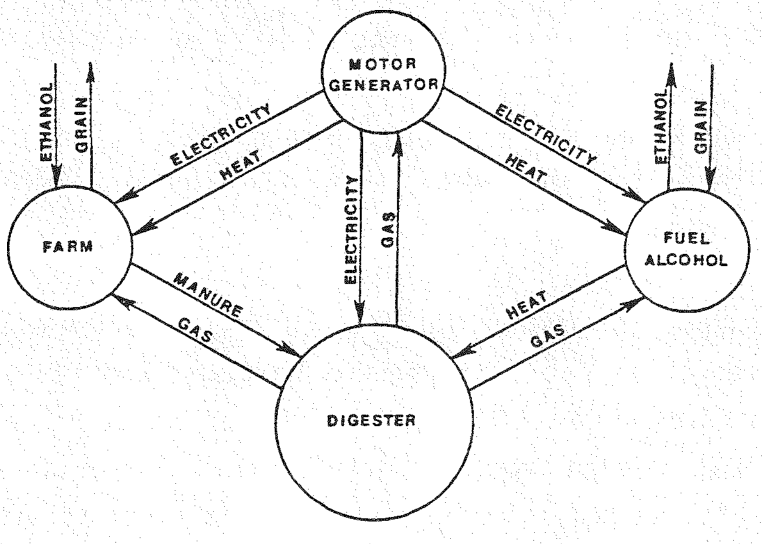
To establish a basis for design and analysis of the specific proposed facilities, an inventory of existing facilities, farm operations, and energy use patterns was conducted. The results of this inventory provide the initial input data for equipment sizing and potential energy integration. Approximately 100,000 pounds of hogs are fed continuously and generate approximately 1500 pounds of readily collectable dry manure solids per day. These hogs are fed a high protein diet consisting of milo, which is produced and stored on the farm, and soy bean meal. Electricity, butane, and motor fuels are the primary types of energy required by this typical farm operation. The following table lists these annual consumptions by type.

Table

Energy Use Inventory

Electricity	39476 kw-hr
Butane	2245 gallons
Gasoline	6129 gallons
Diesel	7155 gallons

The energy integrated system for the Del Valle Hog Farm is shown conceptually in the following figure.



Del Valle Hog Farm
Energy Integrated System

An anaerobic digestion system (digester) using the available manure from the confined hog feeding operation will produce biogas for use throughout the farm operation. However energy use patterns have indicated seasonal requirements for the produced biogas and thus dictate conversion of this energy to a form that is readily usable and/or easily stored for subsequent use. Electrical consumptions have also been determined to be seasonal, with maximum requirements in the winter and summer; motor fuel requirements peak in the spring during planting and in the fall for harvesting or for winter wheat planting.

An energy integrated system designed as shown in the figure to utilize biogas as produced for heating in the winter, for continuous production of electrical energy to meet baseline requirements, and for producing fuel grade alcohol for storage and use throughout the year can best meet the energy demands of this typical hog farming operation. Waste energy in the form of heat can be used thoughout the year for temperature regulation in the anaerobic digester and seasonally for temperature control in the hog farming operation. Integration of these waste energies and primary energy types throughout the farm will lead to a substantial reduction in energy needs and could possibly lead to energy self-sufficiency.

An anaerobic digestion facility for swine manure stabilization and methane production including manure handling and gas utilization system was designed in accordance with information collected from the literature and established from field studies and observations. A 4,000 cubic foot digester was constructed of reinforced concrete with a fiberglass roof for this demonstration facility, and most of the manure handling and gas utilization equipment has been constructed, ordered, and/or is presently on site.

A fuel alcohol facility designed in accordance with the daily motor fuel requirements of the hog farm operation and the available heat generated from the energy integrated system was designed under subcontract by CENTEC Corporation of Reston, Virginia. The system is designed to utilize methane gas generated as an energy source to produce approximately 25 gallons/day of fuel alcohol from the milo used in finishing. Stillage would be wet fed to the finishing hogs by mixing daily with dry feed. A review of commercially available fuel alcohol facilities was also performed to collect engineering specification and performance estimates for comparison with the CENTEC Corporation design estimates. In addition, an extensive analysis of a system designed by SV&G Energy Resources, Inc., Austin, Texas, was performed. These CENTEC and SV&G systems, along with several of the other commercial systems, will be evaluated from a cost/program objectives perpsective and a system will be selected for the Del Valle Hog Farm early in the 1982 - 1983 biennium.

An economic analysis for the energy integrated farm system composed of the anaerobic digestion system, the anticipated electrical generation facility, and a model fuel alcohol facility has been performed. The following table summarizes the results of the economic analysis where three configuration of integration are assumed.

Table
Integrated Farm System
Economic Analysis

	System Configuration		
	Digester	Digester & Co-Generation	Digester, Co-Generation & Fuel Alcohol
Capital Cost	40,000	46,000	76,000
Total Capital Cost $	38,208	44,758	51,174
Annual Operating Cost $	1,700	2,520	12,502
Total Value of Energy Produced $	150,773	124,302	236,988
Produced Energy Cost $/MMBTU	3.70	7.48	12.51
Rate of Return %	8.4	5.5	0.6
Payback Period Yrs.	5.0	6.9	5.1

The tax credits, energy credits, renewable energy credits, and accelerated depreciations used in this analysis are consistent with the provisions of the 1981 Economic Recovery Tax Act. In the first configuration, an integrated farm system containing only a digester costs $38,208 and has the potential for productiing $150,773 in replacement energy over its lifetime. This production results in an energy cost of $3.70 per MMBTU, a rate of return of 8.4% on the investment, and a payback period of 5.0 years. The assumption inherent in the analysis for this configuration is that all produced energy, i.e. biogas, is used on site as produced. According to the inventory of energy use patterns for the Del Valle Hog Farm, this potential is questionable.

In the second configuration, excess biogas above that required for the hog farming operation is used in the co-generation of electricity and hot water. The total value of energy produced for a total capital cost of $44,758 is now $124,302. The produced energy cost, rate of return, and payback period reflect this reduced energy production value. Additionally, all electricity is assumed to be utilized on premises.

In the third configuration, biogas as required is used in the production of approximately 25 gallons per day of 190 proof fuel alcohol for meeting the motor fuel requirements of this farming operation. In addition biogas is consumed in the co-generation facility to meet the baseline electrical requirements of the hog farm. Waste energy in the form of cooling water from the co-generator, condensor water from the distillation column in the alcohol facility, and excess biogas is now available for meeting the heating/cooling requirements of the hog farm and the anaerobic digester system. The total system cost for this configuration of $51,174 is less than expected based on comparisons of total and capital costs for the two previous configurations. This reduction in anticipated cost is due to the $.40 per gallon tax credit allowable for produced energy under the 1981 Economic Recovery Tax Act. The total value of energy produced is seen to be $236,988, resulting in a produced energy cost of $12.51 per MMBTU, a small but positive rate of return of 0.6%, and a payback period on the investment of 5.1 years.

All three configurations have reasonably short payback periods and small but positive rates of return. The third configuration has the advantage that the energy produced can be used directly and immediately or stored for subsequent use; a clear advantage over the other two alternatives.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF TABLES

Section 1

INTRODUCTION

On September 30, 1980, SumX Corporation entered into a cost-sharing agreement with the Texas Energy & Natural Resources Advisory Council (TENRAC) and the U.S. Department of Energy to design, construct, and operate a facility for demonstrating an Energy Integrated Farm System concept at the Del Valle Hog Farm at Del Valle, Texas. Specifically, under this agreement, SumX Corporation is commissioned to determine the technical and economical feasibility of methane production derived from the anaerobic digestion of swine manure and the reliability of this process as an alternate energy source for electrical generation and fuel alcohol production. A schematic of the proposed facilities and materials handing is shown in Figure 1. As it is shown, manure from the hog finishing barn will be used as the feedstock to the anaerobic digestion system while milo will be used as the feedstock for the fuel alcohol facility. The methane and fuel alcohol produced will be utilized to power the hog feeding operations and to supplement farm equipment liquid fuel requirements.

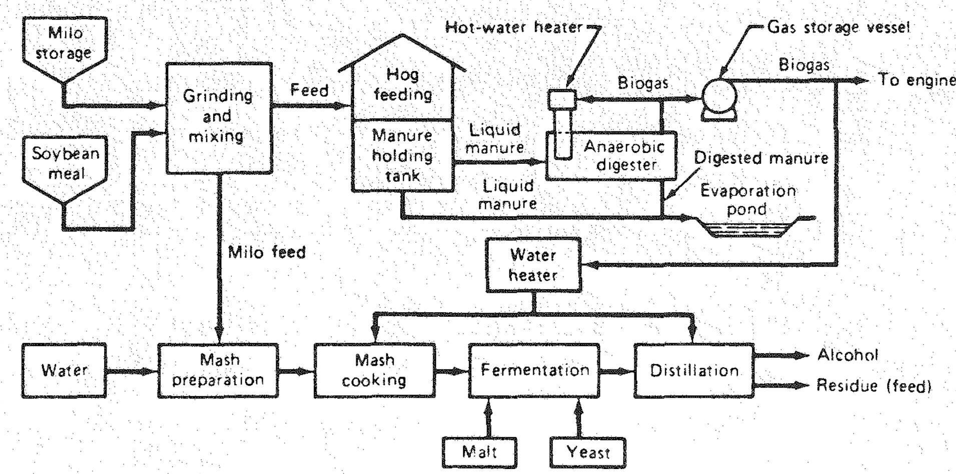


Figure 1: Del Valle Hog Farm
Energy Integrated Farm System

In accordance with the agreement, this program incorporates a three-phased approach. The three phases and their respective tasks are listed below:

PHASE I: SYSTEM DESIGN AND ANALYSIS

1. Monitor on-site energy use
2. Inventory existing facilities
3. Conduct literature survey
4. Field test manure handling and preparation alternatives, manure sampling and analysis.
5. Determine design reactor and ancillary equipment
6. Determine design of alcohol facility
7. Design the energy integrated farm system.

PHASE II: FABRICATION AND INSTALLATION

1. Prepare site
2. Select, procure and install reactor facilities
3. Select and procure alcohol production facilities
4. Start up and operate reactor
5. Start up and operate alcohol production facilities
6. Design and construct integrated system.

PHASE III: DEMONSTRATE INTEGRATED SYSTEM

1. Operate and monitor the performance of the integrated system after initial startup
2. Conduct workshops, etc., as required for technology transfer
3. Produce a manual which can be distributed to other farm operators in an effort to encourage implementation where feasible.

This report presents results of the program developed during the first eleven months of the contract period and is SumX Corporation's final report during the biennium ending August 31, 1981. Phase I: System Design and Analysis was completed in April, 1981, and construction completed to date includes the evaporation pond, manure sump pit, anaerobic digester, the associated pipes and valves, and some electrical lines. The extent of construction completed with appropriate figures is presented in this report. This report also contains an economic analysis of the proposed facilities based on cost information developed under Phase I and estimated service performance. A list of all conferences attended and presentations given in relation to this project is also presented.

Section 2

DESCRIPTION OF FARM AND FARM OPERATIONS

Prior to design of an energy integrated system, it is necessary to develop an extensive data base of existing facilities, conditions, and practices. This section presents the results of the initial inventory of existing facilities and practices at the Del Valle Hog Farm.

The Del Valle Hog Farm, owned and operated by Dan Berdoll, is located ten miles southeast of the Texas Capital on State Highway 71. This farrow-to-finish hog facility is part of a 2,000 acre farm and cattle operation. The Del Valle hog raising and feeding facilities are shown in Figure 2. This hog operation occupies approximately 15 acres on the farm, and consists of three barns, a workshop, water storage tank, feed grinding mill and grain storage bins, and a settling/evaporation pond. The three barns house the breeding/gestation area, the farrowing pens, and the nursery and finishing units.

The breeding/gestation area shown in Figure 3 houses approximately 140 sows and boars in a three-walled barn adjacent to a field enclosure. Every 38 days, 25 to 30 sows are bred artificially and segregated into pens. These gestate sows are moved through the segregated sow pens sequentially according to breeding dates, and a few days prior to farrowing, are transferred to the farrowing barn which is shown in Figure 4. This unit is divided into two separate enclosed rooms, each having pens for 14 sows and litters. The pens are raised above concrete floors to facilitate manure removal and maintain sanitary conditions. The rooms are insulated for temperature control and sanitized to reduce the potential for disease.

After nursing for 34 days, the small pigs are moved into the nursery unit, and the sows are moved back to the breeding/gestation pen for future breeding. Because the small pigs are quite susceptible to disease, the environment within the nursery and the feed mixture and supplements are carefully controlled.

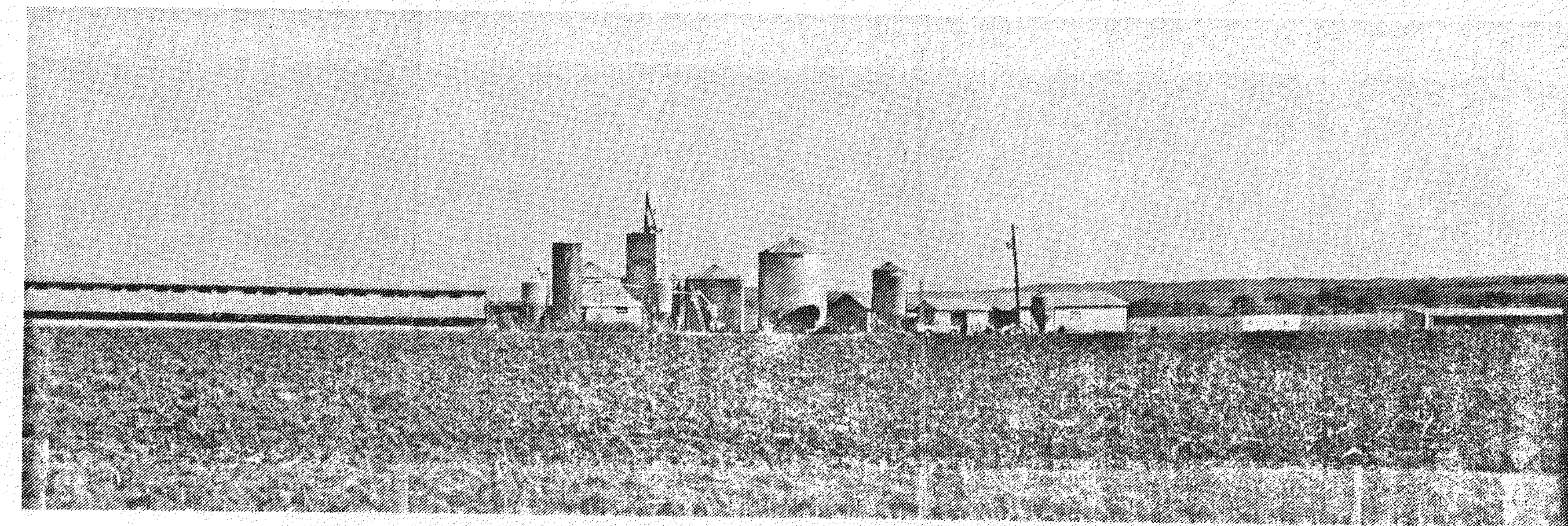


Figure 2: Del Valle Hog Farm Facilities

Figure 3: Gestate Sow Pens

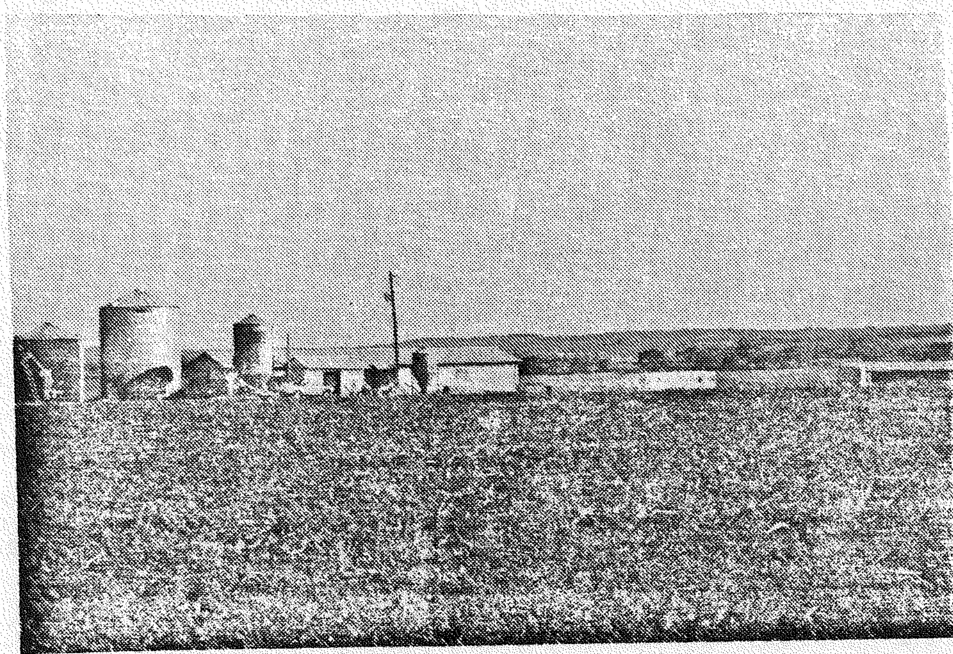


Figure 4: Del Valle Hog Farm Farrowing Barn

After a period of time for growth, the young pigs are moved from the nursery to the finishing area. The nursery and the finishing barn is a single structure and is shown in Figure 5. This area is divided into twelve pens with pigs separated according to weight.

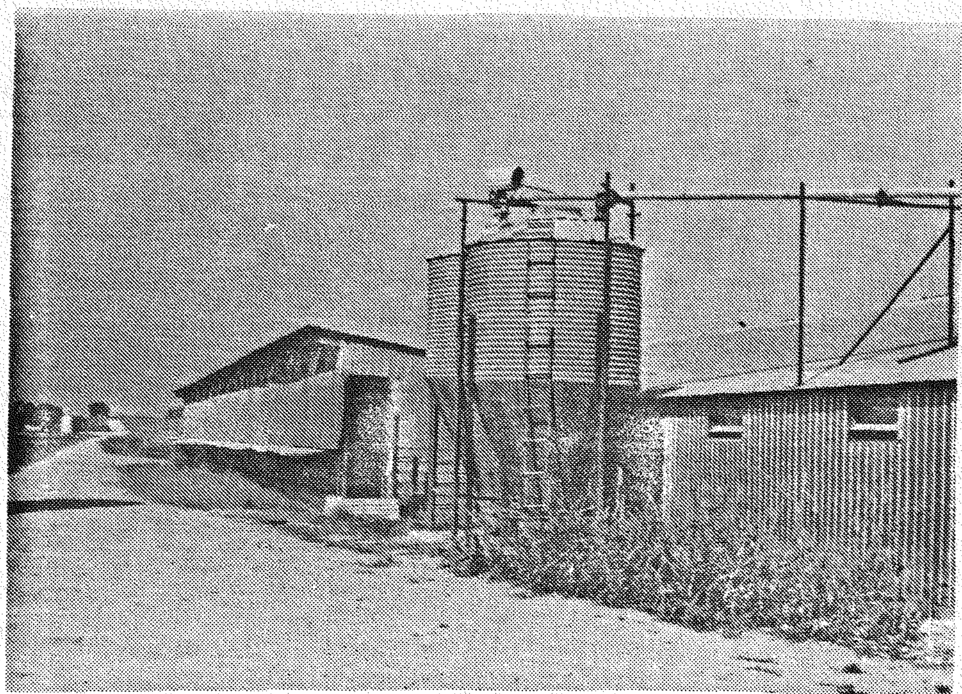


Figure 5: Del Valle Hog Farm Nursery & Finishing Barn

The concrete floor of each pen in the finishing unit is divided into two sections; a sloped and solid concrete surface for feeding and a flat slotted floor for manure deposit. This manure falls through these slots into a subfloor collection pit that runs the complete 215 foot length of the finishing and nursery building. This pit is divided by a concrete wall thus creating two troughs 104 inches wide and 215 feet long. A two percent grade exists in these troughs with depth ranging from 42 inches to 90 inches. The concrete slotted floor in the finishing barn is shown in Figure 6.

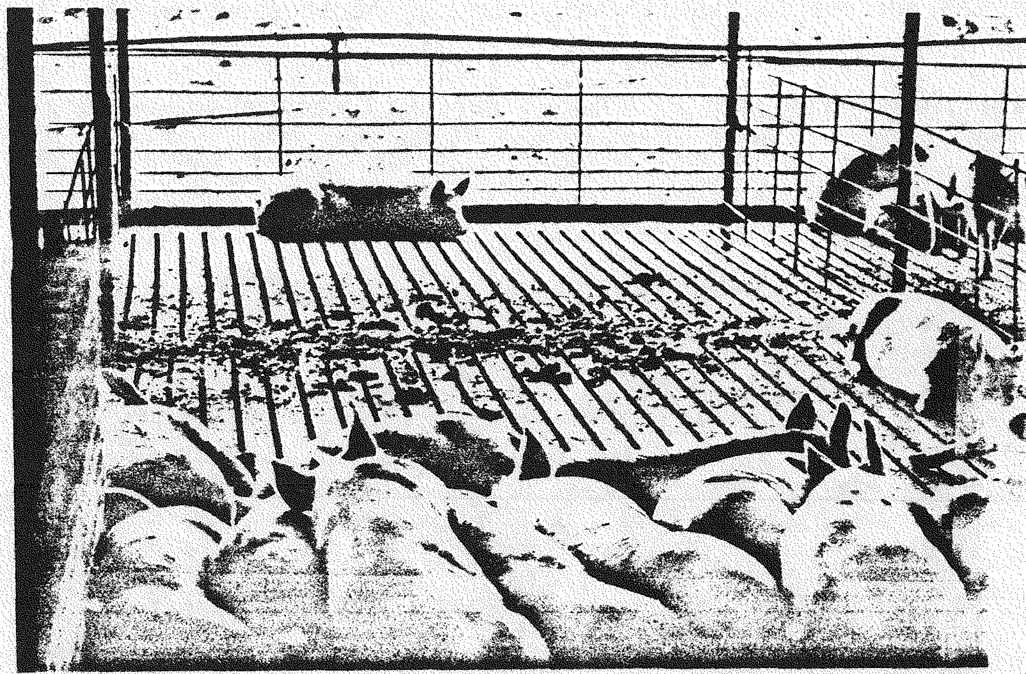


Figure 6: Finish Barn Slotted Floors for Manure Removal

Hogs in the finishing unit are fed a high protein diet of ground milo and soy bean meal which is ground and stored on site and screw augered into feeders in each pen. The finished hogs are sold when they reach a weight of approximately 230 pounds.

FEED HANDLING

Approximately 3200 pounds/day of milo and 1800 pounds/day of soy bean meal are required for the feeding operation. The annual requirements are stored in silos which have a capacity to store approximately 1.5 million pounds. Additional storage is available for feed supplements.

The grain and supplements are ground and mixed in a CRIMPOMATIC feed grinder shown in Figure 7 and stored in various locations around the facility. Feed for the finishing units is augered to the storage and feed bins. Feed storage facilities and feed grinding and distribution facilities are shown in Figures 8 and 9 respectively. Ground feed for the breeding and gestation pens and the farrowing unit are transported via portable storage and augering equipment. Once stored at these locations, feed is taken manually to the various feeding stations because these are controlled feedings rather than free feeders; e.g., feeding rates for gestate sows depend on the period of gestation.

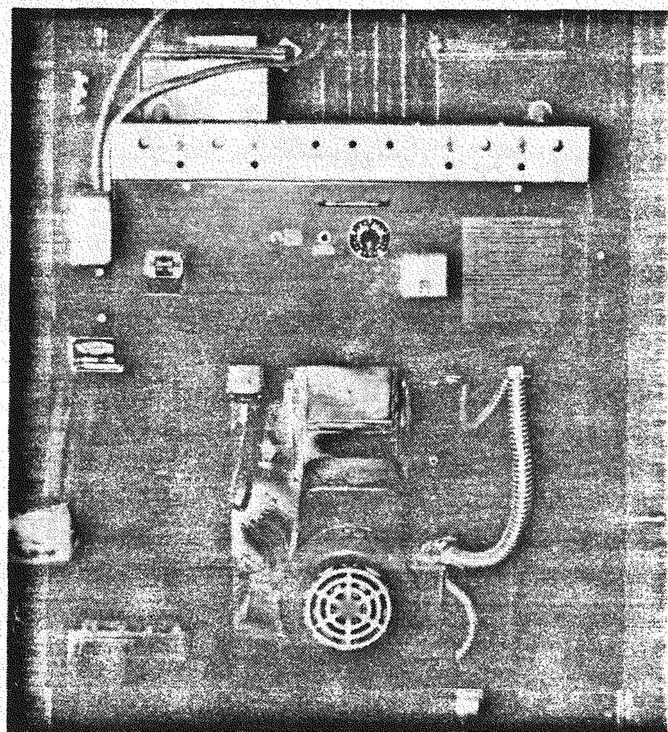


Figure 7: Feed Grinder

MANURE HANDLING

The breeding and gestation pens have covered barns with sloped concrete slab floors. These slab floors are cleared periodically, but no attempts are made to collect and/or remove the manure in these pens. The farrowing pens are raised above the concrete slab floor and have slotted bottoms. The concrete floor is washed daily, and the manure slurry gravity flows through a 10-inch plastic pipe to the .85 acre-feet settling/evaporation pond shown in Figure 10 which is located behind the hog facilities.

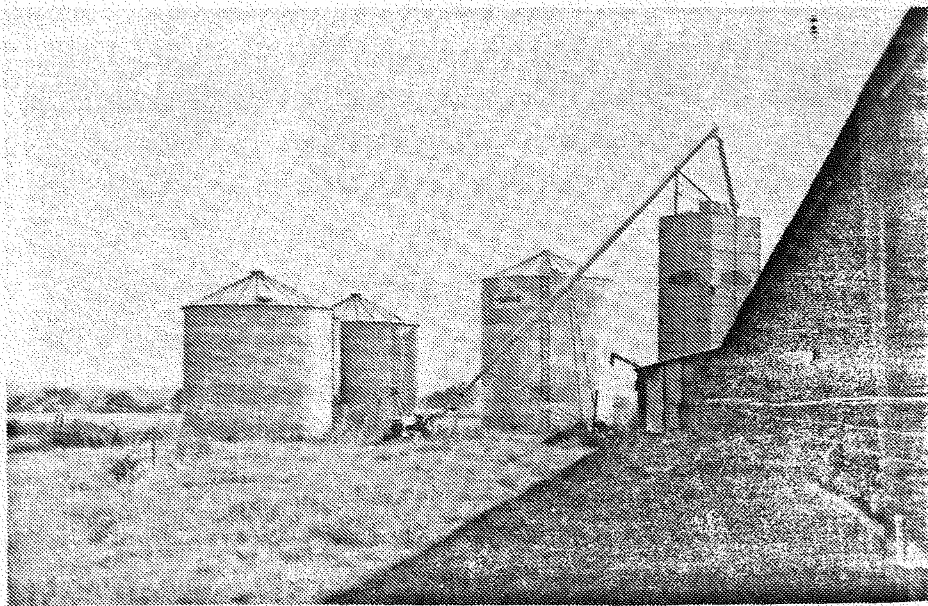


Figure 8: Feed Storage Facilities

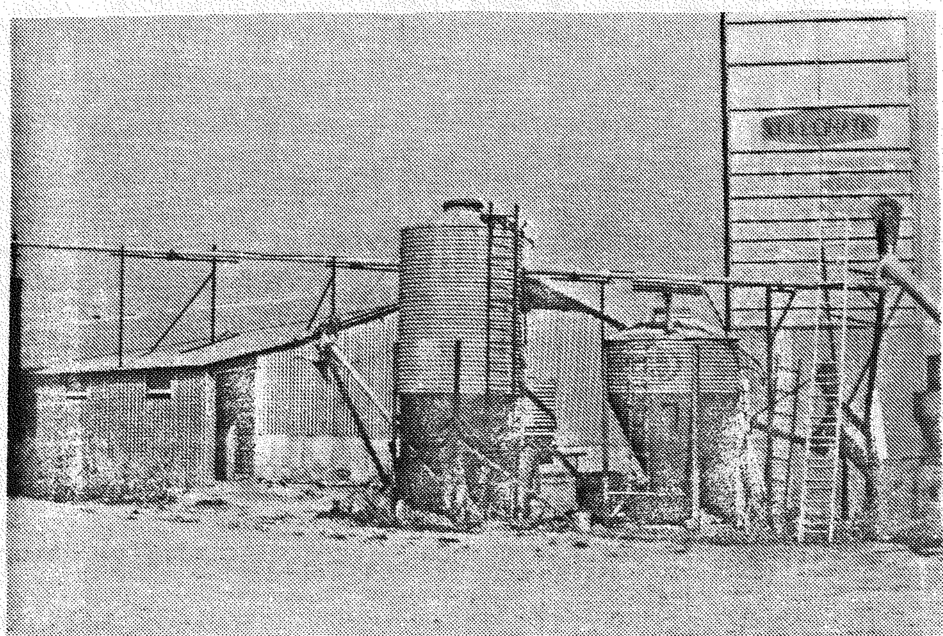


Figure 9: Feed Grinding and Distribution Facilities

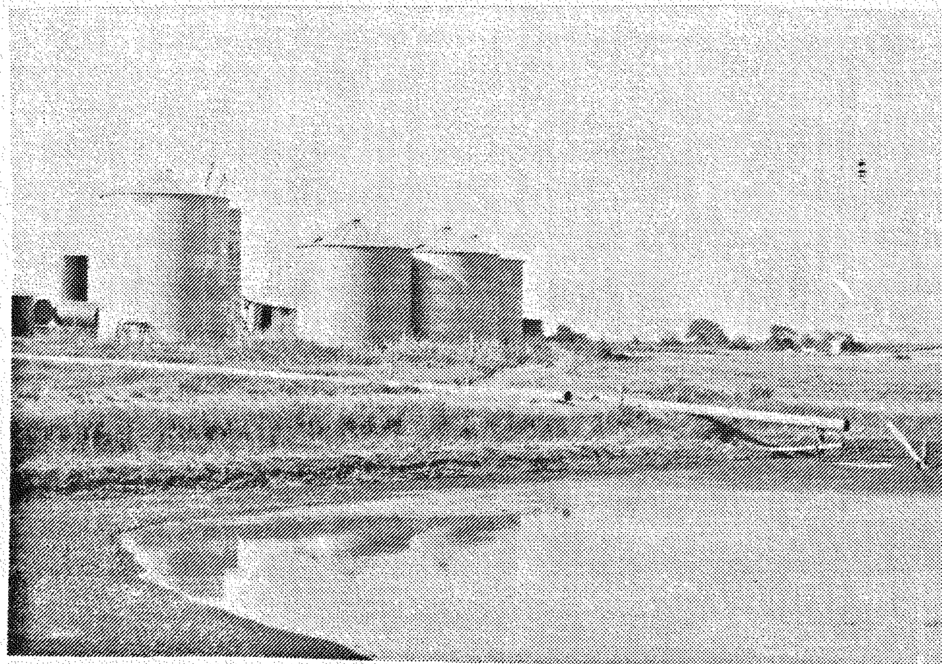


Figure 10: Settling/Evaporation Pond

The nursery unit and the finishing unit are constructed with slotted floors above a 20' x 215' concrete underfloor liquid manure pit. The pit depth varies uniformly at a 2 percent grade from 42 inches to 90 inches in depth. Before this project was initiated the liquid level in the pit was maintained approximately six inches below the top of the tank by a liquid overflow drain system designed to gravity drain excess liquids to the settling/evaporation pond. The solids in the pit were periodically pumped into an irrigation system for land application on adjacent fields of coastal bermuda grass. Similarly, the settling/evaporation pond water was used for feed crop irrigation.

RESOURCE REQUIREMENTS

The current resource requirements for the hog facilities and the associated farm operations include water, electricity, natural gas, and diesel and gasoline fuels.

Water is derived from a well located approximately ½ mile from the hog facility and is stored in an above ground storage tank. A

1/3 h.p. motor pumps this water at approximately 60 psi to spigots located in each of the facilities. In addition, a 1.5 h.p. jet switch pump is located in the farrowing pen, which pressurizes the water to approximately 130 psi, allowing easy daily cleaning of the concrete floor. Water is also supplied to two evaporative coolers to control temperature in the farrowing pen during the summer. It is estimated that water consumption is approximately 2000 gpd in the winter and 4000 gpd in the summer.

Three tractors (John Deere Models 8630 and 4040 and International Harvester Model 640) and one car are powered by diesel fuel. These tractors range from 40 to 225 horsepower. Three pick-up trucks are gasoline powered. A partial listing of farm equipment includes a round baler, a square baler, disk harrows, a hay cutter, hay trailer, and a variety of sprayers.

Each primary feed storage bin has a small motor to power the associated screw auger. Two additional auger motors are used to transport the feed the length of the finishing barn. The mill contains a 220V, 5 h.p. CRIMPOMATIC unit, and a single 2 h.p. auger motor used to lift grain from the storage bins into the grinder-mill.

Section 3
FARM USE ENERGY MONITORING

Energy produced from this project will be effectively used to satisfy a portion of the Del Valle Hog Farm energy demands. To determine the most effective energy utilization strategy it was necessary to conduct an energy use survey. This section presents the results of that inventory. These results are used to develop and design the integrated system.

The energy use pattern for the typical hog farm, and in particular the Del Valle Hog Farm, varies both seasonally and daily. Weather conditions, such as extreme heat and severe cold, affect the comfort level of the finishing hogs and, consequently, their feeding and weight gain patterns. In addition, daily operations and their associated energy consumptions vary; e.g., feed grinding/augering, heating or cooling, pumping water, etc. The integration of these energy consumptions and the alternative energy sources available via this demonstration project should allow the Del Valle Hog Farm to achieve a significant portion of its energy demands.

The primary objective of energy monitoring is to identify and quantify the energy use patterns within the Del Valle Hog Farm operation with respect to fuel types, i.e., butane and electricity. This information will aid in establishing energy balances for the hog farming operation required for developing efficient energy allocations for the energy integrated system.

To inventory existing energy usage within the Del Valle Hog Farm operation a monitoring program was initiated. This monitoring program included placing strip recording watt meters at critical consumption areas, i.e., grinders, auger motors, water pumps, etc., so that electrical requirements can be clearly defined and quantified with respect to average and peak demands, and maintaining purchase records and identifying usages of butane consumed. In addition, records to identify unusual meteorological and/or operational conditions have been maintained to assist in explaining any irregularities or unusual consumption patterns or energy demands.

A summary of electrical consumptions for the period of December 1979 through February 1981 for the Del Valle Hog Farm is shown in Figure 11. Electricity is used in colder periods for concentrated heating in the farrowing unit; e.g., heating pads and high intensity heat lamps, and as the main source of cooling during warmer periods in the farrowing unit via air conditioning and/or fans, and in the nursery unit via recirculation and ventilation fans. During the period from January 1980 through December 1980, the toal electrical consumption for the Del Valle Hog Farm was 39,476 kw-hr, with 5876 kw-hr attributable to the well.

As shown in Figure 11, electrical consumption for the winter of 1980 was slightly higher than the winter of 1981, with this attributable to the winter of 1981 being a milder and drier period than normal. Consumption during the summer of 1980 was extremely high both at the hog barn for cooling and ventilation and at the well for drinking and cooling water due to the unusual heat conditions that persisted in the southwest during this period. A minimum electrical consumption for this facility can be seen in the figure during late spring to be approximately 1800 Kw-hrs/month for total operation and 1440 Kw-hrs/month for hog barn operation. These correspond to a minimum electrical requirement of 60 Kw-hrs/day and 48 Kw-hrs/day, respectively, for operation of the Del Valle Hog Farm. Figure 12 contains strip chart recordings of electrical energy consumption for February 5th and 6th, 1981 at the hog barn. Figure 12a presents total electrical requirements and Figure 12b presents feeding operation electrical requirements. During these two days, the average temperature in Austin was 8° and 7°F, respectively, below normal. The average consumption for the feed augering and lights is shown in Figure 12b to be approximately 2.5 Kw/hr while the average total consumption, shown in Figure 12a, is approximately 4 Kw/hr. This 1.5 Kw/hr differential is consumed in the farrowing unit for concentrated heating of young pigs. Periods of grain milling, as indicated in the figure, increase electrical consumption by approximately 2 Kw/hr.

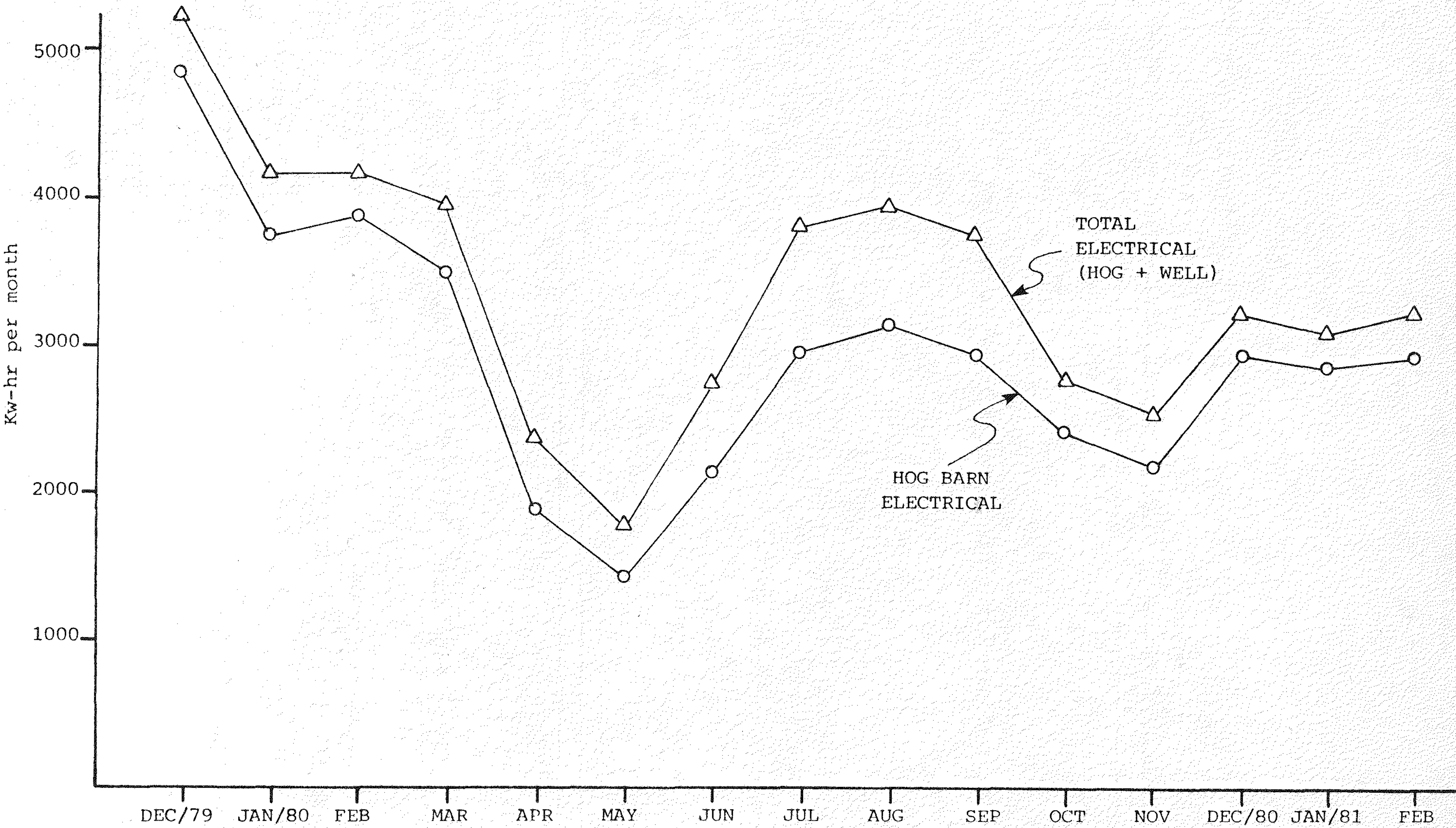


Figure 11: Electrical Consumption at the Del Valle Hog Farm

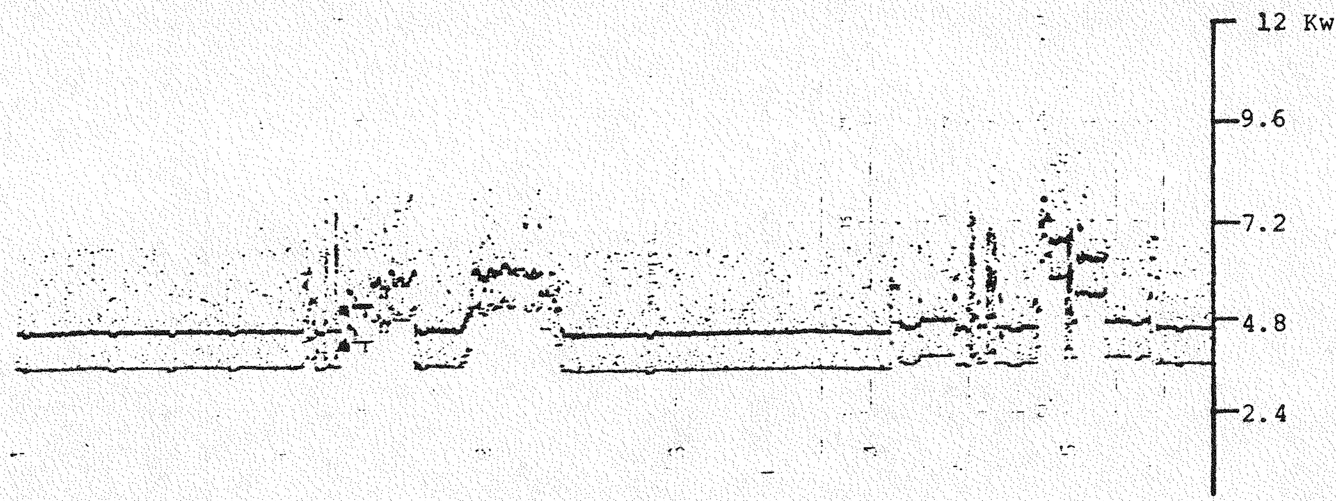


Figure 12a: Total Farm Electrical Consumption

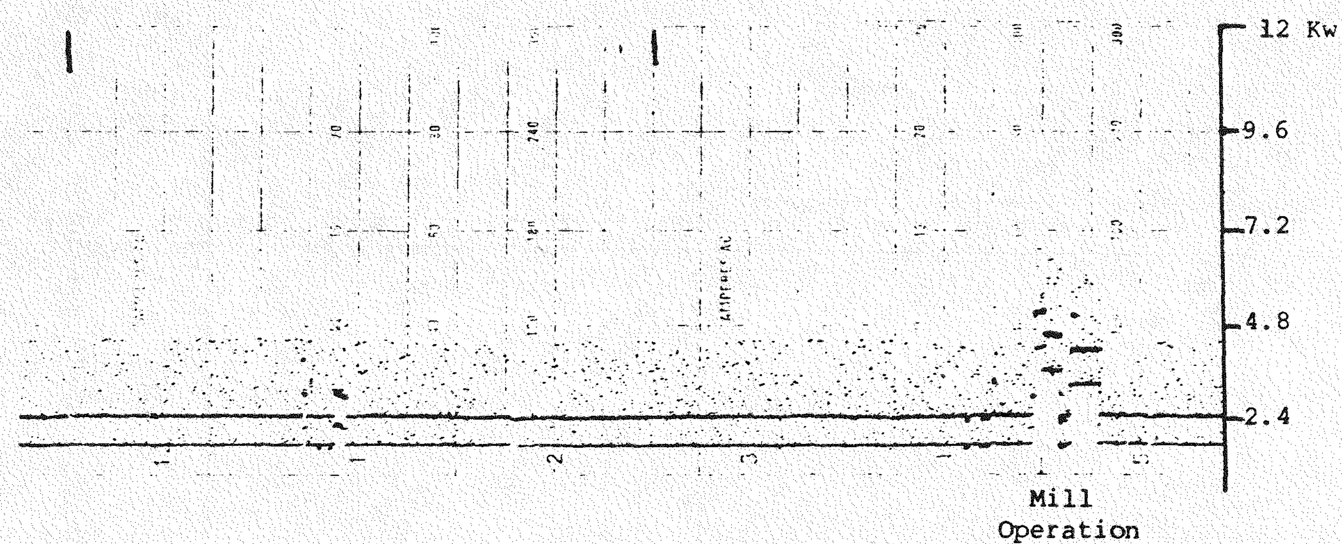


Figure 12b: Mill and Auger Consumption

Figure 12: Del Valle Hog Farm Electrical Consumption for
February 5-February 6, 1981

Butane consumption rates for 1980 are shown in Figure 13. Butane is used exclusively for heating the farrowing and nursery units at the hog farm, therefore usage, as shown in the figure, is high during late fall, winter, and early spring, with none in the warmer periods. During this period the butane consumption for the Del Valle Hog Farm was 2245 gallons.

Record keeping for diesel and gasoline consumptions is performed manually and indicates usage at the farming operation for the October 1980 through September 1981 time period of 7155 gallons and 6129 gallons for diesel and gasoline respectively.

These monitorings of electrical, butane, diesel, and gasoline consumption at the Del Valle Hog Farm will expand to include methane gas generation and ethyl alcohol production on a continuous basis as these systems are put into operation. Proper allocation of the available energy sources, i.e., methane and ethyl alcohol, in the form of electricity, heat, and fuel will be clearly evidenced by the reduced dependency of this farm on external energy sources. The monitoring of the external consumption levels will be a primary performance guideline used in the demonstration phase of this project. On site energy use monitoring will continue throughout the contract period and information collected will be continually used in developing the most efficient and effective alternative for energy integration on the Del Valle Hog Farm.

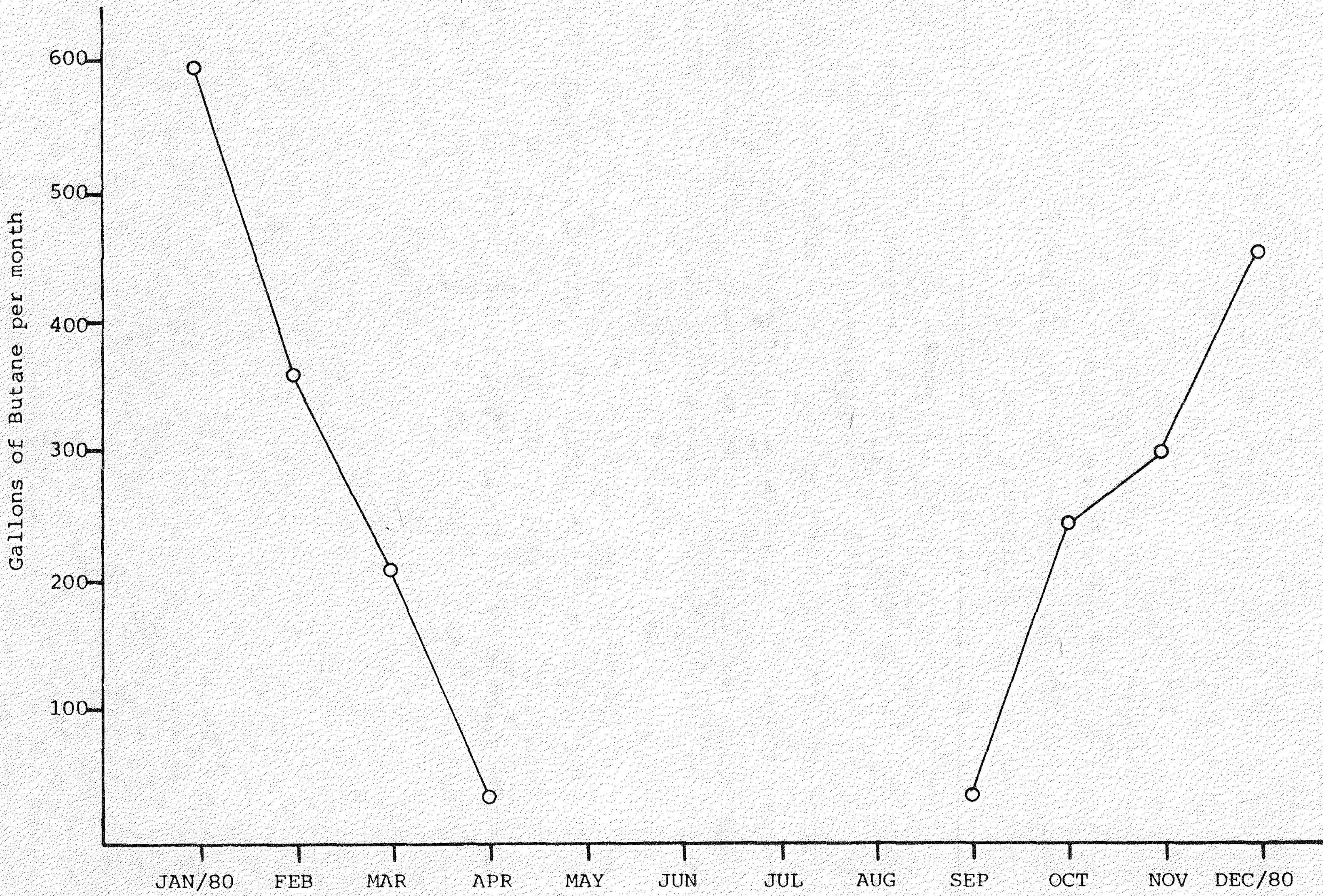


Figure 13: Butane Consumption - Del Valle Hog Farm, 1980

Section 4
DESIGN AND CONSTRUCTION OF THE ANAEROBIC DIGESTION FACILITIES

BASIC DESIGN CONSIDERATIONS

Current design criteria for design and construction of anaerobic digestion facilities for processing animal waste is based primarily on design criteria established for municipal sludge handling and processing equipment. Little data available for design of animal waste digestion facilities has been developed from full scale on-farm facilities.

Selection of materials and equipment sizing for the anaerobic digestion facilities on the Del Valle Hog Farm were determined from the characteristics and quantity of the swine manure and from estimated performance of the proposed facilities, i.e., solids destruction and gas production. A brief discussion of the anaerobic digestion process follows which identifies and describes basic design criteria requirements.

Anaerobic bacteria are found universally in nature, particularly in decaying matter, and have the ability to decompose waste in the absence of molecular oxygen. During anaerobic decomposition, methane and other gases, primarly carbon dioxide, are produced and the degradable organic portion of waste is stabilized (1).

In the first stage of the anaerobic digestion process, facultative acid forming bacteria split the carbohydrates and polysaccarides, proteins, and lipids that make up the complex organic waste, into short-chained simple organic acids, ammonia and carbon dioxide (2). A small portion of the waste is converted into cells (1). The most predominant organic acids formed are acetic acid (CH_3COOH), from the degradation of other fatty acids, carbohydrates, and proteins, and propionic acid (CH_3CH_2COOH) from the degradation of carbohydrates and proteins (3). The most common volatile acid intermediates formed during first stage anaerobic digestion include formic, acetic, and propionic acids (1).

In the second stage of anaerobic digestion, the methane forming bacteria which are obligate anaerobes, utilize organic acids and produce methane gas. After a sufficient period of treatment, the gas, which is insoluble, escapes from the waste stream and the waste is stabilized.

Several different groups of methane-forming bacteria exist and each is identified by its ability to ferment a relatively limited number of organic compounds (4). Therefore, several different methane forming bacteria groups are required for effective waste stabilization and gas production.

During anaerobic digestion, the major portion of degradable waste is converted to methane and other gases yielding little energy to the microorganisms (1). Therefore the rate of growth of the methane formers is slow and only a small portion of the waste is converted into new cells. The formic acid and methanol utilizers grow rapidly and can thrive at a solids retention time of two days, but the most important methane formers, those that utilize acetic acid and propionic acid, grow slowly, and solids retention times of four days and more are required. This slow rate of growth limits the rate at which the digestion process can adjust to changing waste loads, temperature, and other environmental conditions. Thus, relatively long periods of time are required to establish a balanced system (1, 5).

When the system is in balance, the methane formers utilize the acid as quickly as it appears. Both the acid formers and methane formers must exist harmoniously in a common environment. Since the methane formers are slow growers, the acid formers may predominate resulting in a pH drop and further growth inhibition of methane formers. Acid concentrations of 2500 mg/l are deleterious to the propagation of methane producing bacteria (4). The detection of an increased rate of volatile acids concentration is an early warning of an imbalanced system.

The performance of an anaerobic digestion system is affected by and can be controlled by environmental conditions within the digester. The most influential and controllable parameters within a digestion system are temperature, solids loading rate and concentration, pH, and solids retention time. In municipal sludge processing facilities, mixing is usually practiced to prevent upset conditions and to enhance the effectiveness for sludge stabilization. However, unmixed reactors are currently being investigated for digestion of animal waste to reduce both construction and operating costs.

If digester tanks are unheated, the digestion period will depend largely upon the prevailing ambient temperatures. Because the digestion period required to obtain a given percentage of the ultimate gas production will generally decrease with increasing temperature, digesters are usually heated. Digesters will be operated in either the mesophilic temperature range (below 110°F) or in the thermophilic temperature range (above 110°F). Although tests show that total solids and volatile solids reduction may be 5 to 10 percent greater for digesters operating in the higher temperature zone, municipal treatment plant digesters are generally operated in the lower temperature range because the high energy requirements for the thermophilic range are not economically justified (6).

Optimum operating performance in the mesophilic range has been observed to be approximately 95°F (6). Sawyer and Schmidt report that a 55 percent reduction in volatile solids of a raw sewage can be obtained from digesters operating at the optimum temperature for a detention time as short as 11 days (7).

Temperatures below 75°F to 80°F are not usually considered because digestion rate and gas production decline rapidly at these lower temperatures (2). Imhoff and Fair report that gas production decreases with decreasing digester operating temperatures and that gas production stops at temperatures below 40°F (8).

Conventional data that can be used as criteria to determine optimum manure loading rates to the digester are difficult to establish because information reported in the literature is frequently in disagreement and, additionally, most information reported is based on data collected from municipal sludge digestion facilities, not animal waste facilities.

However, investigations are now being conducted in an effort to establish proper design criteria. Unfortunately, most recently completed studies have concentrated on beef and dairy cattle waste rather than swine manure. Therefore the design of the anaerobic digestion system for the Del Valle Hog Farm was based on both the literature and the results of field studies investigating the characteristics of the swine manure.

Loehr and Agnew conducted anaerobic digestion studies on beef cattle waste and report that this animal waste is about as biodegradable as sewage sludge but that larger loading rates can be tolerated for cattle waste (9). The operating parameters and digester performance of their tests are given in Table 1. The loading rates varied from 0.1 to 0.4 pounds of total solids per day per cubic foot. At the lower loading rate, approximately 71 percent of the volatile solids were destroyed and approximately 9 cubic feet of digester gas was produced per pound of volatile solids added. At the higher loading rate, approximately 55 percent of the volatile solids were destroyed and more than 11 cubic feet of digester gas was produced per pound of volatile solids added. The percent of 5-day BOD and the percent of COD reduced remained essentially the same for the range of loadings at approximately 55 and 28, respectively.

Tentative guidelines for maximum loading rates of heating and mixed anaerobic digesters held at 95°F when fed fresh animal manure has been compiled by Smith (2). His guidelines suggest a maximum loading

Table 1: Characteristics of Mixed Liquor, Mixed and Heated Anaerobic Digester for Processing Animal Waste (9)

Loading Rate Lbs TS/c.f./ Day	pH	Volatile Acids (mg/l)	Alkalinity (mg/l)	Total Solids (mg/l)	% Volatile Solids	% Total Solids Reduced
0.1	6.7	100	1,500	7,190	77.8	55.2
0.2	6.8	100	2,050	18,640	79.5	41.9
0.3	6.8	175	1,800	33,340	69.1	30.7
0.4	6.7	175	1,900	41,170	64.6	35.8

Loading Rate Lbs TS/c.f./ Day	% Volatile Solids Reduced*	5-Day BOD (mg/l)	% 5-Day BOD Reduced	COD (mg/l)	% COD Reduced	Gas Production	
						c.f./lb TS Added	c.f./lb VS Added
0.1	71	1,830	52.4	11,725	23.8	7.59	8.97
0.2	53	3,310	57.0	21,980	28.6	7.41	8.76
0.3	44	5,130	55.5	32,750	29.1	8.7	11.9
0.4	55	6,740	56.2	41,160	33.1	8.47	11.3

* % Volatile Solids destroyed calculated from previous data.

rate of 0.37 pounds of volatile solids per day per cubic foot., a hydraulic detention time of 12.5 days and an ammonia-nitrogen concentration not to exceed 1200 mg/l.

Coe and Turk have also conducted studies to evaluate the suitability of the anaerobic fermentation process for animal waste (10). Their results show that waste slurries with twice the solids concentration and fermentation contact times 1/3 that of municipal systems are practical, and that process stability and reliability are excellent. A volatile solids loading rate of 1.0 pound per day per cubic foot was used in their experiments (11). This loading rate is much higher than the loading rates reported by Loehr and Agnew and recommended by Smith, but little trouble was reported.

The solids detention time in the digester must also be considered in the design. Most studies report that increased methane production and solids destruction will occur with increased detention time. However, increased detention time implies a large digester resulting in increased capital expenditures and possibly excessive heat losses.

Results of recent research indicate that a detention time of 10 to 30 days is necessary to maintain a stabilized reactor. Jewell, et al, determined that most of the solids are converted in about three to five days detention time (12). Sheaffer & Roland, Inc. recommend a detention time of 10 to 20 days for reactors used for digestion of animal waste (13).

The quantity of volatile matter added to the digester and the fraction that is actually destroyed dictates the quantity of gas produced by a digester. Theoretically, the destruction of one pound of volatile matter should yield one pound of digester gas (14). Assuming a biogas composition of 65 percent methane and 35 percent carbon dioxide, the specific quantity of the biogas is approximately 0.9, and, therefore, approximately 14.8 cubic feet of digester gas could be produced per pound of volatile solids destroyed. However, gas yields of as low as

12.0 cubic feet per pound of volatile solids destroyed have been observed (14).

The two major constituents of digester sludge gas are methane (CH_4) and carbon dioxide (CO_2). Methane concentrations can be expected to range from 60 to 75 percent of the volume while carbon dioxide will range from 25 to 40 percent (2). Gas composition will vary somewhat with environmental conditions in the digester, but can be expected to be uniform once the digester is operating at steady state (15). The different major constituents of the digester gas and their approximate concentrations as reported by Robinson are given in Table 2 (14).

Table 2: Gases Commonly Produced from Anaerobic Digestion (14)

Gas	Approximate Concentration of Digester Gas (%)
Methane	70.0
Carbon Dioxide	25.0
Nitrogen	3.5
Oxygen	0.5
Hydrogen	1.0

Methane is colorless, odorless, and tasteless and will burn when mixed with small quantities of air. If air concentrations are allowed to reach 5 to 15 percent by volume of the total mixture with methane, the composition will become explosive.

Digester gas may have an objectionable odor and is saturated with moisture. The odor problem is associated with the small amounts of hydrogen sulfide (H_2S) which is a colorless gas and burns with the formation of sulfur dioxide and water vapor. Hydrogen sulfide is extremely dangerous in high concentrations because it rapidly paralyzes the sense of smell (14). However, digester gas usually contains less than 1/10 of 1 percent of sulfur (10, 11).

The heating value of the digester gas produced ranges from 500 to 700 Btu per standard cubic foot with an average heating value of 640 Btu per standard cubic foot (6).

PRIMARY DESIGN ASSUMPTIONS AND DIGESTER SIZING

The initial requirement for developing the anaerobic digestion facility is to determine the characteristics of the manure which will be used as the feed stock to the digester. Relevant characteristics of manure produced from confined hog feeding operations similar to the Del Valle Hog Farm were compiled from various sources and are summarized in Table 3. This data was used as the basis for the preliminary design of the anaerobic digestion system as well as for estimating material balances.

Table 3: Daily Manure Production per 100 Pounds Liveweight Hogs

Total Weight Fresh Manure (Pounds)	Total Volume Fresh Manure (Cubic Feet)	Moisture Content (Percent)	Total Solids (Pounds)	Volatile Solids (Pounds)	Density of Fresh Manure (Lbs./c.f.)	Ref.
8.0	0.13	75	2.0*	0.94	62.0	16
7.8	0.13	75-90	-	-	60.0	17
7.0	0.115	84	2.12*	0.95	61.0*	18
6.5*	-	-	-	0.96	-	13
8.4	0.14*	85*	-	-	62.0*	19

* Calculated from data given.

The basic assumptions used for the design of the Del Valle Hog Farm anaerobic digestion system as compiled from information collected from the literature and from the farm inventory and field studies are shown below:

BASIC ASSUMPTION

Weight of Hogs	= 100,000 lbs.
Manure Production	= 78 lbs/1000 lbs hogs/day @ 81% M.C.
Volatile Solids	= 9.4 lbs/1000 lbs hogs/day
Gas Production	= 14 c.f. biogas/lb V.S destroyed
Heating Value	= 640 Btu/c.f. biogas
Desired Hydraulic Detention	= 15-20 days
Solids Loading	= 8-10 percent
Digester Temperature	= 95°F
Solids Destruction	= 50 percent

The digester size depends primarily on the quantity of manure produced, the manure loading rate, and the desired degree of digestion. Using the data presented in Table 3, and the basic assumptions, the estimated quantity of manure produced is calculated as follows:

Total Manure Weight = 100,000 lbs live wt. x 78 lbs/1000 lbs/day
= 7800 lbs/day @ 81% moisture content

Total Solids Weight = (100% - 81%) x 7800 lbs/day
= 1482 lbs/day

Volatile Solids Weight = 100,000 lbs live wt. x 9.4 lbs V.S./1000 lbs.
= 940 lbs/day

Checking Percent V.S.:

$$\text{Percent V.S.} = \frac{940 \text{ lbs}}{1482 \text{ lbs}}$$

= 63 percent ∴ reasonable

Assuming a desired loading rate of 0.24 pounds of volatile solids/cubic feet of digestion/day as suggested by Smith (2), the desired size of the digester is calculated as follows:

$$\text{Digester Size} = \frac{940 \text{ lbs. V.S./day}}{0.24 \text{ lbs. V.S./c.f./day}}$$

= 3920 c.f.

A hydraulic detention period of 15 to 20 days is desirable as established from the literature. With the digester size set at 3920 cubic feet, the hydraulic detention period is dependent exclusively on the quantity of manure or waste loaded per day. As previously calculated, it is estimated that approximately 1482 pounds of total solids will be produced per day and available for digestion. Adjusting the manure to a 10 percent solids concentration for loading into the digester, the total volume of manure is determined as follows:

$$\text{Total Manure Volume} = \frac{\text{1482 lbs solids/day}}{\text{10\% solids Conc.} \times \text{62 lbs/c.f.}}$$

$$= \text{239 c.f./day}$$

and the hydraulic detention period will be

$$\text{Hydraulic Detention} = \text{3920 c.f./239 c.f./day}$$
$$= \text{16.4 days}$$

Adjusting the manure to the desired 10 percent solids concentration for loading into the digester will require the addition of make-up water. Fresh swine manure, as shown in Table 3, will have a moisture concentration ranging from 75 to 90 percent. Assuming a moisture content of fresh manure of 81 percent (average concentration reported in Table 3), the make-up water requirements are calculated below:

$$\text{Water Required} = \frac{0.90 \text{ (1482 lbs/day)}}{.10} - \text{(7800 lbs/day} \times 0.81)$$

$$= \text{7020 lbs/day} \qquad \text{(842 gallons/day)}$$

This quantity of water is required and available for flushing manure from the underfloor prior to loading the digester.

DIGESTER CONSTRUCTION MATERIALS SELECTION

Materials selected for construction of an anaerobic digestion facility must be durable and corrosion resistant. The liquid swine manure and the product biogas are highly corrosive to steel and any steel appurtenances which are directly exposed to these materials should be protected with a corrosion resistant lining or coating. Materials for major components within the system should provide a long useful life to ensure that economics will justify financing by lending institutions.

Two types of materials were considered for construction of the digester. These materials were steel and concrete. Steel fuel storage tanks with dimensions of 10 feet diameter x 25 feet length (1960 c.f.) are readily available and two tanks of this size, having a volume of approximately 3930 cubic feet, are consistent with the volume requirements of this project. The tanks can be purchased new and delivered to the project site for approximately $1500.00 per tank (21). After being delivered, these tanks would need to be modified with holes drilled and tapped for sampling equipment, heating coils, liquid mixing equipment, influent and effluent pipes, and manure drains. These drilling and tapping operations will result in developing stress concentrations at the site of the activity, which will become highly susceptible to corrosion. It is also noted that the soils at the construction site are from the Houston-Black soils and are characterized as highly corrosive to steel (22). Owing to these considerations, concrete was also investigated as an alternative construction material.

After developing an initial conceptual design, it was determined that a concrete digester, located in the ground to provide earth fill insulation, is cost competitive with the steel tanks. Additionally, concrete is resistant to the corrosive action of both the liquid manure and the Houston-Black soils (22).

Another major advantage of using a concrete tank instead of the steel tank is that the concrete tank can be constructed for a desired geometric design. This feature is important, as it allows more flexibility in operation and, consequently, a more efficient system.

The major disadvantage to constructing a concrete digester is that a separate roof has to be constructed and fitted to the digester. Concrete is unacceptable for this use, as it will leak gas and will not maintain the proper pressure as cracks develop. This occurrence would result in a malfunction of the system and could potentially create explosive conditions.

Materials considered for the construction of the digester roof are steel and fiberglass. The disadvantages of steel for this corrosive environment have been discussed previously. The advantages of fiberglass are that 1) it is corrosion resistant, 2) it is translucent and will act as a solar collector for digester heating, 3) it is easily drilled and tapped for fitting necessary digester piping, and 4) it can be field fabricated by individuals with little fiberglass construction experience.

The digester was therefore constructed of reinforced concrete with a fiberglass roof. The digester is set in the ground to allow gravity flow from the manure collection sump and to the evaporation pond. Additionally, the in-ground construction provides insulation in addition to the three-inch polystyrene sheets located on the exterior of the ten-inch thick walls and under the twelve-inch slab. Because the soil is clay-based, three inches of caliche and three inches of sand were placed in the bottom of the pit, forming a base for the concrete slab. Other aspects of the digester design and fiberglass roof are presented elsewhere in this report.

SITE SURVEY

The immediate area of the proposed construction site was surveyed in October, 1980, to identify and establish topographical features and characteristics. Elevations at the site are keyed to the National Geodetic Survey, Vertical Control Mark Y1221 (elevation 454.31 MSL) located approximately one mile from the site on the Onion Creek bridge on U.S. Highway 71.

Field data collected was used to prepare a one-foot interval topographical map of the study area. This map is used to plan the layout of the proposed facilities and to establish elevation of the manure pit and sump, the digester, and the liquid level of the evaporation pond to provide a design for a gravity flow system.

From results of the survey, it is determined that the ground surface near the end of the finishing barn is at an elevation of approximately 485 feet MSL and slopes to the east to 272 feet MSL over a distance of approximately 240 feet. This topography provides a relief of approximately five percent at the ground surface.

The bottom of the concrete manure collection pit is set at an elevation of 479.31 feet MSL, or approximately 5.7 feet below the ground surface. This elevation was considered the highest elevation for initiating the gravity flow system and was incorporated into the design of the proposed facilities.

EVAPORATION POND DESIGN AND CONSTRUCTION

Pond Design Consideration

Effluent from the digester will be discharged to the evaporation pond at an estimated rate of 239 cubic feet per day or 87,235 cubic feet per year. For operational purposes, the pond should be designed to contain at least one year of storage. Solids and liquids accumulated in the pond will be removed and spray irrigated as necessary on adjacent grass lands to vacate the pond.

The design capacity at the pond is a function of the daily liquid loading and the evaporation/precipitation characteristics of the Austin, Texas geographical area. From meteorological records, this geographical area experiences net annual evaporation of approximately 19.06 inches (23, 24).

It is desirable to construct a pond with as large a surface area as feasible to maximize the benefit of this net evaporation. As a result of topographical and structural constraints at the project site, the maximum surface area that could be dedicated to the disposal pond was approximately 16,000 square feet. This surface area is provided by an 80-foot by 200-foot configuration.

The berm for the disposal pond was constructed on a 2.5::1 slope. The actual depth of the excavation was determined from the desired elevation at the pond surface. Because the anaerobic digestion facility is designed to operate on a gravity flow system, the desired elevation of the pond liquid surface was set at 475.01 feet MSL, or approximately 2.8 feet below the elevation at the manure collection pit sump. This difference in elevation provides a two percent slope for gravity manure movement.

Physical constraints at the site required excavation to begin at approximately the 477.00 foot elevation. With a 2.5::1 slope, this requirement reduces the liquid level surface area to 70 feet x 190 feet to remain within the approximate 80 foot x 200 foot land surface disturbance constraint.

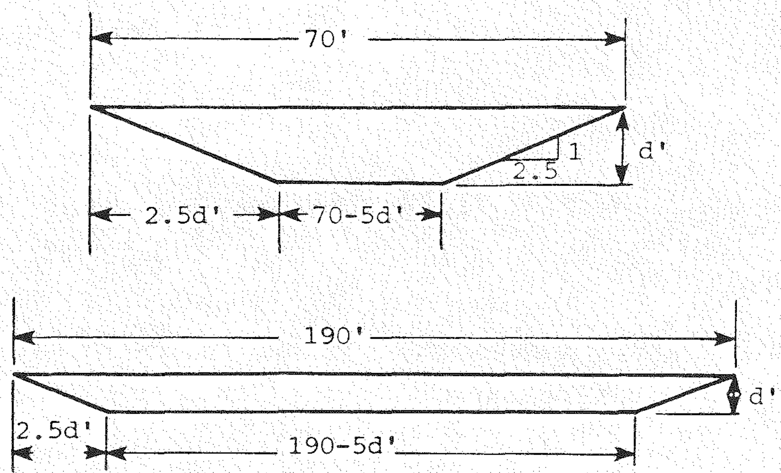
From information provided in the Webberville Quadrangle, Texas, 7.5 minute series topographical map, prepared by the U.S. Geological Survey, the location of the evaporation pond is not within an extensive drainage basin. It is estimated from the map that the drainage area above the pond is approximately six acres. Additionally, this area is above the hog barn and provisions were previously made to direct runoff south and around the barn. Therefore, the runoff is not expected to reach the evaporation pond. The depth at the evaporation pond determines the available storage with the liquid surface area fixed at 70 feet x 190 feet.

Pond Design Calculations

ASSUMPTIONS

Inflow	=	239 cubic feet/day (87,000 c.f./year)
Rainfall	=	32.3 inches/year
Evaporation	=	51.55 inches/year
Net Evaporation	=	19.06 inches/year (1.59 feet/year)

CROSS-SECTIONAL DIMENSIONS



Total Capacity = $13,300\ d - 650\ d^2 + 12.5\ d^3$

Liquid losses due to evaporation are determined using the average surface area, i.e., the surface area when the pond has reached one-half capacity (approximately ½ x 87,200 c.f.). Solving the total capacity equation for d, with a total capacity of 43,600 cubic feet, determines depth below the surface at which one-half capacity will occur. The surface area at one-half capacity is a function of d, or (190-5d) x (70-5d).

Solving for the depth below the surface for one-half capacity,

$$43{,}600 \text{ cubic feet} = 13{,}300\ d - 650\ d^2 + 12.5\ d^3$$
$$d = 4 \text{ feet}$$
$$\text{Surface Area} = (190-5d)\ (70-5d)$$
$$= 8500 \text{ sq. ft. at } \tfrac{1}{2} \text{ capacity}$$
$$\text{Average Annual Losses} = 8500 \text{ sq. ft.} \times 1.59 \text{ ft/year}$$
$$= 13{,}515 \text{ cubic feet/year}$$
$$\text{Total Storage Capacity Required} = 87{,}200 - 13{,}515$$
$$= 73{,}685 \text{ cubic feet}$$

Solving for d

$$73{,}685 \text{ cubic feet} = 13{,}300\ d - 620\ d^2 + 12.5\ d^3$$
$$d = 8.5 \text{ feet}$$

Use a pond depth of 8.5 feet with an additional 2 feet for freeboard.

Notice: Using a depth of 8.5 feet is conservative, as the average surface area for evaporation calculations will actually be larger than that used and, consequently, a smaller total capacity would be necessary.

An excess of material was removed from the pond area with the necessary excavation. This material can be used to provide an additional two feet of freeboard for the pond. Therefore, the height of the berm is set at approximately 470.00 feet. This additional freeboard results in a total surface area of 90 feet x 210 feet. Construction of the pond was completed in January, 1981, and is shown in Figure 14.

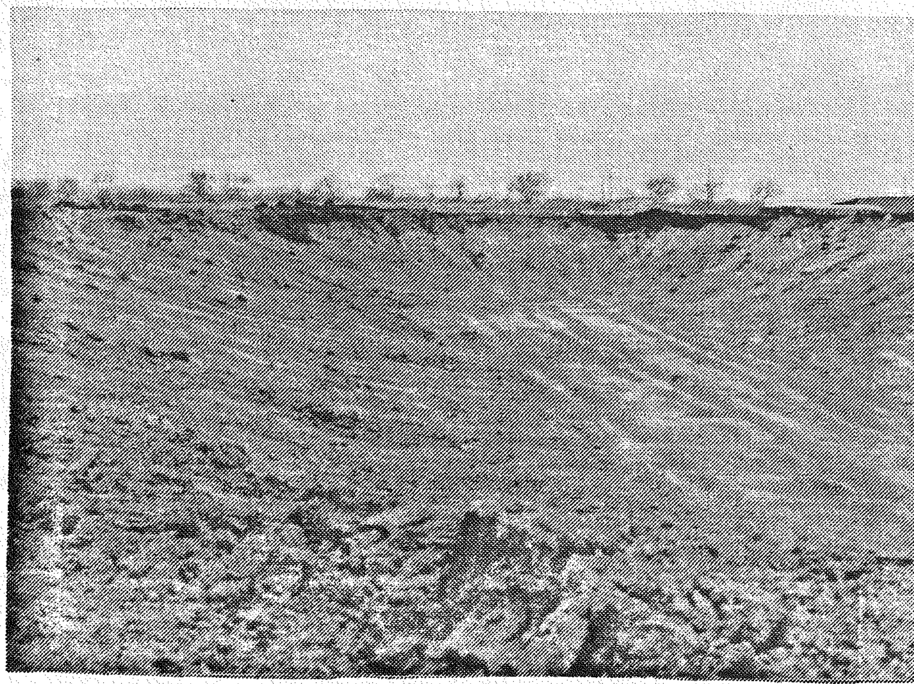


Figure 14: Completed Evaporation Pond

Permits for Pond Operation

Because the construction and operation of the new disposal pond will result in a change in manure management at the Del Valle Hog Farm, a requisition for a permit modification was submitted for review and approval to the Texas Department of Water Resources. A permit modification is not required from the Texas Air Control Board, as the installation of an animal waste stabilization process will result in an improvement to the air quality in the vicinity of the farm, particularly with respect to odors.

In compliance with Articles 7621d-1 and 4477-7, Vernon's Texas Statutes, a request for permit modificiation, including a description of the farm, farm operations, and proposed operational changes was submitted. A copy of that request and the analytical results of soil testing are provided in the Appendix. Also included is the Texas Department of Water Resources response granting that permit modification.

MANURE LOADING DESIGN

It is desirable to load the manure into the digester as quickly as possible after it is generated as regular solids removal and carbon losses will begin almost immediately, resulting in uncaptured methane production. Loading the fresh manure into the digester on a full-scale farm operation is perhaps the most difficult and critical procedure in the design and operation of a feasible system. Flush systems have been used successfully to solve manure handling problems at other confined animal feeding facilities, but the quantity of water required to move the manure is generally too high, resulting in excessive dilution. The final slurry usually has a solids content of one to two percent solids and is not amenable to the anaerobic digestion process which requires an eight to ten percent solids concentration. As discussed previously, a make-up water quantity of approximately 842 gallons/day will be required to adjust the fresh manure to the desired solids concentration of ten percent. This quantity of flush water may not be sufficient to thoroughly move the fresh manure into the digester and mechanical assistance may be necessary.

Little information from field experience is available which can currently be used for design of a manure loading facility. However, in this program, all attempts will be exhausted to utilize a gravity flow system and minimize mechanical manure movement. Therefore, field testing of manure handling will continue until an acceptable method is developed.

The design and analysis of the manure loading facilities is based primarily on the physical features of the construction site and on current manure handling practices and suggestions. From results of the site survey, it is estimated that a slope of approximately two percent is available for moving manure from the waste collection pit to the anaerobic digester. Moormans recommends an eight-inch diameter or larger pipe for gravity flow of animal manure (25). Sweeten indicates that drain pipes of six-inch diameter may not be acceptable, as they have been observed to cause liquid backup and solids buildup in sump pits (26). Therefore, Sweeten recommends an eight-inch diameter pipe or larger for manure drains.

A survey of PVC piping indicated ready availability of piping up to 24-inch diameters. A survey of PVC valve availability was also performed with the following results: gate valves are available up to eight inches, butterfly valves to 24 inches, diaphragm valves to ten inches, and check valves to eight inches (27). Fulton recommends the use of gate valves on swine manure because of the large quantity of undigested grain present in the manure (28). These particles prevent tight seals on butterfly and check valves. Diaphragm valves are an acceptable option but cost approximately twice that of gate valves.

These recommendations of other researchers and the survey of equipment availability resulted in the selection of eight-inch diameter pipe for manure loading into the digester and of gate valves for control of this loading. Pipe leading to the digester was placed at two percent slope while the bypass line, constrained by the length needed to circumvent the digester, was placed at about 1½ percent slope. Gate valves were placed at the lower end of each line.

DIGESTER DISCHARGE SYSTEM

As previously discussed, the digester will be loaded by opening a gate valve and draining the sump pit through an eight-inch diameter PVC pipe. The manure will flow into the digester at a rate determined by the level of the manure in the sump above that of the digester. If the discharge for the digester is not properly designed, this loading and unloading rate will cause a sudden pressure increase in the enclosure, and could potentially cause rupture of the fiberglass roof. This analysis was performed to insure proper design and to thus prevent any such unforeseen accidents.

The discharge from the digester was designed of PVC pipes placed in the walls of the digester with a 90° elbow outside the digester turning the discharge to the vertical. Manure discharge will be accomplished by overflowing of these pipes into a collection sump for draining into the evaporation pond. The proposed hydraulic profile of the manure flow at the Del Valle Hog Farm is shown in Figure 15.

A graphical representation of the application of Bernoulli's equation for computation of the flow rate Q for the proposed manure handling facilities is shown in Figure 16, where Bernoulli's equation is given by:

$$P_1 + \frac{V_1^2}{2g} + Z_1 = P_2 + \frac{V_2^2}{2g} + Z_2,$$

where P_1 and P_2 are the pressures at the sump and at the digester, respectively, V_1 and V_2 the respective flow velocities, g the acceleration of gravity, and Z_1 and Z_2 the respective elevations. Designing for a worst case of 10 feet elevation differential (Z_1-Z_2) and maintaining a desired constant pressure of 2½ inches of water inside the digester results in:

$$10 \text{ ft.} = .21 \text{ ft} + \frac{V_2^2}{2g}$$

$$V_2 = 25.18 \text{ ft/sec}$$

Using eight-inch diameter pipe and Q = VA,

$$Q = 8.79 \text{ c.f./sec.}$$

Now examining the discharge characteristics at steady state (no influent) and using Bernoulli's equation, the elevation differential $Z = Z_4 - Z_3$ is:

$$P_3 + \frac{V_3}{2g} + Z_3 = P_4 + \frac{V_4^2}{2g} + Z_4$$

$$Z = .21 \text{ ft.}$$

When loading the digester, the pressure in the digester is maintained at 2½ inches of water, but the level Z_3 increases, thus creating an overflow since the top of the discharge Z_4 is fixed.

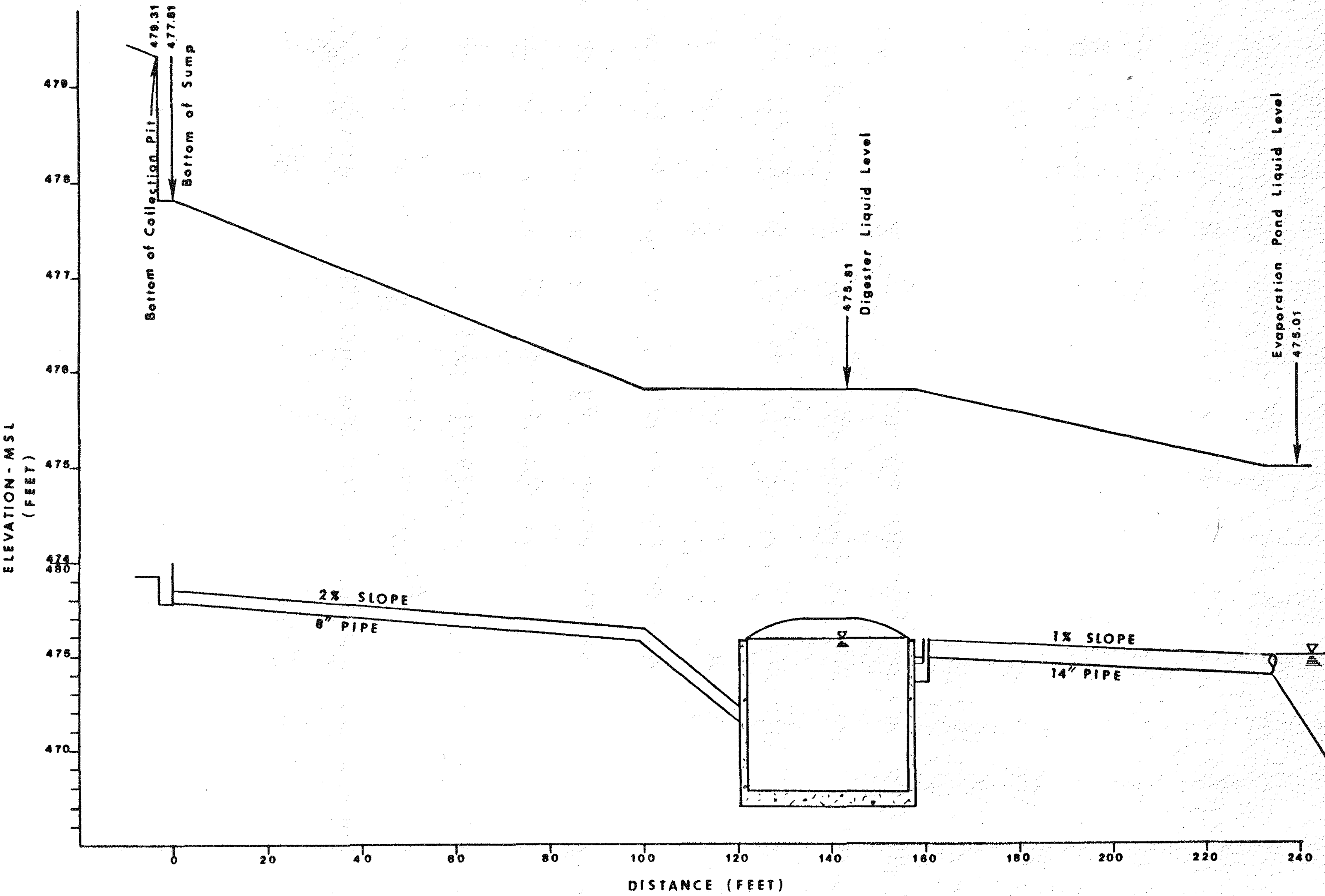
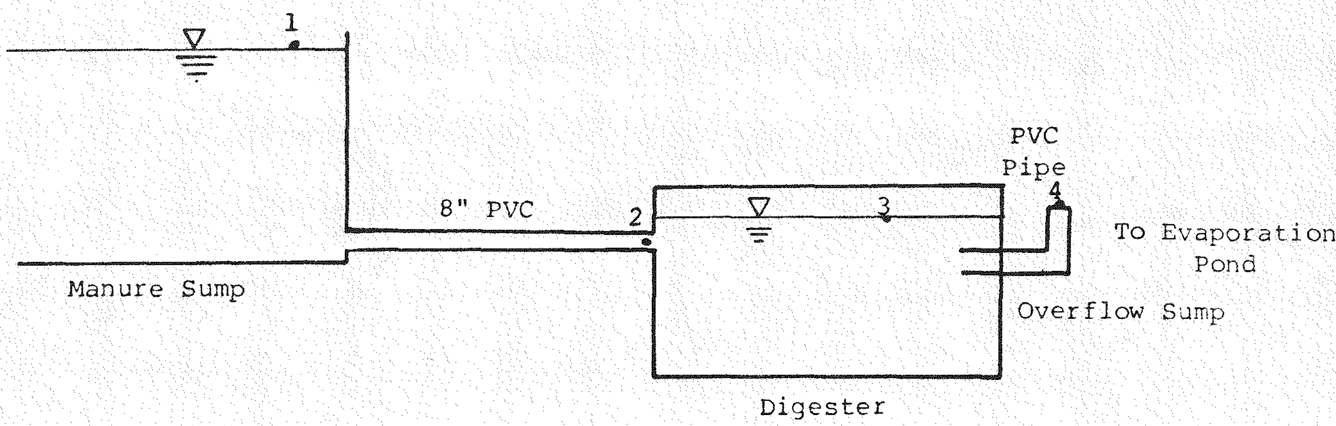


Figure 15: Hydraulic profile of proposed facilities



$$P_1 = 0 \qquad P_2 = .21' \qquad P_3 = .21' \qquad P_4 = 0$$

$$\frac{V_1^2}{2g} = 0 \qquad \frac{V_2^2}{2g} = ? \qquad \frac{V_3^2}{2g} = 0 \qquad \frac{V_4^2}{2g} = ?$$

$$Z_1 = 10 \qquad Z_2 = 0 \qquad Z_3 = 0 \qquad Z_4 = ?$$

FIGURE 16 Graphical Representation of Bernoulli's Equation

Using Bernoulli's equation again,

$$P_3 = \frac{V_3^2}{2g} + Z_3 = P_4 + \frac{V_4^2}{2g} + Z_4$$

$$.21 + Z_3 = \frac{V_4^2}{2g} + .21$$

it is shown that the velocity of fluid discharged from the digester is a function of the rise in fluid level of the digester, given by:

$$V_4^2 = 2gZ_3 \text{ (ft./sec.)}$$

An expression for the digester level, Z(t), may be obtained as follows: Let A(t), the volume of liquids accumulated due to loading of the digester as a function of time, be given by:

$$A(t) = Q(t) - D(t)$$

where Q(t) represents the influent loading and D(t) the effluent discharge of the digester.

As previously derived, Q(t) is given by:

$$Q(t) = Qt \text{ (cu. ft.)}$$

where Q is the influent loading rate in cu. ft./sec. The effluent discharge D(t) is a function of the weir length L of the overflow, the elevation Z of the digester above Z_4, and the velocity V_4 of the discharge liquids; i.e.,

$$D(t) = LZ\,V_4 t \text{ (cu. ft.)} \qquad (1)$$

Substituting for known quantities, A(t) becomes

$$A(t) = Qt - LZ(t) \sqrt{2gZ(t)}\,t.$$

Because A(t) only represents the accumulation of liquids due to loading, it may be expressed as a function of the level Z(t) of the digester, i.e.,

$$A(t) = SZ(t)$$

where S is the surface area of the digester.

Making the appropriate substitutions results in

$$SZ(t) = Qt - LZ(t) \sqrt{2gZ(t)}\, t, \text{ or} \qquad (2)$$

$$Z^{3/2}(t) + \frac{S}{tL\sqrt{2g}} Z(t) = \frac{Q}{L\sqrt{2g}}.$$

The level Z(t) can now be expressed as a function of the loading rate Q and the weir length L for the digester as designed (fixed S). As shown in Figure 16, the overflow is designed to be plastic pipe or pipes mounted to allow overflow into a discharge sump. The length L is thus the circumference(s) of the pipe(s) selected. These pipe circumferences and their associated cross sectional area, A, must be selected to allow discharge volumes as expressed in Equation 1, e.g.

$$LZ(t) \sqrt{2gZ(t)} \leq A \sqrt{2gZ(t)} \quad \text{or} \qquad (3)$$

$$LZ(t) \leq A.$$

This expression insures that for a given flow rate velocity, $\sqrt{2gZ(t)}$, the limiting factor in the flow rate will not be the cross sectional area A of the discharge pipe(s). An additional constraint on L, and thus on the pipe circumference(s) and the pipe cross sectional area(s), arrives from Equation 2 in the limiting case when t approaches infinity, i.e.,

$$Z^{3/2} = \frac{Q}{L \sqrt{2g}} \ . \qquad (4)$$

Table 4 contains digester design selection criteria based on these constraints for allowable digester level increases of from one to six inches. Values of L are computed for various Zs using Equation 4, and discharge areas from Equation 3.

TABLE 4: DESIGN FOR DIGESTER DISCHARGE SELECTION

Z-in	L-ft	≤LZ-ft	D-in	# Pipes	Cirf-ft	Area-Ft^2
1	45.24	3.77	4	44	46.08	3.84
2	16.0	2.67	8	8	16.76	2.79
3	8.71	2.18	12	3	9.42	2.36
4	5.65	1.88	14	2	7.33	2.14
5	4.05	1.69	18	1	4.71	1.77
6	3.08	1.54	18	1	4.71	1.77

As an example, for a two-inch allowable increase in digester level, a weir length L of 16.0 feet is required. The cross sectional area of this weir, given by Area = ZL, is 2.67 sq. ft. Pipes required must thus have a cross sectional area of at least 2.67 sq. ft., and must have a combined circumference of 16.0 feet. Using the nearest available pipe sizes results in a requirement for eight 8-inch diameter pipes having a combined cross sectional area of 2.79 sq. ft. and a circumference of 16.76 feet, both slightly in excess of that required.

The final consideration when selecting discharge pipes for the digester involves determining the volume of gas displaced when the digester is loaded, and designing the gas collection equipment to have a dynamic range adequate to handle this surge of accumulated gas. These estimates are obtained from Equation 2 for the limiting case when t approaches infinity and where maximum digester level increases for selected pipe weir lengths are as shown in Table 4. These digester level increases, Z max., result in gas volume displacements as shown in Table 5.

Table 5: Maximum Rise in Digester ($t \rightarrow \infty$)
and Volume Gas Discharged

Z-in.	Cirf.-ft.	Z max.-in.	Vol. Discharged-cu.ft.
1	46.08	.99	43.3
2	16.76	1.94	84.9
3	9.42	2.85	124.7
4	7.33	3.36	147.0
5	4.71	4.52	197.8
6	4.71	4.52	197.8

Several observations can be made when combining the information contained in Tables 4 and 5. From a gas accumulation dynamic range consideration, the maximum design level increase of one inch in the digester and its associated gas displacement of 43.3 cu. ft. appear optimum. However, to achieve this minimum level increase and its associated gas displacement require use of forty-four 4-inch diameter pipes for discharge. Alternatively, it is shown that only one 18-inch pipe is required. However, using this pipe size will result in a requirement for approximately 200 cu. ft. of excess dynamic range, i.e., additional storage, in the gas accumulation/collection equipment. From these tables, it is apparent that 12-inch to 14-inch diameter discharge pipes are preferable. From a cost evaluation, 14-inch plastic pipe costs 50 percent more than 12-inch pipe. Therefore, three 12-inch discharge pipes with the associated requirement for 125 cu. ft. of excess dynamic range have been designed for the digester discharge and gas collection/accumulation for the proposed anaerobic digestion system.

A plot of the digester level Z as a function of time for the assumed loading rate Q and the design parameters L and S obtained by solving Equation 2 is shown in Figure 17. The volume of gas displaced by the associated rise and the asymptotic bound for these design parameters (shown in Table 4) are also shown in the figure. The design equations used in deriving Equation 2 are based on Bernoulli's equation and on the assumption that the feed source, i.e., manure, is of infinite volume. This assumption, of course, is not the case, and in typical operation at the Del Valle Hog Farm the manure to be loaded daily into the digester occupies a volume of approximately 239 cubic feet. Therefore, after this volume has been loaded, the flow rate Q goes to zero, and the level in the digester returns to an equlilbrium level of three inches below the level of the drain (when three-inch pressure is maintained). For the digester loading as designed, approximately 26 seconds (239 cu. ft/Q = 8.8 cu. ft./sec.) are required to load the manure. An approximation to the digester level after this time is also included in Figure 17. From this figure, the maximum level the digester achieves is .17 ft., which displaces a volume of gas of approximately 84 cubic feet.

Construction of the digester overflow piping and sump was performed by first installing three 12-inch horizontal PVC pipes through the concrete forms prior to pouring the walls of the digester. A base slab and piling was poured to alleviate possible setting problems of the sump. The 12-inch vertical pipes were installed and their height surveyed in. The four-foot by four-foot sump was constructed of reinforced concrete and has a top slab with a manhole cover in the center.

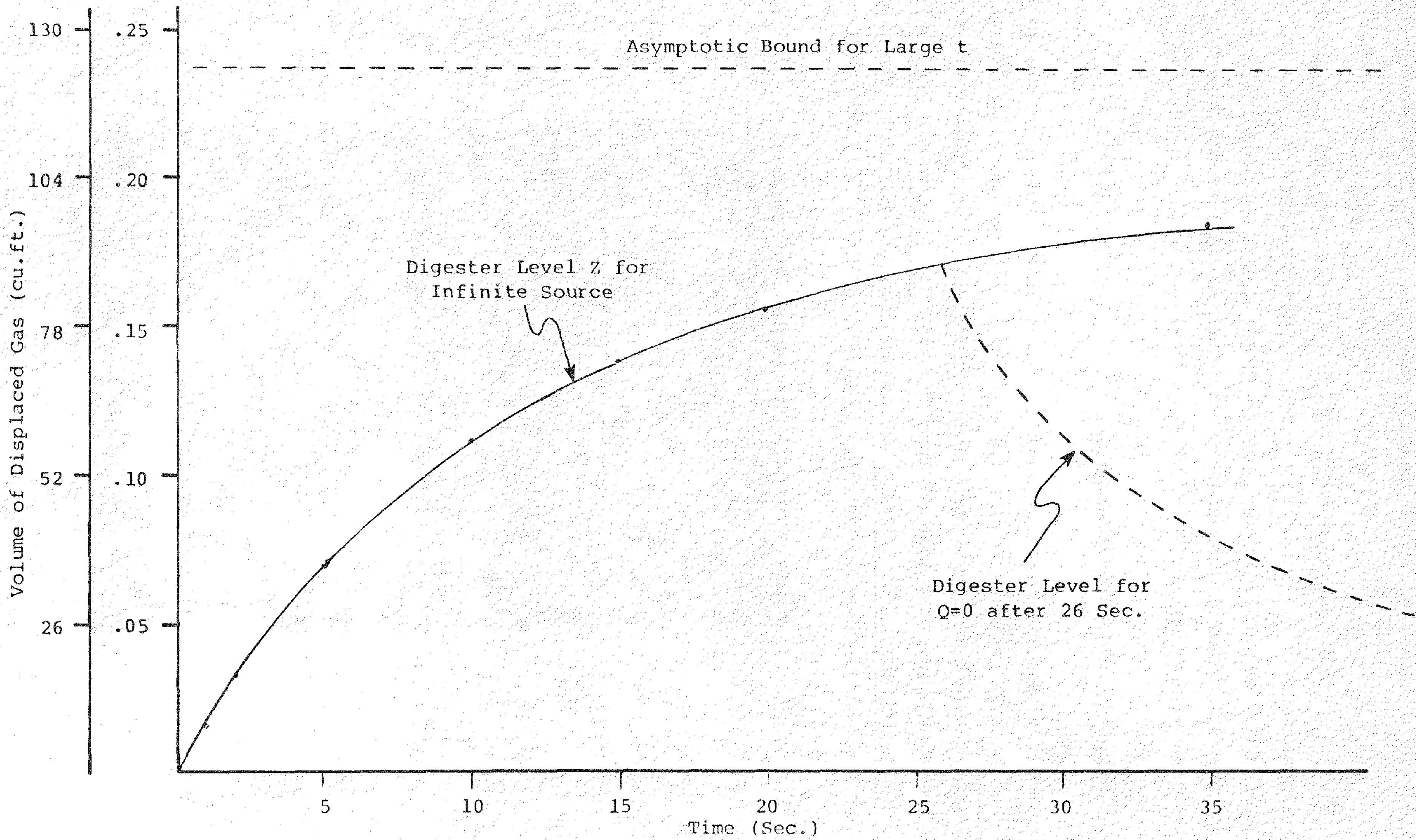


Figure 17: Digester Level in Relation to Time from Start of Loading

The top of the sump clears the top of the vertical pipes by approximately eight inches. A 12-inch pipe exits the sump at a slope that will allow the digester effluent to gravity flow to the evaporation pond. The placement of the discharge pipes during construction of the digester is shown in Figure 18.

DIGESTER SOLIDS REMOVAL DESIGN

Stabilized manure and solids will accumulate in the digester and must be removed periodically. These solids are generally removed from conventional municipal sludge digesters using bottom drains. To facilitate the operation of these drains WPCF Manual of Practice No. 8, Sewage Treatment Plant Design recommends that the bottom of the digester be sloped 6::1 toward the drains (6).

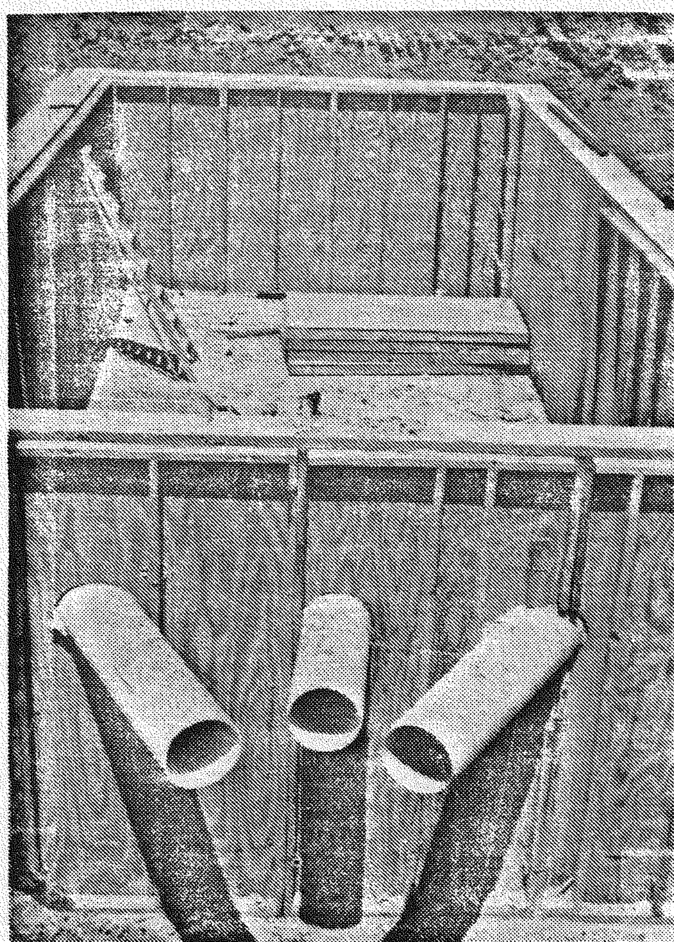


Figure 18: Placement of Digester Discharge Pipes

Consequently, four-inch PVC piping was used to construct six strategically located drains along the bottom of the digester. In addition, the digester floor was poured at a slope of about 6::1 toward the center drains. Piping used for these drains runs through the digester slab and rises parallel to the walls about one foot outside the digester. Four of the drains are equally spaced along the centerline length of the digester, while the other two drains are set midway up each side of the sloping floor near the area of manure loading.

DIGESTER MIXING DESIGN

Controversies have recently developed concerning the performance of mixed and unmixed reactors utilized for anaerobic digestion of animal wastes. From results of studies completed by Jewell, it was determined that unmixed, plug flow reactors could be successfully operated but volatile solids destruction would be lowered to approximately 25 percent of total volatile solids added as opposed to 40 to 50 percent observed in mixed reactors (29). Consequently, gas production rates will also decrease. The major advantage of unmixed reactors is the elimination of mechanical and electrical equipment and a potential energy savings. Fulton estimates that approximately 75 percent of the electrical requirements for the Tarleton State University digester system is required for mixing (30). It should be noted that the total energy consumption used in that analysis does not include energy requirements for the digester heating which is performed directly with the digester gas produced. Therefore, it should not be construed that 75 percent of the energy requirements for supporting the digester system are for mixing.

From laboratory and field experience and observations, Fulton states that unlike cattle manure, swine manure does not appear to be amenable for unmixed reactors because of its rapid settling characteristics (28). In unmixed systems, gas production rates are suppressed and the digestion is more susceptible to experiencing upset conditions as well as having float solids problems.

Two on-farm size anaerobic digestion facilities which utilize swine manure were visited and observed by SumX engineers. These facilities were the Tarleton State University system in Stephenville, Texas, and the USDA-University of Missouri system in Columbia, Missouri. Both systems have been operated at various times for several years and both utilize mixing via gas recirculation. It is also important to note that gas recirculation is accomplished at each facility using a rotary lobe type pump, manufactured by Roots Blower Company, Connersville, Indiana. At the University of Missouri system, Fisher used a design parameter of 1.09 cfm of gas per foot of digester diameter for gas recirculation for agitation as suggested by Forest (31, 32). It is important to note that the mixing schemes for each of the two systems visited are different. At the Tarleton State University system, mixing is performed for 10 minutes every hour, while at the University of Missouri system, mixing is performed for 40 minutes three times per day (28, 33). Therefore, it appears that sufficient mixing may be achieved over a wide range of operating conditions.

Based on these observations, it is recommended that gas recirculation for mixing be installed on the Del Valle Hog Farm anaerobic digestion system to insure optimum solids destruction and gas production. During the course of the demonstration period, various modes of operation will be investigated, including the unmixed mode. These observations will allow for an evaluation and development of optimum mixing requirements.

A Roots rotary lobe pump, Model No. 33XA will be used for agitation and is currently on order. Gas from the digester will be recirculated in the digester through three one-inch diameter black iron pipes which extend vertically down into the digester. The gas discharge of these pipes will be located approximately one inch from the bottom of the digester (28).

It is anticipated that a solids buildup will occur in between the gas recirculation pipes. Therefore, the gas recirculation pipes are designed to be located in between the solids drains.

It is recognized that iron pipes will be susceptible to the corrosive action of the manure. However, because of the excessive heat generated by the high velocity of the recirculated gases, PVC pipe is not recommended. Additionally, the gas recirculation pipes may partially clog periodically and may have to be removed and cleaned by physical rodding. This rodding would probably deteriorate the PVC pipe. The gas blower has been ordered and construction of the gas recirculation system has begun.

GAS HANDLING DESIGN

Biogas, as produced in the digester, must be stored at least temporarily due to the uneven energy demands of this typical farm operation. In addition, in the integrated farm system, electrical generation using an engine/generator will be performed on an as needed basis, and heat for cooking and distillation in the fuel alcohol facility and for heating the digester will require concentrated energy for a short period of time. Alternatives for gas storage include the use of low pressure air bags and compression and storage in high pressure storage vessels (28, 33).

As previously discussed, biogas produced from anaerobic digestion is saturated with moisture and contains a small quantity of hydrogen sulfide (H_2S). Therefore it is highly corrosive to engines and compressors and should be cleaned prior to use.

The conceptual design of the gas handling facilities at the Del Valle Hog Farm includes a gas scrubber to remove H_2S, a gas collection tank for temporary storage and for maintaining the proper pressure on the digester, and a gas compressor/high pressure storage system. The conceptual design of these facilities is shown in Figure 19.

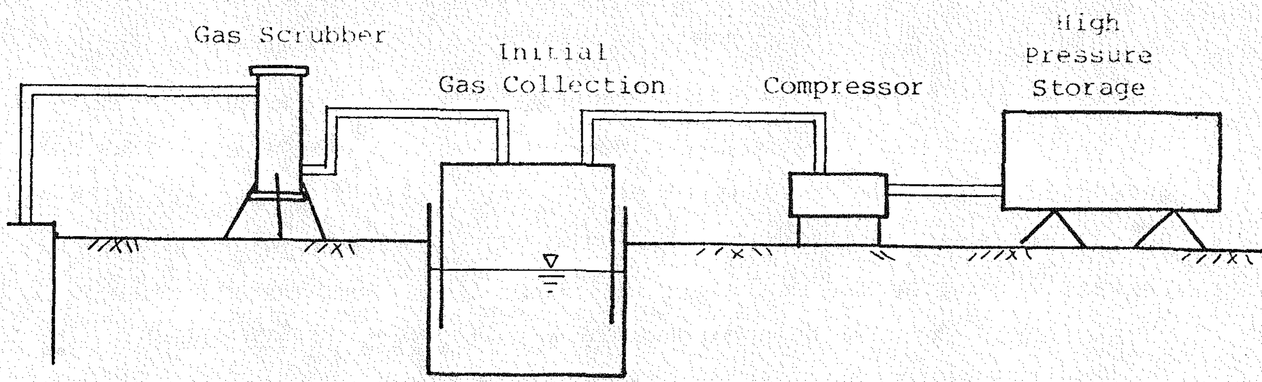


Figure 19: Schematic of Gas Handling Facilities

Gas Purification

The iron oxide or "iron sponge" process for removing hydrogen sulfide from biogas has been successfully demonstrated for small gas streams contaminated with small quantities of hydrogen sulfide (34, 35). This process utilizes iron impregnated on wood chips which will react with the hydrogen sulfide to form iron sulfide and water. The "iron sponge" material can be located in a cylinder through which the contaminated gas is passed. The sulfur will remain attached to the wood chips. Iron sponge material, available from Connelly-GPM, Inc., contains approximately 15 pounds of iron oxide per bushel (36).

An iron sponge gas scrubber designed for hydrogen sulfide removal at the Del Valle Hog Farm has been constructed based on the assumptions listed in Table 6.

Table 6: Iron Sponge Design Assumptions for Hydrogen Sulfide Removal

Gas Production	= 6580 c.f./day (biogas)
Hydrogen Sulfide Conc.	= 100 grains/100 c.f. biogas (estimated)
Sulfur content of H_2S	$\simeq$ 94 percent
Sulfur Removal Rate	= 2.5 lbs. sulfur/lb iron oxide
Iron Oxide Concentration	= 15.0 lbs/bushel (commercial)
Density of Iron Oxide	= 1.0 c.f./1.0 bushel (commercial)
Minimum Sponge Life Desired	= 1 Year

The estimated sulfur production from the biogas produced at this facility is:

$$\text{Total Production} = 6580 \text{ c.f./day} \times 100 \text{ grains/c.f.} \times .94 \text{ sulfur} \times 1 \text{ lb/7000 grains}$$
$$= 0.88 \text{ lbs. sulfur/day (325 lbs/year)}$$

The iron oxide requirement based on this estimated production level is:

$$\text{Iron Oxide Required} = \frac{325 \text{ lbs/year sulfur}}{2.5 \text{ lbs sulfur/lb iron oxide}}$$
$$= 130 \text{ lbs iron oxide/year}$$

The required volume for this quantity of iron oxide becomes:

$$\text{Volume} = \frac{130 \text{ lbs} \times 1.0 \text{ c.f./Bushel}}{15 \text{ lbs/bushel}}$$
$$= 8.67 \text{ c.f.}$$

The iron-sponge gas scrubber tank designed to meet these specifications is 20 inches in diameter and 54 inches in height, creating a storage volume for the iron oxide of 9.8 c.f. A schematic of the iron oxide facility as constructed is shown in Figure 20.

Gas Storage/Compression Design

Biogas production estimates for the Del Valle Hog Farm range from a conservative 4000 cu. ft/day to an optimistic estimate in excess of 6000 cu. ft/day. Fulton, in the operation of the anaerobic digestion system at Tarleton State University, notices accelerated gas production and accumulation at loading time and shortly thereafter and continuous accumulation the remainder of the day (28). Continuous accumulation based on the Del Valle Hog Farm biogas production estimates would be from 170 cu. ft./hr. to 250 cu. ft./hr. Gas production rates considerably above these could be expected for a short period of time after loading. In addition, as previously discussed in the design of

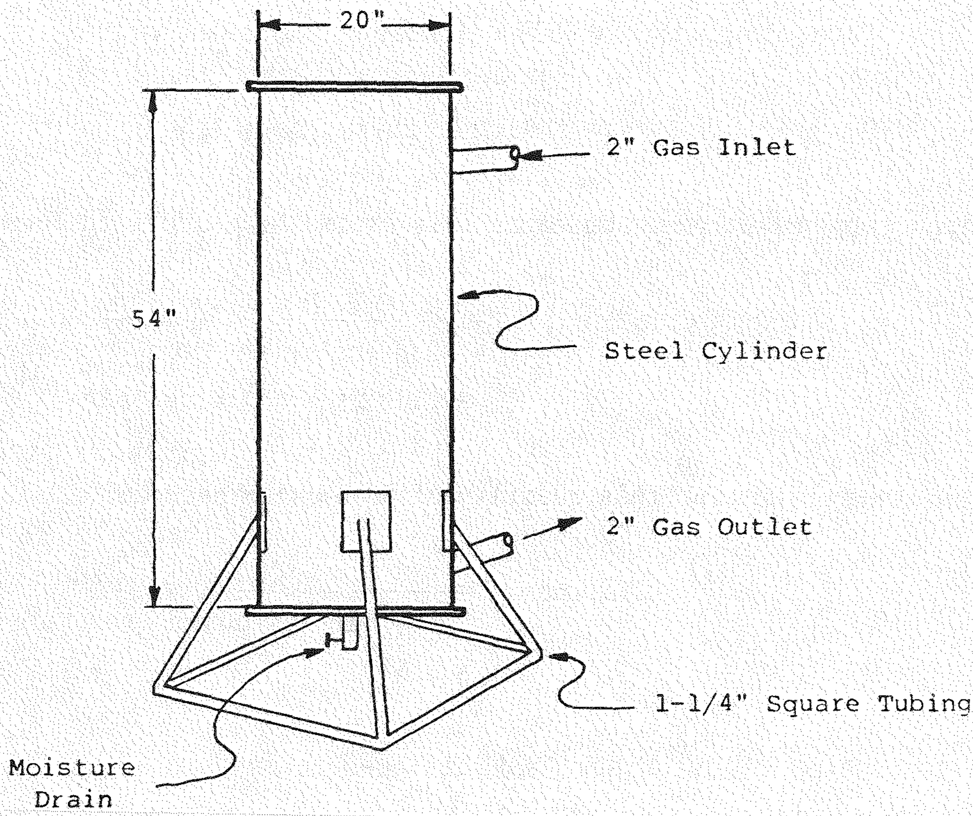


Figure 20: Schematic of Constructed Iron Oxide Facility

the digester loading and discharge system, a surge of approximately 84 cu. ft. of gas can be expected at loading.

Figure 21 presents in graphic form the biogas accumulated in the inverted collection tank as a function of time for the assumed minimum rate of 170 cu. ft/hr. Compressor startup (assumed at 250 cu. ft for this analysis) results in a moving of these accumulations into the storage vessel at a rate determined from compressor specifications as noted. For the 4.8 cu. ft/min. (1½ h.p.) compressor, approximately two hours of run time are required to move the accumulated biogas and that being produced in real time into the vessel. For the 15 cu. ft/min. (5 h.p.) model, approximately 20 minutes are required. The 4.8 cu. ft./min. compressor will cycle every 3.6 hours; the 15

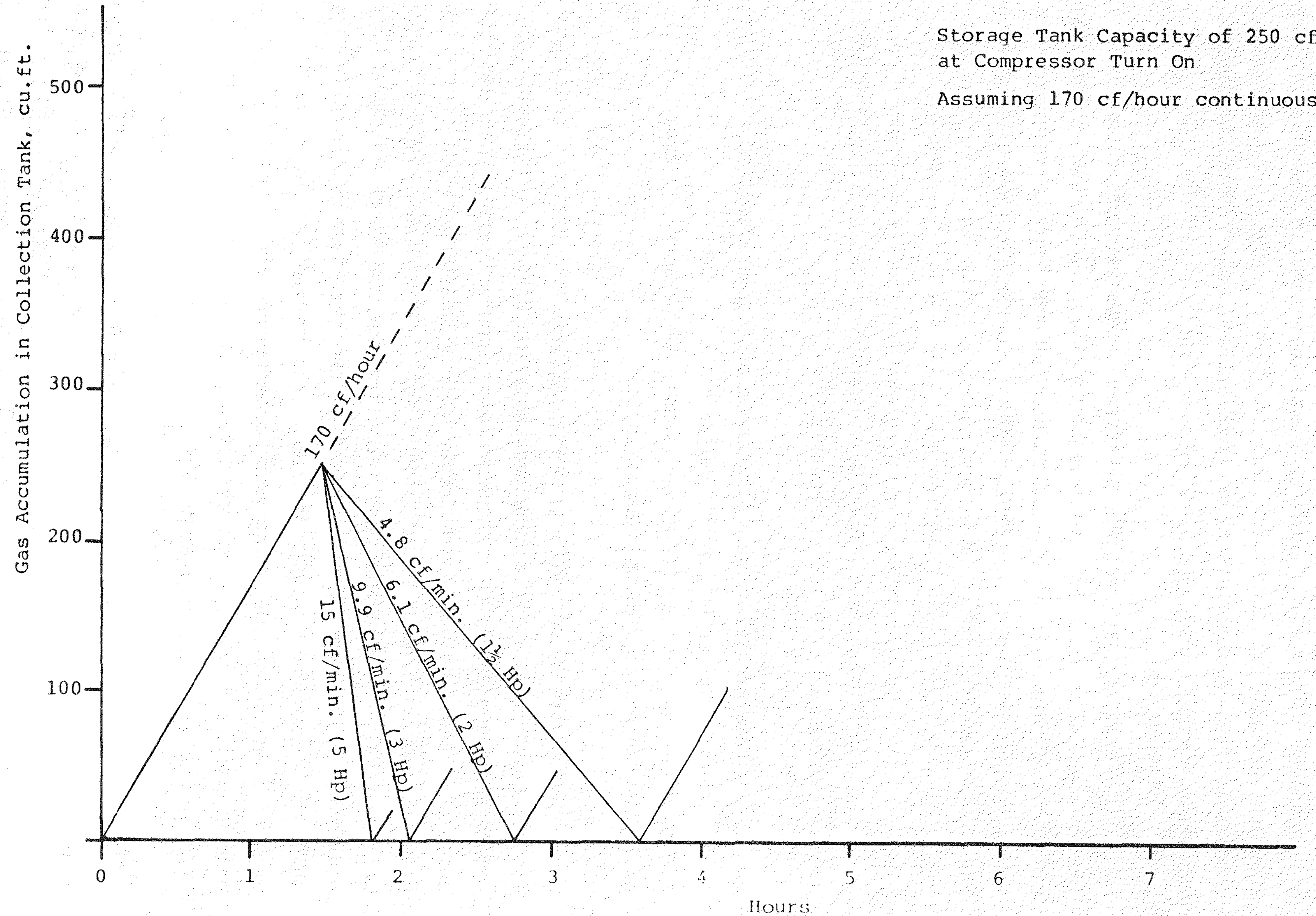


Figure 21: Biogas Accumulation at 170 cf/hour Gas Production

cu. ft/min compressor every 1.8 hours. From these curves, the smaller unit appears preferable. Figure 22 contains a similar analysis for the assumed production rate of 250 cu. ft/hr. The 4.8 cu. ft/min. compressor now requires 6.6 hours while the 15 cu. ft./min. compressor requires only 23 minutes.

Results of an analysis performed to evaluate gas accumulations for accelerated production rates are shown in Figure 23. An accelerated biogas production rate of 500 cu. ft/hr. for one hour is assumed, with the rate dropping back to 170 cu. ft/hr. continuous thereafter. When the compressor starts up, the accumulation in the tank continues to increase for both the 4.8 cu. ft/min. and the 6.1 cu. ft./min. compressors, clearly indicating a requirement for additional dynamic range in the gas collection tank. For the larger units, no additional dynamic range above turn on capacity is required.

These analyses and their corresponding results tend to suggest a requirement for a medium to large capacity compressor; i.e., 9.1 cu. ft./min. to 15.0 cu. ft./min. Larger compressors are available but obviously unnecessary for this application.

Conversations with representatives of various compressor manufacturers have resulted in a reevaluation of these conclusions (37). Compressors operating on saturated gas should operate at least 80 percent of the time to ensure proper warm-up and temperature control to prevent condensation in the cylinders and the crankcase. Failure to do so can result in a significant reduction in compressor lifetime. In addition, gas leakage by the rings into the crankcase occurs primarily when the compressor is not in use. Long periods of inoperation can result in accumulations which can be dangerous when operating with a combustible gas. In typical operation, these are vented to an area removed from the compressor/motor area.

These considerations have led to a design meeting these requirements when operating with saturated/combustionable gas and consistent with the gas production/accumulation rates estimated for the

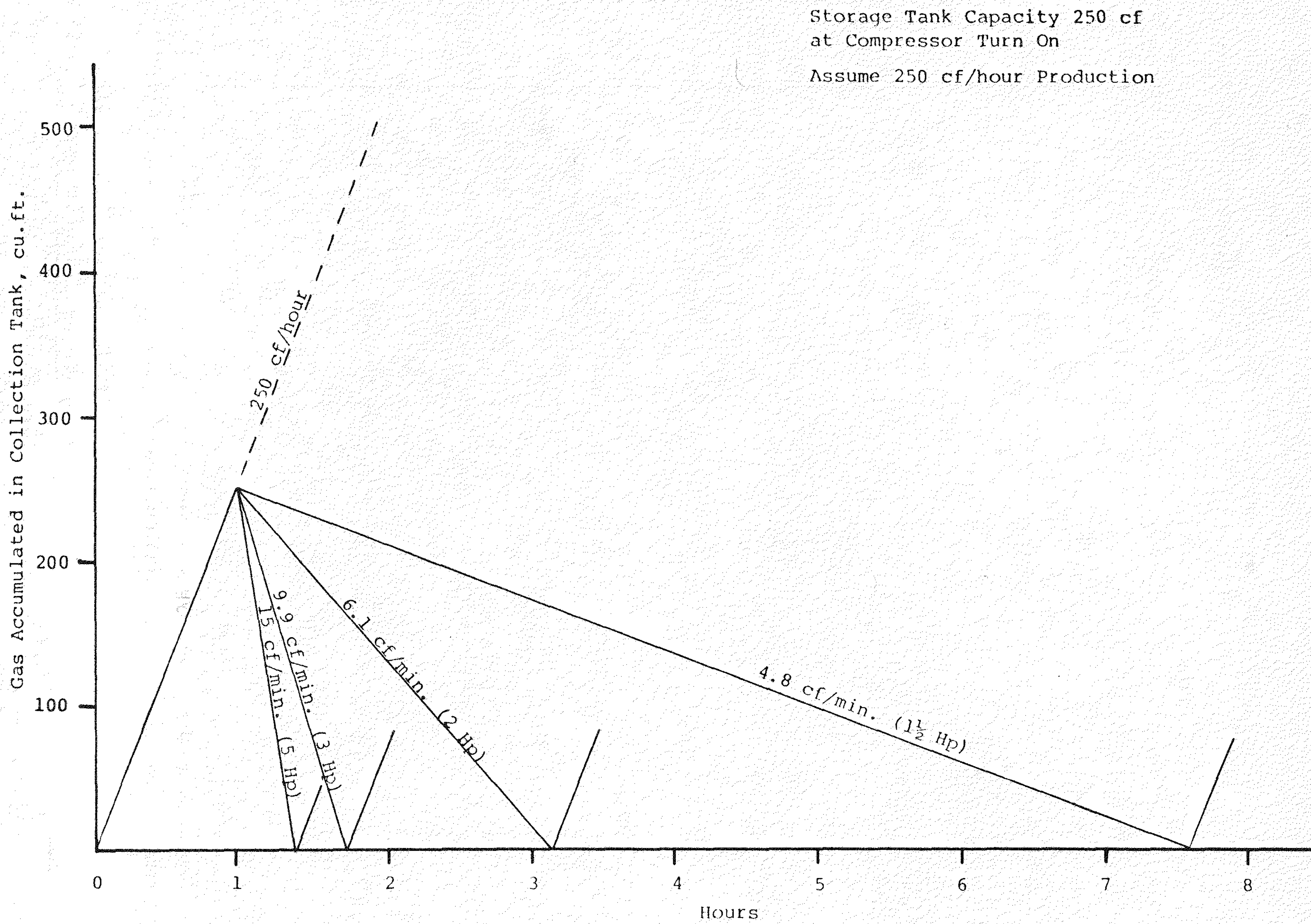


Figure 22: Biogas Accumulation at 250 cf/hour Gas Production

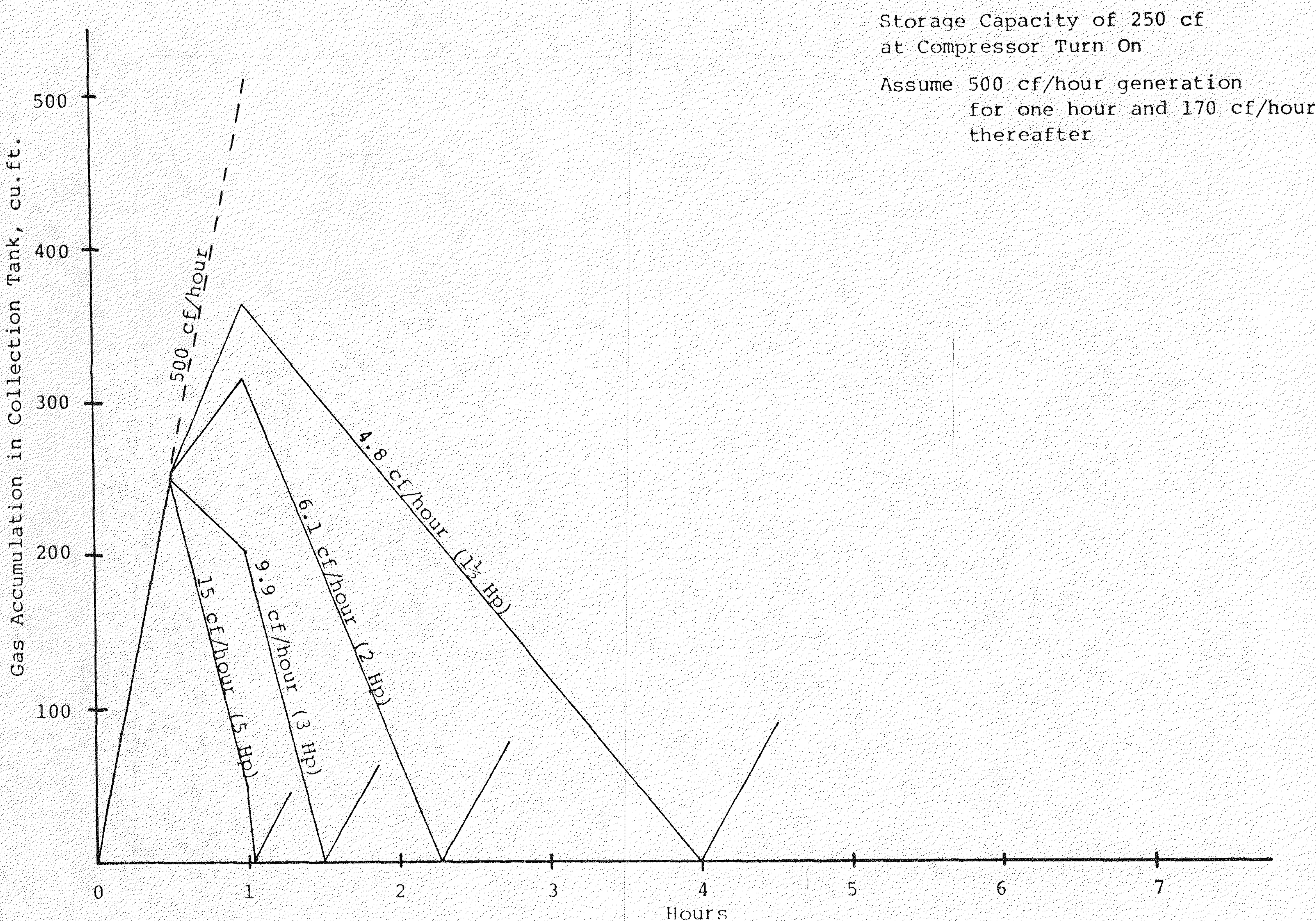


Figure 23: Biogas Accumulation for Accelerated Production Rate

Del Valle Hog Farm. A medium sized compressor operating with an off-spec (lower horsepower than rated) motor will turn at minimum speed and produce a gas flow rate of approximately 5 cu. ft./min. As shown in Figures 21 and 22, this unit will operate approximately 70-90 percent of the time. A Model 270B LeRoi/Dresser two stage gas compressor with a 1½ horsepower motor was selected & is currently on order.

An inverted fiberglass tank floating inside a series of concrete rings filled with water will serve for collecting gas from the digester prior to compression and storage in high pressure butane storage vessels. These concrete rings have a diameter of eight feet and are thirty inches high creating a volume of approximately 125 cubic feet per ring. Four rings will provide 500 cubic feet of water storage. A fiberglass tank of seven-feet diameter and 10.5-foot height selected for gas collection provides 350 cubic feet of storage capacity, 40 percent over the assumed 250 cubic feet of storage required at compressor start-up. A butane high pressure storage tank 56 feet in length and 7 feet in diameter has been located in Plainview, Texas, and has been purchased to provide the required high pressure storage. This tank has a working pressure of 150 psi. Operating at 8 atmospheres; i.e. approximately 120 psi, this 16000 gallon tank will provide storage for approximately 16000 cubic feet of biogas, which represents three day storage at the estimated gas production for the anaerobic digestion system at the Del Valle Hog Farm.

CONCRETE DIGESTER STRUCTURAL DESIGN

Design Assumptions

The inside geometric design of the concrete digester is 8 feet deep X 15 feet wide X 35 feet long pursuant to the preliminary design calculations. Manure will be loaded at mid-depth on the side of the digester and near the rear with an eight-inch diameter PVC pipe. The liquid level in the digester will be maintained and effluent will be gravity discharged using three 12-inch diameter PVC pipes. The pipes will be located at the discharge end of the digester at approximately the 1/3 depth. These discharge pipes will be utilized as risers and are exposed to the atmosphere at approximately two-inches above the top of the concrete digester wall. This liquid level will prevent oxygen from entering the digester at the concrete/fiberglass interface should a break in the seal occur.

The bottom of the digester is sloped at approximately 6::1 toward the center of the digester to assist in solids concentration for drainage in accordance with recommendations provided in the Water Pollution Control Federation Manual of Practice No. 8, Sewage Treatment Plant Design (6). Six 4-inch diameter PVC pipes are located strategically at the bottom of the digester to allow solids to be pumped from the digester. The gas recirculation inlets will be staggered between the drains as previously discussed.

Concrete Reinforced Steel Design and Piping Details

Selection and placement of steel reinforcement for the construction of the concrete digester was determined using the 1980 Concrete Reinforcing Steel Institute (CRSI) Handbook, which is based on the 1977 ACI Building Code (38). Double mats of 12 inch spaced #4 reinforcing bar were used in all walls and the slab. Detail specifications for the digester are available upon request. Placement of reinforcing steel during construction is shown in Figure 24.

Figure 25 shows the bracing that was required prior to placing concrete to form the digester walls.

Fiberglass Roof Construction

The fiberglass roof was field fabricated using plyboard forms for custom fitting. Bolts were imbedded along the top of the digester

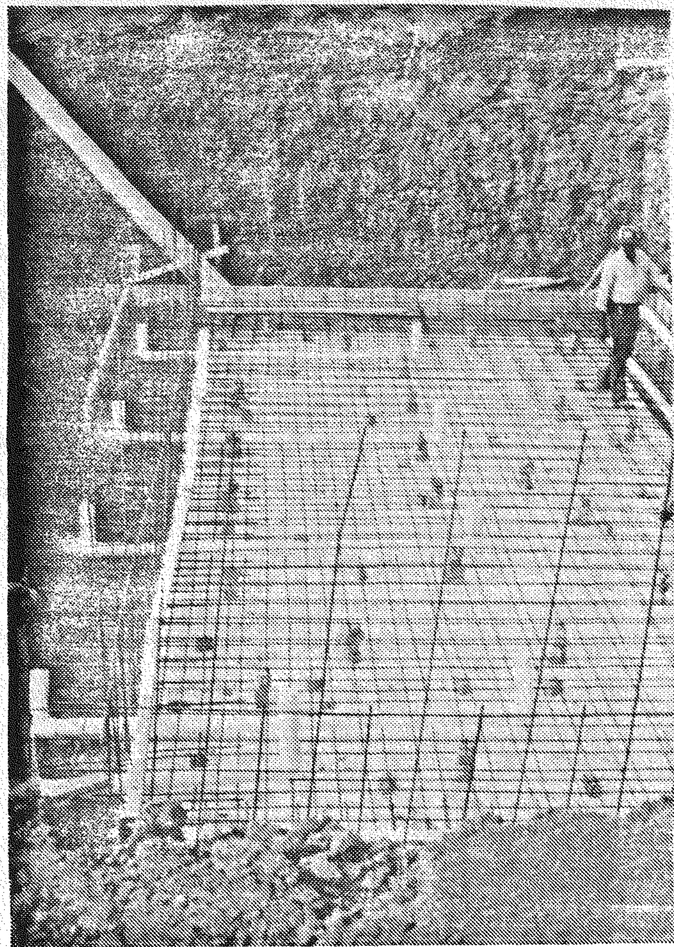


Figure 24: Reinforcing Steel for Anaerobic Digester

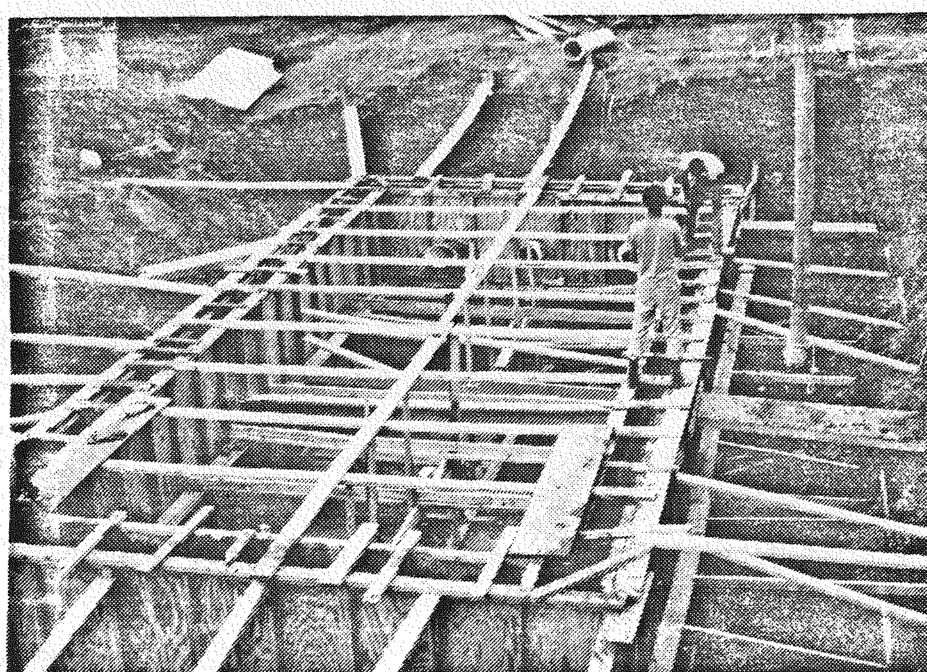


Figure 25: Concrete Wall Bracing

walls on 18 inch centers to anchor the top. Individual fiberglass panels were drilled to fit the bolt spacing, set in place, and fiberglassed together. Silicone sealant was used to form a gasket between the concrete and the fiberglass. Pieces of angle iron several feet in length were then drilled to fit the bolt spacing and distribute the holding force evenly across the fiberglass lip. To further assure a seal along the concrete-fiberglass interface, the liquid level in the digester will be maintained at approximately two inches above the top of the concrete wall. The fiberglass roof sections are shown stacked in Figure 26. The fiberglass roof in place and secured to the concrete digester is shown in Figure 27.

DIGESTER HEATING DESIGN

Digester Heating Requirements

An analysis of heating requirements for the digester was performed based on the design dimensions of 15 foot width X 35 foot length X 8 foot height, a concrete wall thickness of 10 inches and a slab depth of 12 inches. The estimate of total heating requirements for the digester is obtained by summing the heat required to raise the temperature of the raw manure loaded daily and the heat losses through the walls of the digester.

The raw manure heating requirements are estimated by the following:

$$Q_h = WC(T_2-T_1)$$

where Q_h is the heat required to raise the manure to T_2 in Btu/day, W the weight of manure and liquids added to the digester in lbs/day, C the mean specific heat of manure (assumed to be 1.0 Btu/lb-°F), T_2 the desired digester temperature (95°F) and T_1 the manure temperature at loading (assumed to be ambient temperature). The total weight W of manure and liquids added to the digester daily is a function of total manure produced daily and the desired solids concentration of the slurry

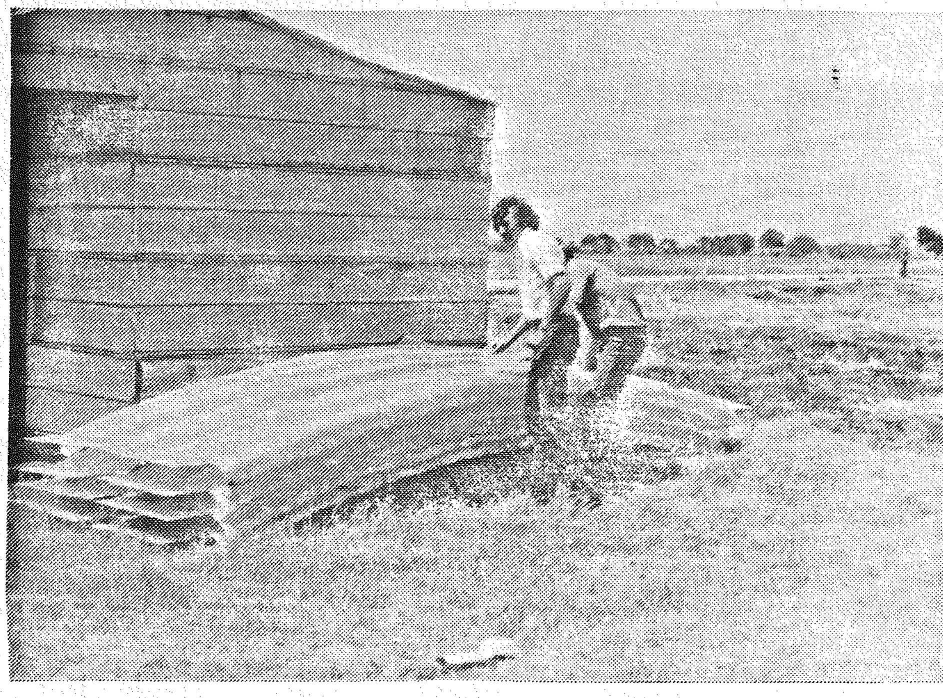


Figure 26: Fiberglass Roof Sections

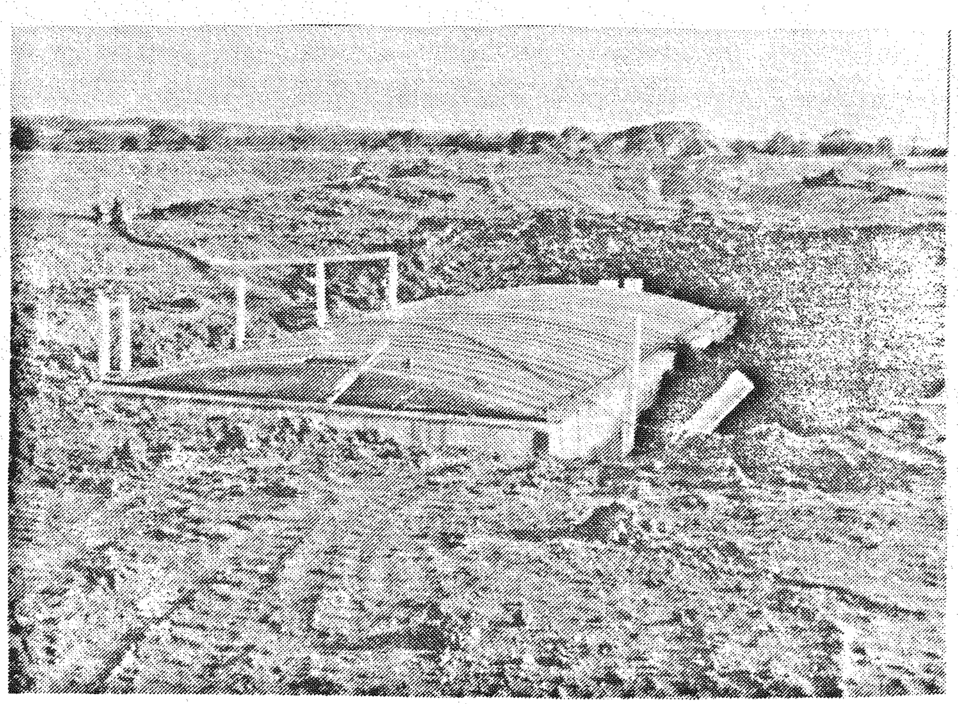


Figure 27: Fiberglass Roof In Place

at loading. Moisture contents of 75 to 85 percent are common for raw manure; solids concentrations in the slurry of 8 to 10 percent are recommended for digester loading. For this analysis, a moisture content of 81 percent for the raw manure and a solids concentration of 8 percent are assumed. Based on the results of manure handling and sampling studies completed to date, an 8 percent solids concentration is more likely to be achieved with the proposed manure handling system than the optimum 10 percent concentration and is therefore used in this analysis.

At the Del Valle Hog Farm where 100,000 lbs of hogs are fed daily, approximately 7800 lbs/day of manure is produced (78 lbs/day/100 lbs hogs). From the assumed 81 percent moisture content and 8 percent solids concentrations at loading, W can be computed as follows:

$$W = \text{Weight Manure (81\% M.C.)} + \text{Weight Water Added.}$$

Using solids concentration of 8 percent, then

$$.08 = \frac{\text{Weight of Solids in Manure}}{W}$$

Using moisture content of 81 percent, then

$$\text{Weight of Solids in Manure} = 19\% \text{ of Weight Manure.}$$

Thus

$$W = \frac{(.19)(7800)}{.08}$$

$$= 18{,}525 \text{ lbs/day.}$$

Therefore the daily raw manure heating becomes

$$Q_h = 18{,}525\ (95° - T_1)\ \text{Btu/day}$$

The heat losses through the walls of the digester Q_l are estimated as follows:

$$Q_l = UA\,(T_2 - T_1)$$

where Q_l is the heat loss in Btu/hr., A the surface area of the digester (sq. ft.), T_2 the desired digester temperature (95°F), T_1 the ambient temperature (assumed to be 70°F for subsurface placement), and U the coefficient of heat transfer (Btu/hr.-sq.ft.-°F). Based on the design dimensions for the digester, the surface area (discounting the top) is 1325 sq.ft. It is assumed that the biogas collected on top of the solids under the fiberglass top will form an insulation barrier between the solids and the ambient conditions, with no losses assumed. In fact the fiberglass top will have some transmittance to solar radiation and may serve much like a flat plate solar collector. However, no heat gains are assumed.

The coefficient of heat transfer U is a function of the thermal conductivity of the material serving as the insulating barrier and the thickness of the material. For concrete placed adjacent to ground which is predominately wet, the thermal conductivity is 3.0 Btu/hr.-sq.ft.-°F/inch thick. For a 10-inch concrete thickness the coefficient of heat transfer U is 0.3 Btu/hr.-sq.ft.-°F (6). For comparison, six inches of fiberglass batt insulation typically used in homes has a coefficient of heat transfer of approximately .05 Btu/hr.-sq.ft.-°F. Therefore it is evident that concrete alone in contact with moist earth is not good insulation. If, however, no insulation is provided, the heat losses for the digester as designed are:

$$Q_l = (1325)(.3)(25)$$
$$= 9937.5 \text{ Btu/hr.}$$

The heat losses per day are 238,500 Btu/day. Using the assumed heating value for the biogas produced of 640 Btu/cu.ft. and a 60 percent efficiency for converting the biogas to usable heat, approximately 620 cu.ft./day of biogas will be required to compensate for heat losses in the digester. This number can be reduced linearly as a function of the coefficient of heat transfer, <u>i.e.</u>, thermal conductivity.

A survey of insulation suppliers and concrete subcontractors resulted in an overwhelming recommendation for use of Expanded Poly Styrene (EPS) insulation (39). This EPS is moisture resistant, has a compressional strength of 12.2 lbs/sq.in. (it can be used under the slab) and has a thermal conductivity of .23 Btu/inch thickness. In addition, it is relatively inexpensive (approximately 20% of the cost of polyurethane for equivalent thermal conductivity). Three inches of EPS insulation placed on the outside walls and under the slab and sealed with marine sealant will provide a coefficient of heat transfer of .077 Btu/hr.-sq.ft.-°F. The corresponding heat losses for the digester and for this coefficient of heat transfer is therefore:

$$Q_l = 2540 \text{ Btu/hr.}$$

$$\text{or} \quad Q_l/\text{day} = 60{,}960 \text{ Btu.}$$

Approximately 160 cu.ft./day of biogas will be required to compensate for daily heat losses while using the three inches of EPS insulation as compared to 620 cu.ft./day for no insulation.

From an economic evaluation, the fuel cost of equivalent energy in this area is approximately $6.00/MM Btu. This 460 cu.ft./day savings corresponds to 294,400 Btu/day savings or approximately $2.00/day in equivalent fuel cost. Three inches of EPS installed on the digester as designed costs approximately $720; therefore the EPS insulation will return its expense in less than one year. For these reasons EPS insulation was installed when the digester was constructed.

The total heating requirements for the digester Q, the sum of heat losses and heat required for raw manure heating, becomes

$$Q = Q_l + Q_h \text{ Btu/day,}$$

$$= 60{,}960 + 18{,}525\,(95°\text{F} - T_1)$$

where T_1 is assumed to be the average daily temperature. Table 7 contains seasonal total heating requirements, Q, for the digester.

Table 7: Total Heating Requirements

Season	Average Ambient, T°F	Q, Btu/Day
Winter	49.7°F	900,000
Spring	68.6°F	550,000
Summer	86.4°F	220,000
Fall	69.8°F	530,000

These digester heating requirements obviously vary considerably for the Del Valle Hog Farm system, and these variations have a significant effect on the integration of other components, such as electrical generation and ethyl alcohol production, of the energy integrated system. These estimates for heating requirements have been used in equipment and facility sizings for this study. It is anticipated that the system will be modified and improved after the digester has been loaded, biogas production measured, and total digester heating monitored over a sufficient data collection period.

Digester Heating Design

Digester heating will be obtained by using a closed loop hot water heater/heat exchanger to transfer the necessary heat to the digester for maintaining the desired 95°F operating temperature. The in-digester heat exchanger will consist of galvanized pipe coiling throughout the manure slurry. A small in line water pump will circulate the water throughout the closed loop to bring about the necessary heat transfer.

From the digester heating requirements listed in Table 7, in the worst case, approximately 900,000 Btu must be transferred to the digester. Assuming an efficiency of heat transfer of 60 percent implies a total heating capacity in the hot water heater of 1,500,000 Btu. Water heater codes in the State of Texas regulate the maximum capacity of hot water heaters to less than 200,000 Btu/hr., with capacities above this falling into the category of boilers, which have special regulations, codes, and inspections. It is recommended that a water heater with 199,999 Btu/hr. capacity be used to avoid the legal problems. Therefore in worst case conditions the hot water heater/heat exchanger recirculation pump will operate for approximately 6.1 hours per day.

At the assumed efficiency of 60 percent, 120,000 Btu/hour will be transferred to the digester. An analysis for determining the pipe size and necessary lengths to effect this desired heat transfer was performed and is described in the following. For the assumed ambient operating temperature of 95°F in the digester, a 25°F temperature differential will exist between the heated water and the digester slurry (operation above 120°F = 95°F + 25°F will result in the formation of a caked manure layer on the pipe creating an insulation effect). Given the equation of heat transfer of

$$Q = V(\Delta T)A \quad \text{Btu/hour}$$

where Q, the heat to be transferred, is 120,000 Btu/hour, A is the surface area of the pipe, and V the heat conductance, given by

$$V = \frac{1}{\frac{1}{h_1} + \frac{\delta}{k} + \frac{1}{h_2}}$$

with h_1 the convection heat transfer coefficient of the pipe per unit of surface area in Btu/hr.-°F, δ the pipe thickness, k the pipe material thermal conductivity in Btu/hr.-ft.-°F (assumed to be 34 for galvanized pipe), and h_2 the convection heat transfer coefficient in the manure per unit of pipe surface area.

h_1 is obtained from the Nusselt number

$$Nu = \frac{h_1 D}{k}$$

where D is the diameter of the pipe, and K the thermal conductivity of water at the given temperature; therefore

$$h_1 = \frac{K\ Nu}{D}.$$

A solution for Nu is as follows:

$$Nu = 0.0155\ Pr^{0.5} Re^{0.83}$$

where Pr, the Prandtl number, is approximately 3.64 for 120°F water, and Re, the Reynolds number, is approximately 2000.

The convection heat transfer coefficient of the pipe to the manure, h_2, is similarly a function of Nu, i.e.,

$$h_2 = \frac{K\ Nu}{D},$$

where

$$Nu = 0.53\ (GrPr)^{\frac{1}{4}}.$$

Pr is again the Prandtl number and Gr the Grashof number. The product GrPr for 95°F manure is:

$$GrPr = (4.5 \times 10^8)(\Delta T)L$$

where L is the outside diameter of the pipe and ΔT is 25°F as indicated previously.

These expressions for h_1, h_2, V, and Q have been used for various sizes of pipe to estimate the surface area A of pipe required, and thus the length L; these results are tabulated in Table 8. For example, 42.9 square feet of ½ inch pipe would require 193 linear feet of pipe, and 50 square feet of one-inch pipe would require 145 linear

Table 8: Pipe Sizing for Digester Heating

Pipe Size (In.) ID	OD	h_1	$(\frac{\delta}{K})^{-1}$	h_2	V (Btu/hr.-°F)	Surface Area $A(ft^2)$	Linear Feet-L	Velocity (ft./sec.)	Head Loss ft.-lb./lb.
		(Btu /	hr. -	°F)					
.5	.848	3987	2345	121	111.8	42.9	193	15.92	344
.75	1.050	2015	2720	115	104.6	45.9	167	7.06	43.1
1.0	1.315	1119	2590	109	95.7	50.0	145	3.97	9.72
1.5	1.90	534	2040	99	80.2	59.9	120	1.77	1.15
2.0	2.375	314	2176	94	70.0	68.6	110	0.99	0.267

feet. Additional columns in the table present required flow velocities and head losses for these various pipe sizes.

Based on these velocities and their corresponding head losses, a pipe of at least 1.5-inch inside diameter will be required. From a cost evaluation, two-inch pipe costs approximately 50 percent more than 1.5-inch pipe. In addition, hot water heaters typically are sized for 1.5-inch inlet and outlet. Based on these considerations, galvanized pipe of diameter 1.5 inch was used for the heat exchanger placed in the digester.

The use of galvanized pipe was chosen over black iron because of the corrosive conditions occurring in the digester and the need to enter the digester to replace any pipe that might be pitted through. This replacement would require the digester to be emptied followed by a start-up period and the higher price of galvanized pipe was thought to offset this risk. A possible deleterious effect would be zinc toxicity which would occur if the zinc ion preferentially sorbed onto bacteria flocc instead of staying solubilized in the water. Although zinc toxicity is not anticipated, the zinc concentration in both the solid and liquid portions of the digester will be monitored.

Construction of the digester heating coil was accomplished using ½ inch galvanized pipe to construct three frames resembling a capital H with a bar across the top. Holes were drilled into the floor of the digester to accommodate the legs of the frame, and the heating coil pipes were attached to the frames using standard U-clamps. Also, stabilizing rods protruding fore and aft and on each side were added to the H-frame system. These horizontal bars were placed into holes drilled into the wall of the digester and provide support against sways. The heating coil pipes enter and exit through the fiberglass roof, and a silicone sealant was used at the galvanized metal-fiberglass interface. A diagram for the heating coil placement in the digester is shown in Figure 28. The actual heating coil installed and the support frame is partially shown in Figure 29.

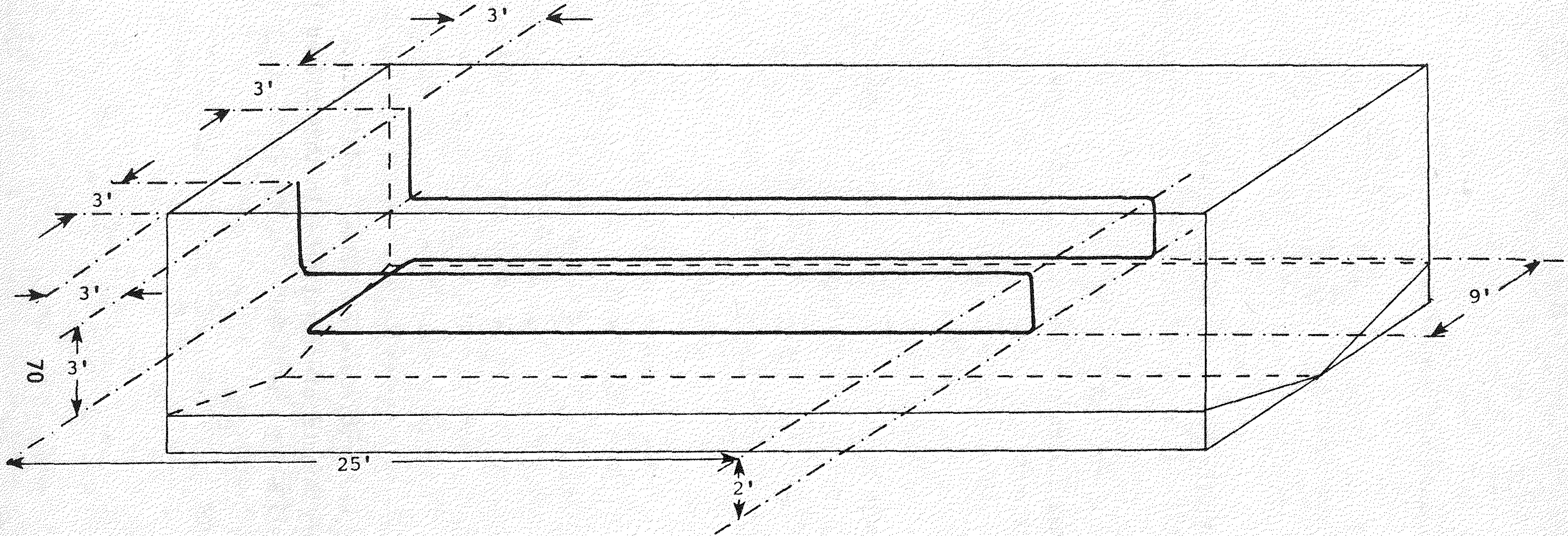


Figure 28: Pipe Heat Exchanger Placement for Digester

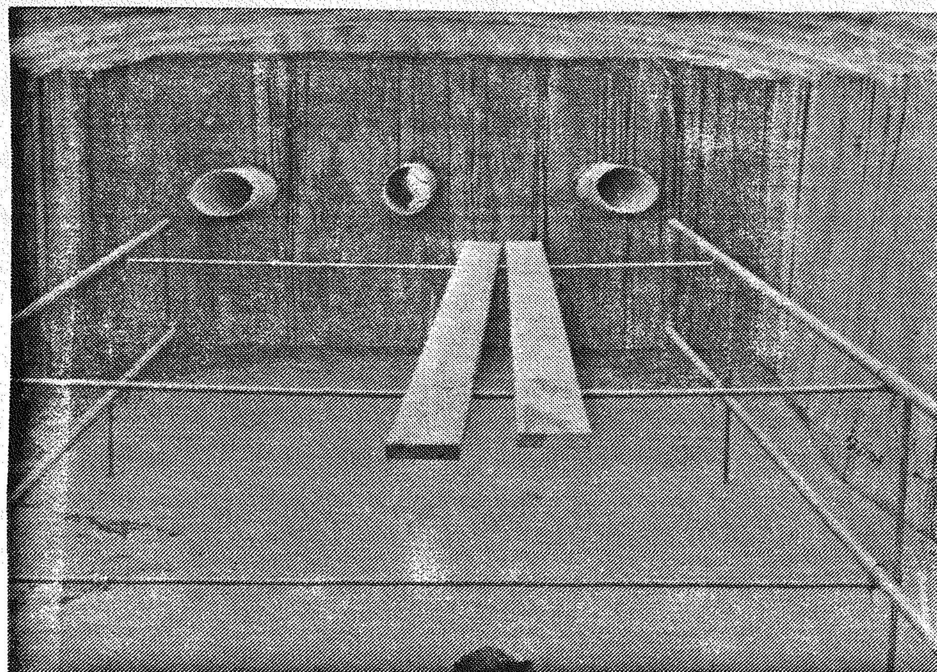


Figure 29: Digester Heating Coil and Support Frame

For the required heat transfer of 120,000 Btu/hour and the 25°F temperature differential, 4800 lbs/hour (120,000 ÷ 25) of water must be circulated through the heat exchanger. At 8.34 lbs/gallon, this requirement corresponds to a flow rate demand for the recirculation pump of 575 gal/hour, or approximately 10 gal/min. A Cole-Parmer Model C-7124-40 5-speed mini hydronic circulator pump has been selected to meet these flow rate and head loss requirements. This pump can handle flow rates up to 13.5 gal/min. at heads of 3.5 feet, both in excess of the Del Valle Hog Farm requirements.

As mentioned previously, a commercial hot water heater with 199,999 Btu/hour capacity has been selected for digester heating. The flow rate from this heater will be 10 gal/min. The volume of water contained in the 120 feet of 1.5 inch pipe is 1.47 cubic feet, or 11.8 gallons. Therefore the recirculation pump will vacate the heat exchanger volume every minute of operation. In this closed loop, the hot water heater storage volume serves as a buffer for storage of preheated water at 120°F. The heat recovery rate for a 199,999 Btu/hour hot water heater operating on a 25°F temperature rise is 600 gal/hour, therefore excessive storage volume in the heater is unneccesary. For these reasons an 80 gallon commercial unit, Grainger Model 3E124, has been selected for this application.

DIGESTER SYSTEM DESIGN SUMMARY

A summary of the equipment and facilities required for the anaerobic digestion system at the Del Valle Hog Farm is shown in plan view and elevation view in Figures 30 and 31, respectively. A summary of the equipment requirements and the manufacturer/supplier is presented in Table 9.

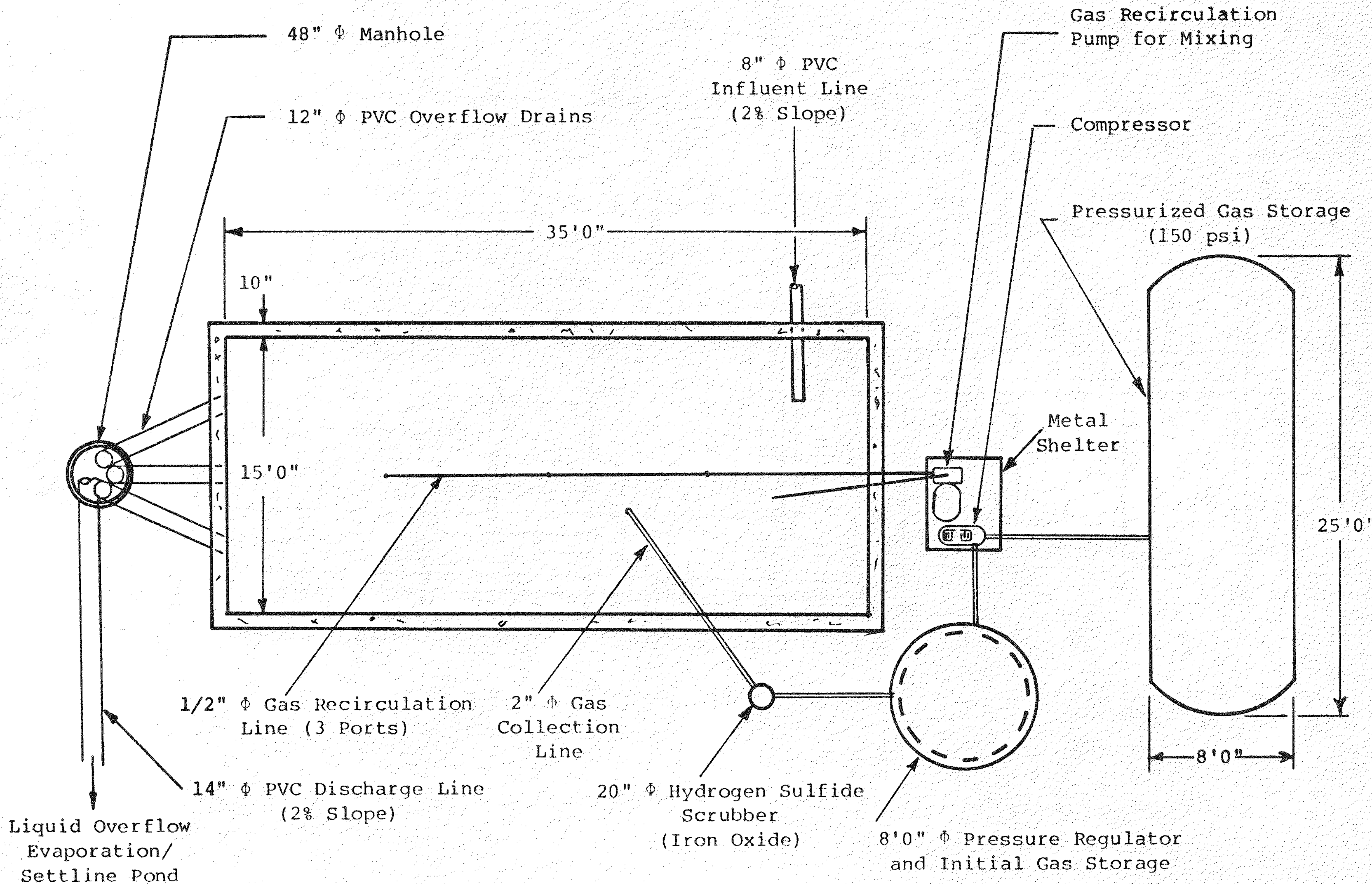


Figure 30: Plan View of Proposed Anaerobic Digestion Facilities

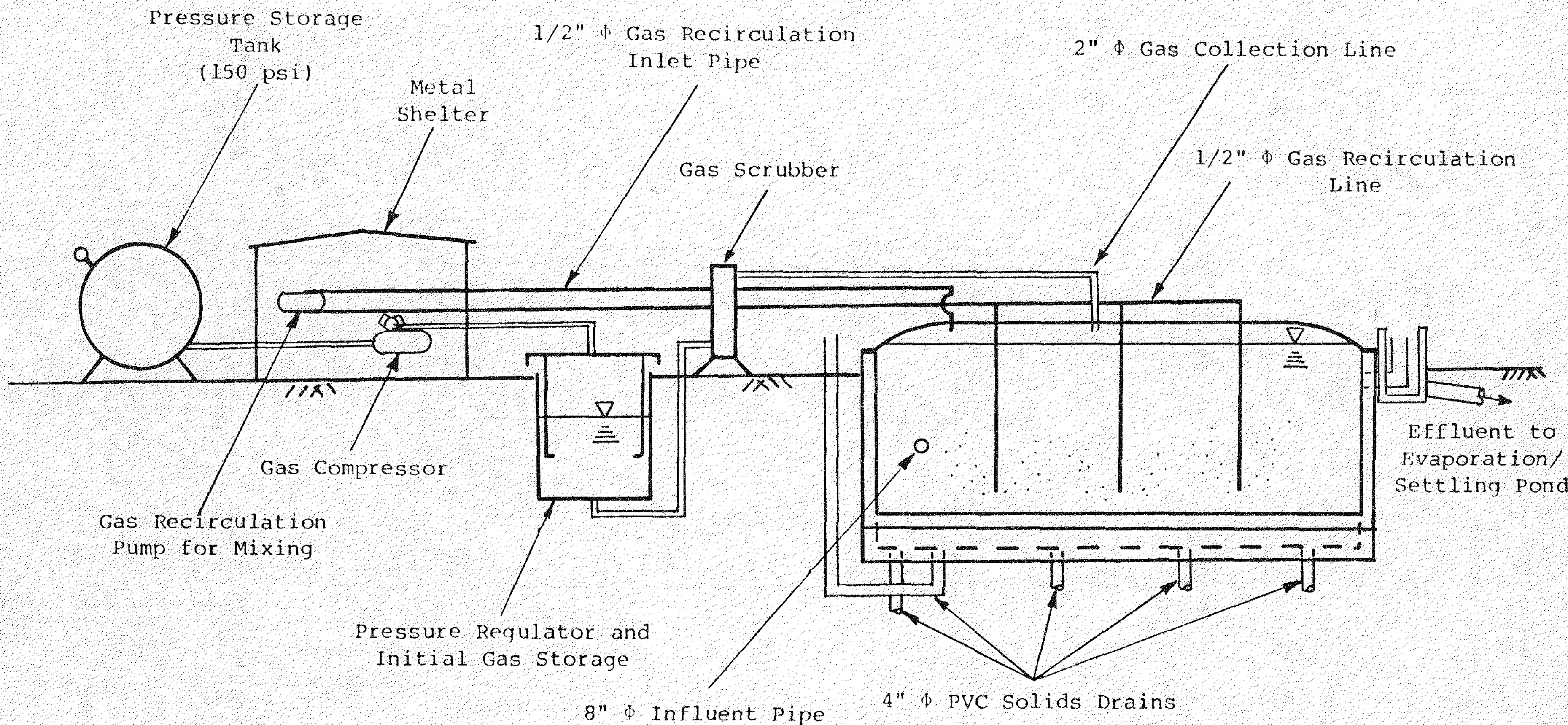


Figure 31: Elevation of Proposed Digestion Facilities

Table 9: Equipment Requirements for Anaerobic Digestion Facilities

Item	Quantity	Supplier/Manufacturer
Sump Pit	1	Field Construction
Concrete Digester	1	Field Construction
Fiberglass Roof	1	Clay Fulton Mfgr.
Wash Sand	20 yds.	TXI, Inc.
Gravel	10 yds.	TXI, Inc.
EPS Insulation	1,350 sq. ft.	Dove Plastic Manufacturing
PVC Piping		George Warren Company
14" ϕ	40 ft.	
12" ϕ	40 ft.	
8" ϕ	200 ft.	
4" ϕ	180 ft.	
2" ϕ	40 ft.	
1" ϕ	40 ft.	
PVC Valves		George Warren Company
8" ϕ	2	
Black Iron or Galvanized Pipe		Austin Pipe & Supply
1½" ϕ	120 ft.	
1" ϕ	30 ft.	
3/4" ϕ	100 ft.	
Concrete Sump	1	Austin Concrete
Gas Scrubber	1	Alco Steel Fabricating
Iron Sponge	9 cu. ft.	Connelly-GPM
Evaporation Pond	1	Field Construction
Flush System	2	AG-PRO Flush Systems
Scraper System	2	Moormans
Concrete Rings 8' ϕ	4	Austin Concrete
Fiberglass Tank	3,000 gal.	Plastic Fluids Systems
Hot Water Heater	1	Grainger
Water Recirculation Pump	1	Franco Equipment
Gas Compressor	1	Franco Equipment
High Pressure Gas Storage	18,000 cu. ft.	-------
Diaphragm Pump	1	Central Texas Corp.

Section 5
FUEL ALCOHOL FACILITY DESIGN

The increasing demand for petroleum-based fuels and their associated price increases have stimulated new interest in alternative energy sources in the United States. The most notable and highly publicized alternative has been the blending of alcohol and gasoline into gasohol for use as a motor fuel. Alcohol, produced from agricultural wastes, grain, sugar cane, etc., represents a renewable and replenishable fuel alternative.

In a typical farming operation such as the Del Valle Hog Farm, energy consumption for hog and grain production is nonuniform and quite seasonal. Providing energy independence and self-sufficiency for this farming operation requires the production of a fuel that is both easily produced and stored and compatible for use in existing equipment. Alcohol or alcohol blends appear to fulfill these objectives.

Preliminary estimates for the Del Valle Hog Farm indicate that the anaerobic digestion/methane generation system in this demonstration project will produce up to approximately 6500 cubic feet per day of biogas (methane and carbon dioxide). A portion of this gas will be used directly for generation of electricity and heat. The remainder, if not used, would need to be stored or simply flared. The flaring is totally unacceptable and large storage is expensive. An alternative is to use excess gas as an energy source for the production of alcohol. This fuel alcohol system must meet three objectives: 1) the alcohol production facility must be economically feasible; 2) the production technique must be energy efficient, and 3) the operation of the facility must require little monitoring and maintenance to minimize interference with the typical day-to-day farm operation.

During the Phase I: Design and Analysis and the initial portion of Phase II: Fabrication and Construction, various alternatives have been evaluated for meeting the fuel alcohol production objectives at the Del Valle Hog Farm. Initially a subcontract agreement was entered into with CENTEC Corporation, Reston, Virginia, to provide detailed specifications for the desired fuel alcohol facility. The agreement speciified the following basic system requirements:

- o Provide for maximum alcohol yield per unit of milo as a feedstock,
- o Provide equipment design (turn-down and turn-up capability) with sufficient production dynamic range to accommodate seasonal variations of energy and availability and on farm energy requirements,
- o Minimize operation monitoring and maintenance,
- o Operate daily rather than intermittently to allow efficiency of heat recovery and its utilization throughout the farm, and
- o Maximize the capacity of the integrated system by utilizing state-of-the-art techniques.

To meet these requirements, CENTEC Corporation designed a facility to produce fuel ethanol from milo requiring five basic processing steps:

- o Prepare the mixture of ground milo and water (mash)
- o Cook the mash with enzymes to break complex starch molecules into simple starches (liquefaction)
- o Convert the starches to fermentable sugars (saccharification)

- Ferment the sugars with yeast to produce ethanol with liberation of CO_2 being a by-product of the reactions

- Recover the ethanol via distillation

A flow diagram of the batch system designed for performing these processing steps is shown in Figure 32. The overall system is designed to produce one batch of mash per day. Fermentation is begun for one batch of mash daily and one fermented batch is distilled to recover alcohol daily. The saccharification and fermentation of the mash requires approximately 72 hours and the distillation process requires seven hours. The fermentation step takes three days; therefore, four fermenters are required, since a three-tank system would require the emptying and filling of the still pot and a given fermenter simultaneously.

The mash is prepared for cooking by pumping a measured amount of water into the still pot. While water is flowing into the pot, liquefaction enzymes are added and ground milo flows from the feed hopper into the still pot. During this process, agitation in the still pot ensures good mixing. The appropriate controls for the cooking phase are activated to provide the necessary heat to maintain the mash at approximately 210°F. The mash is fully cooked in 2½ to 3 hours.

After cooking, the mash is transferred to a cleaned fermenter to begin the saccharification and fermentation steps. Saccharifying enzymes are added to the fermentation tank and conversion to sugar proceeds for one to two hours. At that time, fresh water and yeast are added to the fermenter, and fermentation continues. The temperature controller is also activated to remove the heat of fermentation and maintain the fermenting mash at 85 to 90°F. The fermentation process continues for 72 hours.

After the still pot contents have been emptied, a fermented batch and the material in an ethanol recycle tank are transferred to the still pot and the controls are activated to perform distillation. The

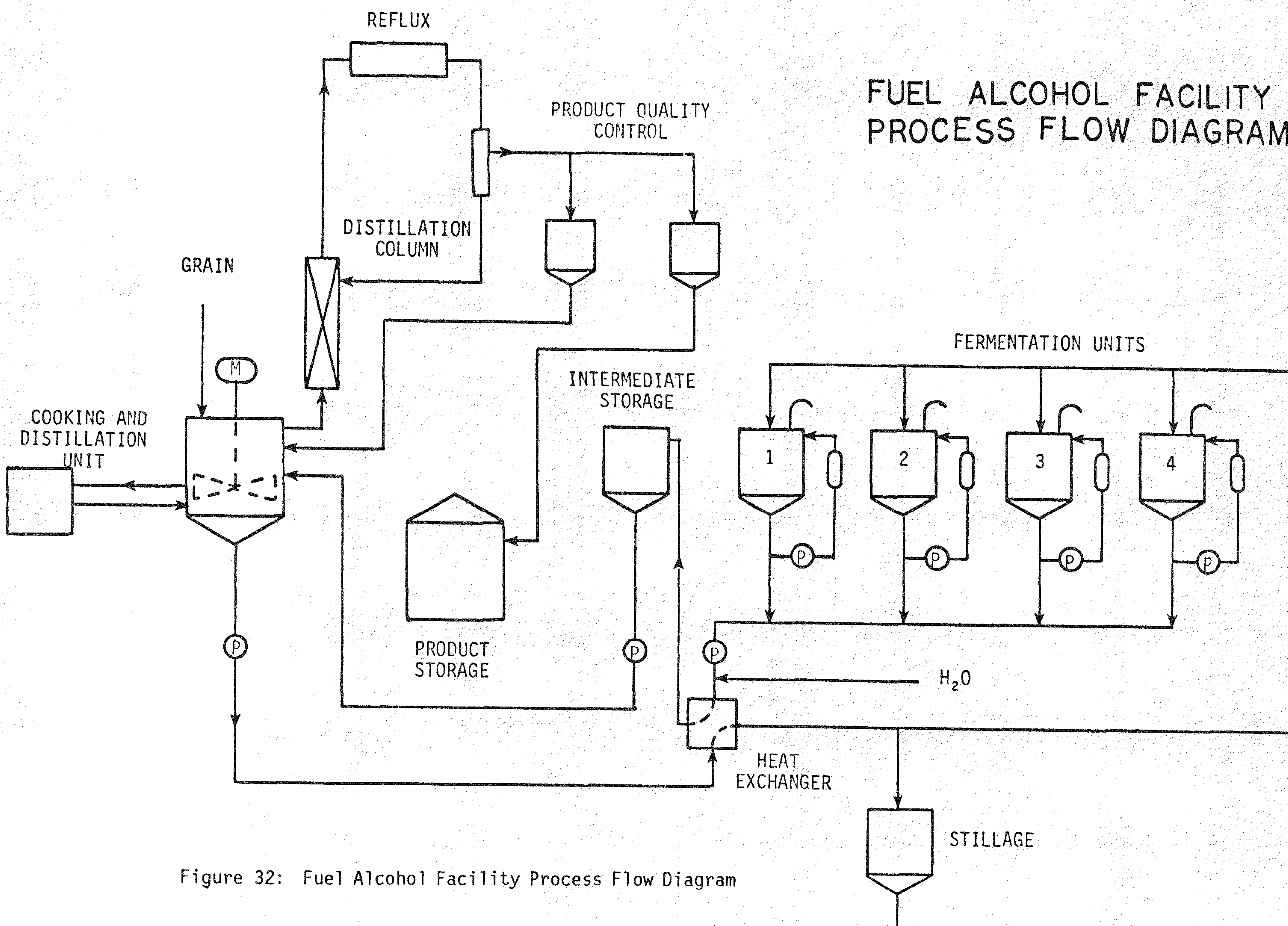


Figure 32: Fuel Alcohol Facility Process Flow Diagram

distillation process boils the ethanol out of the mash and utilizes a reflux stream to remove water from the vapors, thereby providing a more concentrated product. The reflux ratio, or ratio of reflux to product takeoff, remains approximately constant.

A batch distillation process results in an uneven composition of the overhead alcohol-water mixture, and this mixture decreases in ethanol concentration with time. If the distillation is stopped as soon as the composition of the ethanol product reaches the lowest acceptable proof level, a considerable amount of alcohol would remain with the mash in the still pot. To improve recovery, the remaining overheads are routed into an ethanol recycle tank as soon as the overheads composition drops to a predetermined level. This second "cut" is added to the next fermented batch ready for distillation. By recirculating this lower proof cut, almost all the alcohol which was produced by fermentation can be recovered. The product "cut" (mixture highest in ethanol concentration) is removed first and routed to a product tank separate from the recycle tank.

The material remaining in the still pot after distillation is very low in alcohol and high in water, suspended solids, and soluble solids. This stillage is transferred to a storage tank and can be blended with animal feed for disposal.

The system as designed by CENTEC Corporation was evaluated from the perspective of meeting both the technical and economic objectives of the integrated farm program. The system clearly met the defined technical objectives. An economic analysis of the system, however, failed to support these objectives owing to the prohibitively excessive fabrication costs. Therefore it became necessary to investigate the state-of-the-art in fuel alcohol systems in an attempt to identify a system for meeting both the program's technical and economic objectives.

A list of alcohol manufacturing engineering firms was obtained from the National Alcohol Commission. A list of firms contacted, the location of an operating facility (if any) and its respective production rates, and comments are included in Table 10. In addition, several systems were identified for site visits and demonstrations; those sites visited are indicated by an asterisk (*) in the table. Most of the facilites identified have fuel production rates considerably in excess of that required at the Del Valle Hog Farm and correspondingly high costs: e.g. Lindsay Manufacturing (36 gal/hour), Seven Energy (40 gal/hour), Nabal (40 gal/hour), etc. Some, however, such as Pure Energy (48 gal/day), General Irrigation (2 gal/hour), Tri-Star (40 gal/day), and Tallgrass (30 gal/day) have rates consistent with those required. In addition, Modular Fuel Systems (75 gal/day) theoretically has a turn-down capability to 20 gal/day. These reviews of commercially available fuel alcohol facilities have provided engineering specifications and performance estimates for comparison with the CENTEC Corporation system.

In addition, a system designed by SV&G Energy Resources, Inc., Austin, Texas, has been reviewed extensively for comparison with these other alternatives. The SV&G system is unique in that the conversion of the starches to fermentable sugars is accomplished using acidic hydrolysis instead of by enzymatic hydrolysis as proposed by CENTEC and all other manufacturers surveyed. This feature, although offering no apparent advantage over the other systems for conversion of milo (or other grains) to alcohol, does allow by system modification for conversion of agricultural residues such as milo stubble or straw into fermentable sugars, and subsequently into fuel alcohols. A block diagram of the SV&G system for providing the conversion of milo to alcohol is shown in Figure 33.

The SV&G system utilizes the pot concept where cooking, fermenting, and distilling will be performed in a single tank with two tanks required for continuous (daily) operation. This pot concept is presently used by several alcohol manufacturers including Tri-Star Corporation, Tallgrass Research Institute, and Reinke Manufacturing. Cooking is performed under pressure with the system designed to utilize either enzymatic or acidic conversion of starches to sugars. SV&G has successfully experimented with both conversion techniques and prefers and recommends the acidic conversion technique. The advantages of this

Table 10: Alcohol Engineering Manufacturing Firms Contacted

Firm Contacted	Operating Facility	Production Rate	Comments
*Lindsay Manufacturing Lindsay, NE	Harry Nienaber Dairy Lindsay, NE	36 gal/hour	Owned/Operated by Lindsay Replacing Distillation Column
*Pure Energy Corp. Lincoln, NE	Test Farm Lincoln, NE	48 gal/day	Owned/Operated by Pure, Demonstration Facility
*Seven Energy Corp. Lakewood, CO	Brian Hultine Clay Cty, NE	40 gal/hour	Hultine Dealer for Seven, Replacing Distillation Column
*Nabal, Inc. Lincoln, NE	T-Bone Feed Lots Fairfield, NE	40 gal/hour	Replacing Distillation Column
*Reinke/George Boucher Deshler, NE	George Boucher Ravenna, NE	4 gal/day 10 gal/hour	Not in Operation
*Tri-Star Corp. Vandalia, IL	Lincoln Land College Lincoln, IL	40 gal/day	Educational Tool
Ken Fuhr Leigh, NE		?	Rebuilding System
Wenger Manufacturing Sabetta, KS			Provide Cooking and Extrusion Equipment Only
*Modular Fuel Systems Houston, TX	Modular Fuel Systems	75 gal/day	Demonstration and Training Aid
ACR Process Corp. Westfield, NJ	Hydro, OK	400 gal/hour	

*Sites Visited

Table 10: Alcohol Engineering Manufacturing Firms Contacted (Cont'd)

Firm Contacted	Operating Facility	Production Rate	Comments
Elwood Stills Plainfield, IL		6 gal/hour	Research Tool
Process Design Associates Lincoln, NE		10 gal/hour	Under Development
MRC Energy Systems Plymouth, IN		25 gal/hour (min)	
Harrison & Ellis Cairo, GA		50 gal/3½ hour cycle	
Tri Star Corporation Vandalia, IL	FS Corporation Bloomington, IL	40 gal/day	Efficiency and Feeding Studies
Industrial Boiler Thomasville, GA			Boiler Plants Only
General Irrigation Carthage, MO	Dr. Meral Alexander Baylor University Waco, TX	2 gal/hour	Modified for Solar Oeration
AFS Research Corp. Waco, TX		1500 gal/day	Under Construction
Tallgrass Research Institute Formoso, KS		5 gal/day 15 gal/day 30 gal/day	Pot Stlls
Agri-Stills of America Springfield, IL		800 gal/day	

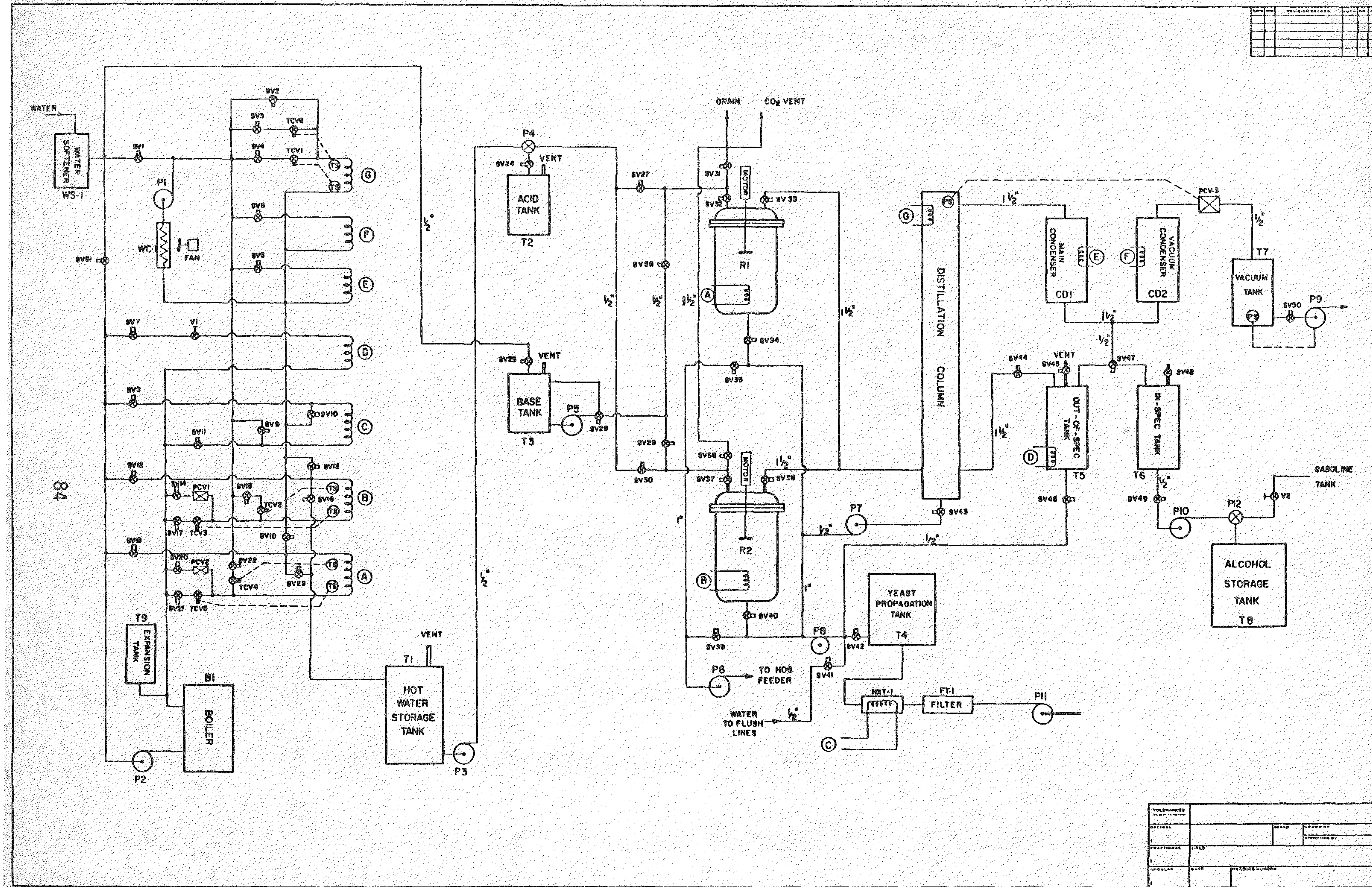


Figure 33: SV&G Fuel Alcohol System Block Diagram

technique over enzymatic conversion are 1) local supply of less expensive ingredients (sulfuric acid and lime), 2) more simple cooking time/temperature schedule, 3) less susceptible to disease, 4) less sensitive to processing errors, and 5) whole (unground) grain and/or crop residues may be converted. The disadvantages are 1) the cooking vessels must be able to withstand a hot (250°F) 1% sulfuric acid concentration and 2) conversion efficiencies are slightly reduced as reported in Industrial Fermentation, Vol I, Chap. 2 and demonstrated to date by SV&G (48).

The fermentation in the SV&G system will be performed in ten hours as compared to forty-eight to seventy-two utilized by enzymatic conversion manufacturers. This fast fermentation is due to 1) high yeast innoculation at fermentation start-up and 2) acidic conversion resulting in a definite fermentation termination.

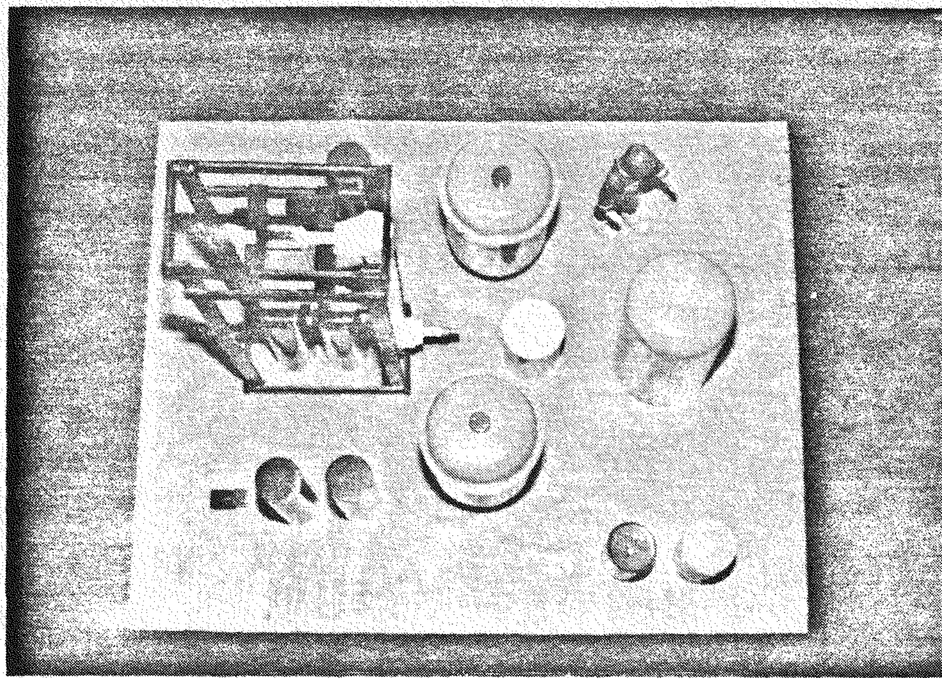
Distillation is performed under vacuum similar to the systems manufactured and marketed by Modular Fuel Systems and General Irrigation. The distillation column is a packed tower controlled by maintaining a constant temperature near the top. A condenser used to maintain the desired temperature for regulating reflux ratio controls ethanol concentration of the product. A 180 proof ethanol mixture is produced until the reflux ratio becomes prohibitively large (measured by the accumulation of liquids in the tower bottom), at which time the temperature in the top of the tower rises and off-spec (lower proofage) ethanol is produced for the remainder of the run. The completion of a run, measured by monitoring the temperature in the distillation pot, results in a product stillage with less than 0.5% ethanol concentration.

SV&G has been experimenting with the acid hydrolysis of milo grain and the vacuum distillation for ethanol removal for approximately one year. During this period over 60 laboratory scaled batches have been processed through fermentation and distillation. A 1/16 scale model of a system proposed for the Del Valle Hog Farm has been constructed and operated for eight months. Figure 34 contains a photograph of a vacuum distillation system model. Based on this research, SV&G estimates the following daily performance for a system designed for the Del Valle Hog Farm:

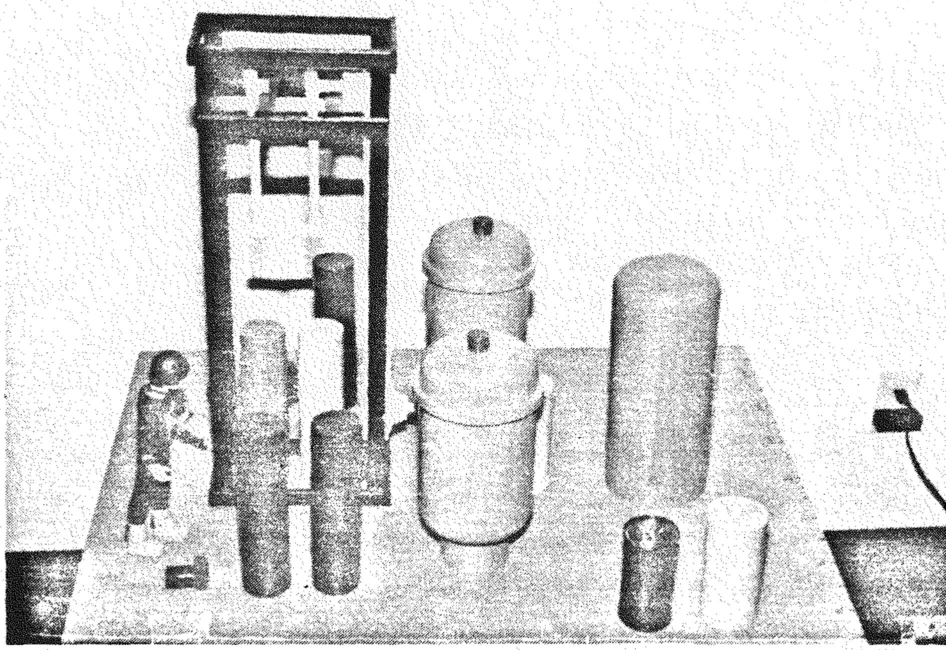
Input: 11.3 bushels of grain
226 gallons of water
1.3 gallons sulfuric acid
19 pounds of lime
750 watts continuous electrical
1.5 X 10^6 BTU of heat

Output: 24 gallons of 180 proof ethanal
2200 pounds of stillage at 85% moisture content

To allow economic and technical review of the state-of-the-art in fuel alcohol facilities, several of these manufacturers of small scale facilites including Harrison and Ellis, Tri-Star, Tallgrass, General Irrigation, Modular Fuel, and SV&G, have been asked to submit technical and cost proposals for evaluation. A cost and system performance grid, including manpower, water, energy, etc. requirement, will be established for evaluation of these proposals, and a system will be selected for recommendation to TENRAC AND USDOE for purchase and installation at the Del Valle Hog Farm.



a) Top View



b) Side View

Figure 34: SV&G Energy Resources Alcohol Facility Scale Model

Section 6

FIELD TESTING OF MANURE HANDLING AND ANALYTICAL SAMPLING

EXISTING MANURE HANDLING FACILITIES

The Del Valle Hog Farm presently collects manure from the finishing barn in a pit located under the slotted floors. A concrete wall the full length of the barn separates the pit into two long (215 feet) troughs, each eight feet eight inches wide. These troughs have a two percent grade starting at a depth of three feet six inches on the shallow end and sloping to a depth of seven feet six inches on the deep end. The bottom surface at the deep end of the pit is set at an elevation of 479.31 feet MSL. Present manure handling involves maintaining a constant liquid level in the pit, measuring seven feet at the deep end, and allowing liquid overflows to drain into an evaporation pond. Solids settling to the bottom of the pit are removed periodically for land spreading using tractors, a suction pump, and storage tanks. The constant liquid level in the pit serves two purposes; it reduces temperature variations in the nursery located over the shallow end of the pit by creating a barrier to prevent air circulation and it prevents odor buildup in the pit volume. These present manure handling and removal procedures have proven adequate at the Del Valle Hog Farm even though they are quite labor intensive.

MANURE REMOVAL STUDY

The objective of this study is to determine a manure removal technique that can meet the daily loading requirements of the anaerobic digestion system, both in total solids concentration and in mixing, while not affecting the operation and environment of the finishing and nursery units at this farm. The digestion process, resulting in regular solids removal, starts immediately after the manure has been deposited. Therefore the maximum benefit from the manure is obtained by removing the manure as quickly as possible from the pit and loading it into the digester for anaerobic digestion. There are presently two accepted and practiced techniques for removing manure from this type of pit. These techniques are flushing and scraping. Flush systems have a reservoir of liquid which, when released, creates a surge of water that flushes the surface. Flush systems have the advantages that they require little maintenance, perform reasonably well, and are relatively inexpensive (26). However, in general, these systems require a large volume of water to achieve acceptable performance, especially in pits or floors that are quite long.

Facility Observations

To review manure flushing/handling state of the art, three operating flush systems in operation were visited: two on confined feeding swine operations and one on a dairy operation. Farrell Angel operates a swine operation in Cameron, Texas, and presently flushes a pit 165 feet long every 16 hours with 600 gallons of water (40). The pit has a two percent grade the same as the Del Valle Hog Farm, but is 50 feet shorter. The flushing operation cleans the upper end of the pit well, but leaves a manure buildup in the lower end. The owner/operator indicates that this buildup is not significant. It does, however, contribute to the fly breeding and the odor problems. It is possible that this buildup is a result of design problems in the sump at the end of the pit. The sump volume is not adequate to contain the flush water and manure for one flush, and as a result, the flush water and manure backwash up the pit. Proper design could possibly solve this problem, but only experimentation could assure this conjecture.

A confined feeding swine operation and anaerobic digestion system located at the University of Missouri at Columbia was visited (41). Dr. James Fisher, USDA-SEA, has been operating the anaerobic digester utilizing the swine manure as feedstock for five years. Manure from the breeding, gestation, nursery, and finishing barns are flushed daily into a sump where settling occurs. Overflow liquids are pumped directly into an evaporation pond. Manure with solids concentrations of approximately six to eight percent is pumped into the digester. This flush system appeared to work well as designed, but considerably more water (solids concentrations of one percent have been measured for flushing) was used in the flushing operation than needed for mixing at the Del Valle Hog Farm.

The third flush system visited, located at Sansom and Sons Dairy, Webberville, Texas, uses flush systems in the milk barn, in the covered entry way, and in confined feeding barns (42). The flush water from the milk barn is trapped by a series of dams for use in flushing succeeding sections of the facility. Approximately seven feet of gravity have been constructed in the facility to aid in flushing.

These visits to various flush system operations indicate that a flush system should meet the requirements at the Del Valle Hog Farm, provided large quantities of water are not required for the 215-foot long pit. In the event that large quantities are required, a combination flush and scraper system will be considered.

Scraper systems are commercially available for pits 215 feet in length, and from the literature, appear to work well (25). However, the have the disadvantages that they are expensive, require continuous lubrication, and contain mechanical moving parts such as motors, pulleys, gears, and cables, that require considerable labor for maintenance.

Del Valle Field Study

In this manure removal study, several attempts have been made to initially vacate the pit so that techniques for daily removal could be evaluated. All liquids and solids that would migrate to the deep end were removed from the pit. The pit was then flushed several times with 1600 gallons of water per flush in an attempt to move the remaining solids to the deep end for removal. Little if any movement was noticed. The owner/operator of the Del Valle Hog Farm at this time indicated that he had never completely removed all solids from the pit. These solids have been collecting for years and are adhering to the floor and walls of the pit. Daily deposits of liquid and those solids that would migrate were pumped from the pit to the evaporation pond to simulate daily loading of the digester. It was observed that solids in the shallow end of the pit began to dry and harden, which is undesirable. Therefore, the pit was allowed to refill and preparations were begun for construction of those parts of the anaerobic digestion system that would be required for daily manure removal during operation. These facilities will be utilized for initial and total removal of manure from the pit in the completed digestion system.

A sump of a volume necessary to contain a single daily flush is required at the end of the pit. The estimated manure production at the Del Valle Hog Farm is 7800 lbs/day (78 lbs/day/1000 lbs · 100,000 lbs). At a density of 62 lbs/c.f., this manure occupies a volume of 125.8 c.f. The moisture content of the manure when deposited is approximately 81 percent. To achieve the desired eight to ten percent solids concentration, water must be added, and this water will be used in flushing the sub floor pit. The amount of flush water required to achieve a ten percent solids concentration is 113 c.f. or approximately 850 gallons. Therefore, the volume of the sump must be adequate to contain the total of 239 c.f. liquids and solids per day.

In addition, the depth of the sump was minimized to ensure that the manure will gravity flow from the sump to the digester, and then overflow to the evaporation pond. The topography of the area indicates that grades exist in the vicinity of the collection pit and sump to facilitate this gravity flow. From the bottom of the pit, measured at 479.31 feet MSL, the grade slopes to an elevation of 472 feet in a few hundred feet. An evaporation pond, designed to meet the requirements of the Del Valle Hog Farm anaerobic digestion system, has been constructed in this area. The evaporation pond has been designed for an elevation of 475 feet above sea level when full. Therefore, a total of 4.31 feet of grade is available for the sump, the piping from the sump to the digester, and the overflow of the digester to the pond. Drain pipe grades of 1/8 inch to 1/4 inch per foot (one to two percent) are recommended in systems using scraper or flush systems (25). The digester is located approximately 100 feet from the sump pit, and allowing for a two percent grade in the drain pipe, leaves only 2.31 feet (4.31 feet - (.02) x 100 feet) for the sump and the digester overflow. A two percent grade from the digester to the evaporation pond (approximately 40 feet) now leaves only 1.51 feet for the depth of the sump.

Two dimensions of the sump are now defined, 1.5 feet deep and 21 feet wide (the width of the collection pit). The requirement for a volume of 239 c.f. to contain one day's collection of solids, liquids, and flush water allows for solution of the required sump width--7.58 feet. Pipe and sump dimension specifications were provided to a concrete subcontractor and a sump was constructed. Figure 35 shows the sump pit under construction. A photograph of the completed sump taken at ground level is shown in Figure 36; a photograph showing the eight-inch pipe mounted in the side wall and the pipe in place downhill to the digester excavation is shown in Figure 37.

After installation of gate valves on the drain pipe, the lower end of the present collection pit was removed to allow draining of solids and liquids into the sump. When the wastes were drained directly to the evaporation pond, channelization of the liquid portion through the solid portion of the slurry occurred in the collection pit, leaving a solids buildup that released objectionable ammonia gas. A loss of approximately six hogs occurred in the enclosed nursery and finishing barn. Previously, this ammonia had been held in the water due to the acidic and anoxic conditions. A crude field constructed scraper was pulled down one side of the collection pit to remove the solids. Cable was attached to the front and rear of the scraper so it could be pulled from the front or rear of the collection pit. After several passes, the scraper had removed a considerable amount of solids but the width of the scraper was not as wide as the pit and solids collected on the side walls. A temporary flush system using an irrigation pump and pipes flushed evaporation pond water into the shallow end of the pit, and water discharged through the sump drain to the evaporation pond. Pumping 100 gpm through the collection pit was not sufficient to remove the solids buildup.

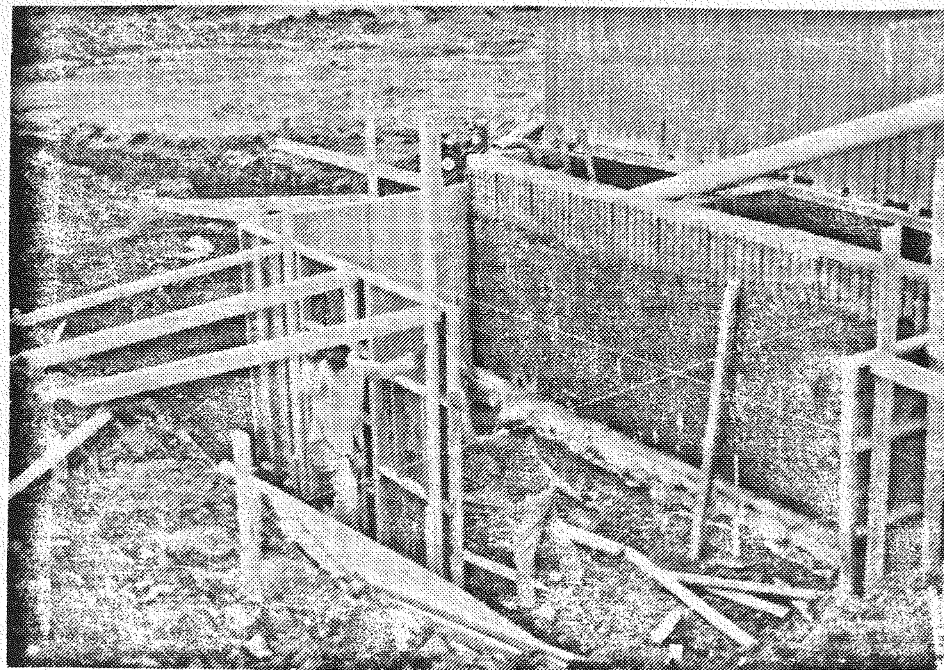


Figure 35: Sump Pit During Construction

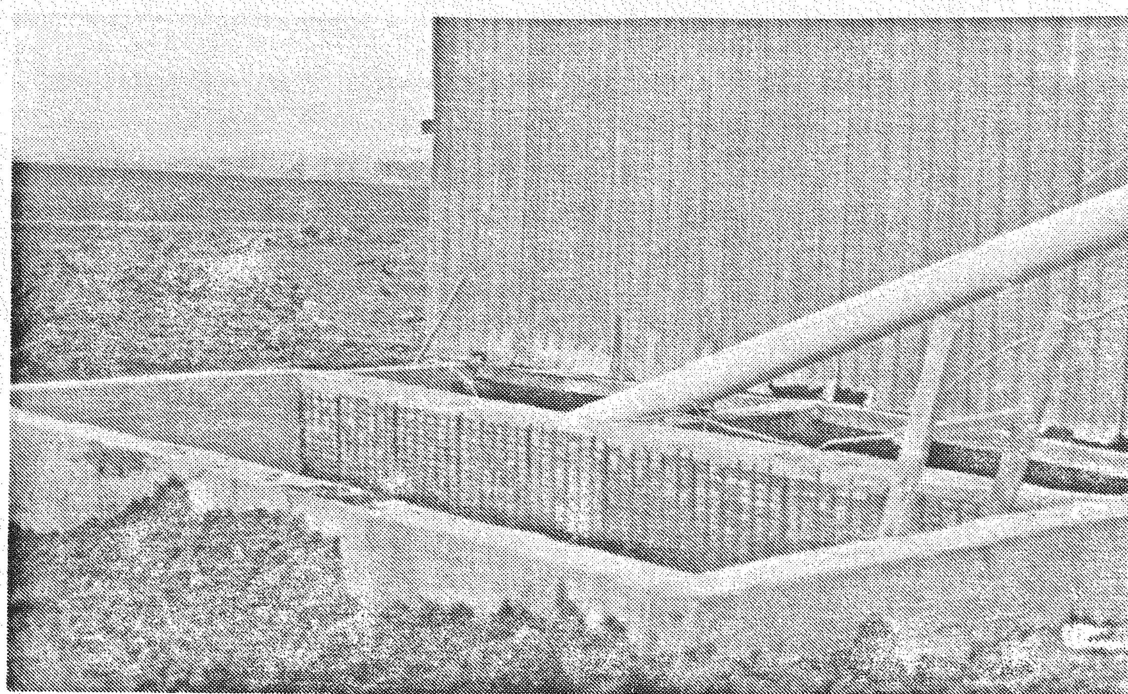


Figure 36: Completed Sump Pit

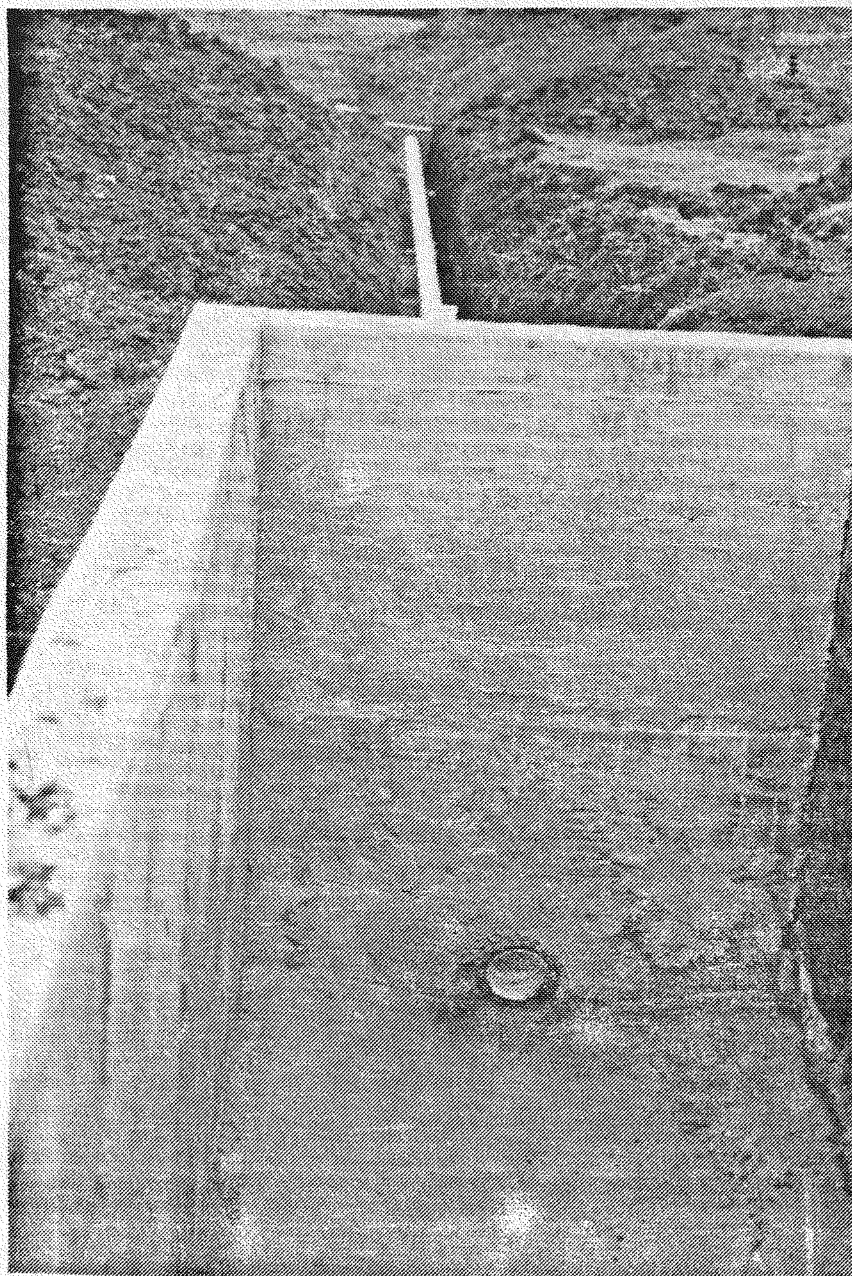


Figure 37: Sump Pit with 8-inch Diameter Drain

ANALYTICAL SAMPLING OF MANURE

Analyses on samples of manure collected during a two-week period while removing the liquids and those solids that would migrate to the deep end of the pit were performed. A summary of results from these analyses is shown in Table 11 for five samples. For comparison, Table 3 summarizes results compiled from several other researchers of daily swine manure production. Total solids concentrations for these Del Valle Hog Farm samples varied from 4.0 percent to 5.4 percent, which is considerably lower than those shown in Table 3 ranging from 15 to 25 percent. Based on the manure removal problems previously discussed, these results were anticipated. Tests conducted on the flowing portion of the slurry sampled during the scraper-solids removal showed a 30 to 35 percent solids concentrations.

The volatile solids concentrations shown in Table 3 range from 47 to 84 percent. Fischer reports volatile solids concentrations of 82 percent (43). The concentrations measured on the five samples taken at the Del Valle Hog Farm range from 73 to 80 percent. These results are clearly in agreement with the published results for volatile solids concentrations. Once a manure removal procedure has been developed, it is anticipated that the total solids concentrations of the manure at the Del Valle Hog Farm will be consistent with the publised data.

Manure handling and removal studies will continue throughout Phase II and the initial portions of Phase III to aid in developing techniques for manure loading and in collecting performance data on methane gas production rates. These data will be of much benefit to confined feeding swine operations considering construction of anaerobic digestion systems and will comprise a considerable portion of the Phase III demonstration and information exchange for this program.

Table 11: Analytical Sampling Results of Five Manure Samples

	SAMPLE 1			SAMPLE 2	
	A	B	E	C	D
Sample Wt. (g)	21.34	20.41	18.19	24.91	23.80
Wt. Total Solids (dry @ 103°C) (g)	1.04	.96	.73	1.17	1.28
TDS (mg/l)	48,700	47,000	40,100	47,000	53,800
(%)	4.9	4.7	4.0	4.7	5.4
Wt. Vol. Solids (30 @ 550°C) (g)	.78	.69	.46	.97	1.03
Wt. Non-Volatile (Total Volume) (g)	.26	.27	.27	.20	.25
% Vol. Solids $(\frac{Vol.}{Tot.})$	75	72	63	83	80

Section 7
ENERGY INTEGRATION

The reliable rate of methane gas production will be established during start-up, operation, and monitoring of the anaerobic digestion system. This information, in addition to data collected from on-site energy monitoring, will form the basis for the final energy integration system design and technology integration.

The primary objectives of this analysis will be to establish an overall energy integrated system. Figure 38 demonstrates the concepts involved in the Energy Integrated Farm System at the Del Valle Hog Farm. The farm itself is the end user of all produced energy in excess of that required for system operation, and in turn the farm supplies all feedstocks, i.e., grain and manure, for system operation. Anaerobic digestion is the heart of the complete system, in that all energy for production of fuel alcohol and electrical generation are dependent on continuing and lifelong operation of the digester. For its operation, the digester is dependent on the farm for a continuous supply of manure. Successful operation of the digester results in an excess of methane gas for use by the other components of the system and the farm.

The motor/generator is dependent only on a continuous supply of energy for internal combustion. The loading of the motor/generator and thus its rate of consumption of available methane is determined by the system demands for electricity. Its operation to meet these demands results in by-product heat in the form of hot water.

The fuel alcohol facility is dependent on all components of the integrated system; it requires grain as its feedstock for ethyl alcohol production, it requires methane for cooking and distillation, and it requires electricity for pumping and mixing. Its product, fuel grade alcohol, will be used to support farm activities involved in producting the feedstock for the total energy integrated system, the grain. Its by-product, heat in the form of hot water, can be used throughout the system.

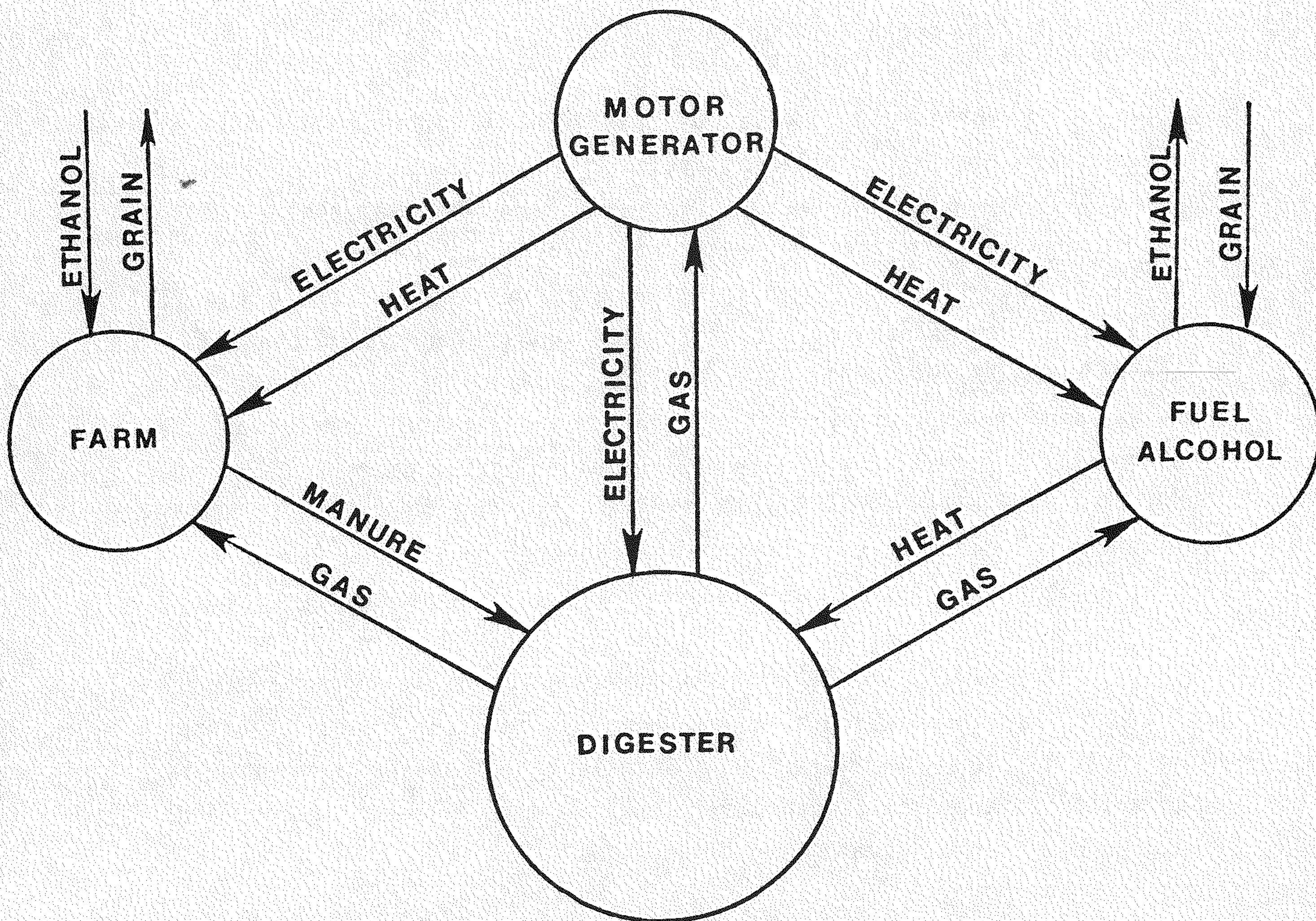


Figure 38: Energy Integrated Farm System
Del Valle Hog Farm

DEL VALLE HOG FARM ENERGY BALANCE

Energy balance estimates, based on assumptions documented throughout this report, are shown in Figure 39 for the Del Valle Hog Farm. As shown, the farm operation requires approximately 48 Kw-hr/day electricity for baseline operation; e.g., mill augers, high pressure water pump, 100 Kw-hr/day in high cooling and ventilation periods in the summer, and 510,000 Btu/day of heating in the winter. This energy for heating can be in the form of electricity, methane, or hot water.

The confined feeding hog operation provides a quantity of manure sufficient for producing of approximately 6500 cu. ft./day of biogas having energy value of 640 BTU/cu. ft. In return, the digester system requires a maximum of 900,000 BTU/day of heating in the winter and a minimum of 220,000 BTU/day in the summer. This heat may be derived in the form of hot water from a gas hot water heater, from cooling water for the motor/generator, and/or from heat exchangers and condenser coils in the ethyl alcohol facility.

A motor/generator operating on biogas will consume, according to a Koehler Company catalog, approximately 30 to 40 cu. ft. of biogas per Kw-hr. of electricity generated (44). Nayeloff and Gunkel experimentally estimate consumption to be .18 HP/liter methane/min., which equates to 16 cu. ft. methane/Kw-hr., or approximately 26 cu. ft biogas/Kw-hr. (45). Heat rejected in the cooling water according to Koehler is approximately 200 Btu/cu. ft. of biogas consumed. This energy in the form of electricity and hot water is available throughout the integrated system. Sizing of a motor/generator for integration into the Del Valle Hog Farm system will be established when excess methane gas availability for internal combustion is determined from field measurements. Gas engines, when operating at some fraction of peak loading, do not consume that same fraction of gas from peak loading consumption. For example, according to the Koehler Company, a 7.5 Kw water cooled system operating at 100 percent load consumes 130 cu ft./hr., and at 25 percent load, 85 cu. ft./hr (44). Operating at 25 percent loading consumes 65 percent of the fuel consumed at peak loading. Clearly, when selecting a

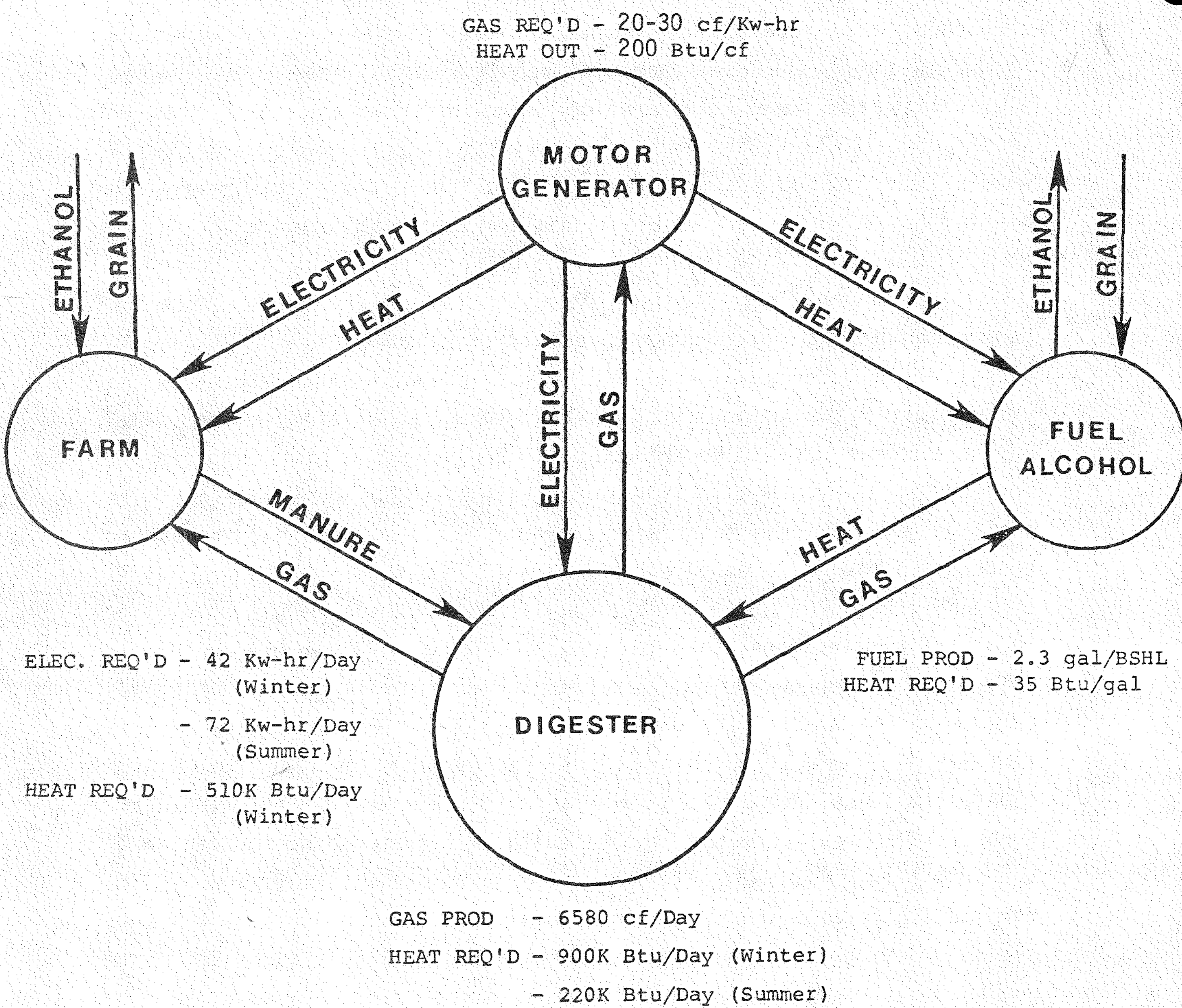


Figure 39: Energy Balances, Del Valle Hog Farm

motor/generator set, reliable estimates of methane gas availability and electrical consumption rates are necessary. An underestimation of electrical consumption will result in an incorrect specification for the motor/generator, with the result being an inability to meet electrical demands. An overestimation of gas availability results in motor/generator operation cosiderably below that of optimum performance.

The fuel alcohol facility requires grain, electricity, possibly heat from the motor/generator, and biogas from the digester as shown in Figure 20. In return, the facility provides the digester with excess heat and fuel alcohol for meeting farm requirements. The cost of this operation is approximately 45,000 Btu/gallon of 190 proof ethyl alcohol produced and .435 bushels of grain/gallon produced.

SYSTEM INTEGRATION

Monitoring of the energy consumptions and the enrgy productions for the various components of the Energy Integrated Farm System represents the only viable method for achieving complete system integration. Therefore, monitoring of energy balances, including methane, electrical, alcohol, and heat production and information collected will be continually reviewed to upgrade the integrated system.

A microprocessor system, Model SX-410, manufactured by SumX Corporation for data acquisition applications, will be utilized for performing these data monitorings. This SX-410 data acquisition system contains a Motorola 6820 microprocessor, necessary analog to digital (A/d) and digital to analog (D/A) models for performing acquisitions and control, and sufficient memory and programmability for storage of data and data analysis/reduction.

Initially, all function in the integrated system, i.e., loading of digester by opening the gate valve, flushing of manure pit, pH adjustments in the digester and the alcohol facility, methane gas flow rates to motor/generator, etc., will be performed manually to develop an understanding of what/why/how operations should be performed. This information will eventually lead to integration and computer control of most day-to-day operations and will provide data for establishing critical check points for manual monitoring. A completely automated system is of course desirable, and the successful degree of automation at this integrated farm system will be measured by the reduced labor dependency of the system on this owner/operator, and by the energy available with this level of automation to meet the varying energy demands of this farming operation.

Section 8
ECONOMIC ANALYSIS

An economic analysis was performed for the Del Valle Hog Farm integrated system based on the techniques developed by Hashimoto, et.al. (46) and utilized by Lindley and Hirning (47) on the North Dakota State University Energy Integrated Farm System. The economic model formulation is included in the Appendix A of the North Dakota, Phase I report, Reference 47, and is not repeated herein.

Three system configurations have been analyzed for the Del Valle Hog Farm integrated system. Configuration 1 contains a digester system only where biogas produced would be used in direct combustion for space heating, water heating, gas cooling, and digester heating. The replacement fuel is assumed to be butane at a cost of $0.60 per gallon. Configuration 2 is composed of an anaerobic digestion system and a motor/generator for co-generation. Electrical energy produced would be used on site to meet the continuing electrical demands of the farm, i.e., grinding, augering, cooling fans, etc. Cooling water from the motor/generator would be used for space heating and digester heating. The replacement fuels are assumed to be butane as before, and electricity at $0.05/kw. hr. The motor/generator selected for this analysis is a Koehler Model 7.5R61 liquid cooled natural gas generator set capable of producing up to 7.5Kw continually when consuming approximately 130 cu. ft./hour of natural gas. Under normal operation, the unit will operate below peak load and would consume approximately 100 cu. ft./hour of biogas to produce 4kw. hr./hour.

The third configuration contains an anaerobic digestion system, a Koehler 7.5Kw generator, and a fuel alcohol facility. The assumed fuel alcohol facility for this analysis is capable of producing approximately 25 gallons per day of 180 proof ethanol.

Table 12 presents the assumptions used in the economic analysis which is modeled after that of Linley and Hirning (47). Table 13 contains the results of these systems configuration analyses.

Table 12:

Economic Analysis Assumptions

Digester Size	4,000 cu.ft.
Gas Production	5,000 cu.ft./day
Interest Rate	15%
Inflation Rate	10%
Fuel Escalation Rate	15%
Tax Rate	20%
Butane Cost	$.60/gal.
Electricity Cost	$.05/Kw-hr
Gasoline Cost	$1.20/gal
Investment Tax Credit	10%
Energy Credit	10%
Alcohol Production Tax Credit	$.40/gal
Renewable Energy Credit	40% (4000 max.)
Useful Life	15 years

Table 13:

Economic Analysis

Digester	Digester	Digester & Co-Generation	Digester, Co-Generation & Fuel Alcohol
	System Configuration		
Capital Cost	$ 40,000	$ 46,000	$ 76,000
Adjusted Capital Cost	28,000	32,800	56,800
Total Capital Cost	38,208	44,758	51,174
Maintenance Cost/Yr.	1,400	1,820	2,870
Labor Cost/Yr.	300	700	2,920
Feedstock Cost/Yr.	-	-	6,712
Competitive Fuel $/MM Btu			
Butane	6.46	6.46	6.46
Electricity	-	14.65	14.65
Fuel Alcohol	-	-	10.00
Energy Produced MM Btu			
Gas or Hot Water	1,095	550	447
Electricity	-	155	63
Fuel Alcohol	-	-	730
Total Value of Energy Produced $	150,773	124,302	236,988
Produced Energy Cost $MM Btu	3.70	7.48	12.51
Rate of Return %	8.4	5.5	.6
Payback Period Yrs.	5.0	6.9	5.1

For a capital cost of $40,000 in Configuration 1, the adjusted capital cost after tax credits is $30,736, which with amortization becomes $41,946 over the useful life of the system. For the assumed competitive fuel cost of $6.46/MM Btu for butane and for the energy produced in the form of gas and hot water of 1095MM Btu/year, the total value of the energy produced over the useful lifetime of the system is $150,733. This fuel costs $4.58MM Btu, resulting in a rate of return of 7.1 percent and an effective payback period of 5.52 years.

For Configuration 2, the Koehler generator increases the price of the system by $6,000, raising the adjusted capital cost to $35,646 and total capital cost to $48,648. The replacement fuel for this system, in addition to butane at $6.46/MM Btu, is electricity at $14.65/MM Btu. The total value of this energy for the assumed production rates is $124,302, which factors into a produced energy cost of $8.85/MM Btu. The rate of return for this system configuration is 3.27 percent and the payback period is 8.01 years.

In Configuration 3, the model ethanol facility costing $30,000, raises the total system cost to $76,000, or $60,198 after credits. The total capital cost thus becomes $82,146. Annual operating expenses for this system configuration include, in addition to maintenance and labor, an estimate of grain cost used as feedstock for the ethanol production. The competitive (replacement) fuel cost is unchanged for butane and electricity, and is $10.00/MM Btu for fuel alcohol. The total value of energy produced is $306,560 over the lifetime of the system. The produced energy cost is $12.07/MM Btu with a rate of return of .85 percent and a payback period of 6.95 years.

The rate of return is seen to decrease as system complexity and system cost increases. This trend is a result of inefficiencies in energy production as energy is transformed from biogas to electricity or from biogas to electricity and to ethanol. The corresponding cost of energy produced increases as complexity increases. However, these analyses assume a high level of energy utilization which is impractical when the energy source is of one form.

The payback period for Configuration 3 is seen, however, to decrease instead of following the trend established by the produced energy cost and the rate of return. This result occurs because the rate of return and the produced energy cost do not include factors accounting for fuel escalation rates over the lifetime of the system. This escalation rate, when combined with the quantity of energy produced in this configuration, reverses the trends, and thus reduces the effective payback period.

In summary, all three configurations have reasonably short payback periods and small but positive rates of return. These factors favor any and all of the system configurations. Configuration 3 has the advantage that the energy produced is in a form that can be used directly and immediately, i.e. heat and/or electricity, or can be stored for subsequent use, i.e., fuel alcohol. The other configurations do not offer all of these advantages and are therefore not as desirable.

Section 9
PRESENTATIONS

Because a primary objective of this program is to disseminate useful information derived from the project, several papers were presented during this biennium. A list of those presentations is provided below:

Occasion:	Texas Solar Realities '81 Conference
Location:	Austin, Texas
Sponsor:	Texas Energy and Natural Resources Council
Date:	March 17, 1981
Presentation Title:	Demonstration of Biomass Derived Fuels
Presented by:	David Malish

Occasion:	Swine Short Course
Location:	Texas A&M University College Station, Texas
Sponsor:	Texas A&M University
Date:	April 6, 1981
Presentation Title:	Hog Biomass to Horsepower
Presented by:	Dan Raley and Dan Berdoll

Occasion:	High and Rolling Plains Extension Swine Short Course
Location:	Plainview, Texas
Sponsor:	Texas Agricultural Extension Service Texas A&M University
Date:	April 8, 1981
Presentation Title:	Hog Biomass to Horsepower
Presented by:	Dan Raley and Dan Berdoll

Occasion:	Renewable Energy Conference
Location:	University of Texas Austin, Texas
Sponsor:	University of Texas Solar Energy Society
Date:	April 23, 1981
Presentation Title:	Address on Biomass
Presented by:	Hank Kidwell

Occasion:	Energy Integrated Farm System Workshop
Location:	Austin, Texas
Sponsor:	U.S. Department of Energy
Date:	April 27, 1981
Presentation Title:	Agriculturally Derived Fuels for Del Valle Hog Farm, Del Valle, Texas
Presented by:	Dan Raley

Occasion:	Biogas Production and Utilization Seminar and Tour
Location:	Texas A&M University Research Center Stephenville, Texas
Sponsor:	Tarleton State University Texas Agricultural Extension Service Center for Energy and Mineral Resources Texas A&M University
Date:	May 28, 1981
Presentation Title:	Energy-Integrated Farm Operation Using Biogas
Presented by:	David Malish

REFERENCES

1. McCarty, P. C., "Anaerobic Waste Treatment Fundamentals," Part One, Public Works, 95 (9), pp. 107-112, September, 1964

2. Smith, R. J., "The Anaerobic Digestion of Livestock Wastes and the Prospects for Methane Production," Agricultural Engineering Department, Iowa State University, November, 1973.

3. Jeris, J. S., and P. C. McCarty, "The Biochemistry of Methane Fermentation Using C^{14} tracers," Journal of the Water Pollution Control Federation, 37, pp. 178-192, 1965.

4. Malina, Joseph F., "Separate Sludge Digestion," Manual of Wastewater Operations, The Texas Water Utilities Association, Lancaster Press, Inc., Lancaster, Pennsylvania, pp. 319-359, 1971.

5. Wastewater Engineering: Collection, Treatment, Disposal, Metcalf and Eddy, Inc., McGraw-Hill Book Company, 1972.

6. WPCF Manual of Practice No. 8, Sewage Treatment Plant Design, Water Pollution Control Federation, Washington, C.D., 1972.

7. Sawyer, C. N., and H. E. Schmidt, "High Rate Digestion," Journal of The Boston Society of Civil Engineers, Vol. 42, No. 1, p. 1, January, 1955.

8. Imhoff, K., and G. M. Fair, Sewage Treatment, John Wiley and Sons, Inc., New York, N.Y., 1940.

9. Loehr, R. C. and R. W. Agnew, "Cattle Waste - Pollution and Potential Treatment," Journal of the Sanitary Engineering Division, American Society of Civil Engineers, 93, SA 4, pp. 55-72, 1967.

10. Coe, Warren B., and Michael Turk, "Processing Animal Waste by Anaerobic Fermentation," Animal Waste Management Program, Hamilton Standard, Division of United Aircraft Corporation, 1973.

11. Coe, W. B. and Michael Turk, "Economic Evaluation of Asset Recovery From Animal Waste by Anaerobic Fermentation," Animal Waste Management Program, Hamilton Standard, Division of United Aircraft Corporation, May, 1973.

12. Jewell, et al, Anaerobic Fermentation of Agricultural Residue: Potential for Improvement and Implementation, Springfield, Virginia: National Technical Information Service, 1978.

13. Energy Harvester System Brochure, Sheaffer & Roland, Inc., Chicago, Illinois, 1979.

14. Robinson, J. C., "Sludge Digester Gases," Manual of Wastewater Operations, The Texas Water Utilities Association, Lancaster Press, Inc., Lancaster, Pennsylvania, pp. 429-444, 1972.

15. Sawyer, C. N., and Perry L. McCarty, Chemistry for Sanitary Engineers, Second Edition, McGraw-Hill Book Company, 1967.

16. Graves, R. E. and L. R. Massie, Manure Facts and Figures, Agricultural Engineering Department, Cooperative Extension Programs, University of Wisconsin, Madison, Wisconsin, October, 1972.

17. Stewart, Billy R. and John M. Sweeten, Liquid Manure Management for Swine Operations, Texas Agricultural Extension Service, the Texas A&M University System, College Station, Texas, April, 1974.

18. Maddex, Robert L., "Liquid Manure Systems," Agricultural Engineering Department, Cooperative Extension Service, Michigan State University, November, 1965.

19. Humenik, Frank J. and Michael R. Overcash, Design Criteria For Swine Waste Treatment Systems, Environmental Protection Technology Series, EPA-600/2-76-190, September, 1976.

20. Letter quote from Les Lorned, Imperial Tank Company, San Antonio, Texas, June 13, 1980.

21. Specification/Information Brochure, Corrosion Resistant Linings and Coatings, Corrosioneering, Inc., Grafton, Ohio, received June, 1980.

22. Soil Survey of Travis County, Texas, Soil Conservation Service, U.S. Department of Agriculture, June, 1974.

23. Meteorological Data for Austin, Texas, Station No. 13958, as reported from the Municipal Airport, National Oceanic and Atmospheric Administration. U.S. Department of Commerce, 1978.

24. Water Evaporation Studies, In Texas, Bulletin 787, Texas Board of Water Engineers and the U.S. Department of Agriculture, November, 1954.

25. Moorman's Brochure, Multi Wrap Automated Scraper Systems, Moorman Manufacturing Company, Quincy, Illinois provided 1980.

26. Sweeten, John M. and William S. Stevens, Flush Systems for Manure Removal in Southwestern Swine Buildings, Texas Agriculture Extension Service, The Texas A&M University System, April, 1978.

27. ASAHI/American Brochure, Corrosion Resistant Thermoplastic Valves, Medford, Maine, June, 1979.

28. Personal Communication--Dr. Ed L. Fulton, Tarleton State University, Stephenville, Texas, December, 1980.

29. Jewell, et. al., Anaerobic Fermentation of Agricultural Residue: Potential for Improvement and Implementation, Springfield, Virginia, National Technical Information Service, 1978.

30. Fulton, Edward L., Methane Generation from Animal Waste, Center for Energy and Mineral Resources, Texas A&M University, Tarleton State University, U.S. Department of Energy, June, 1980.

31. Sievers, D. M., James R. Fischer, and Charles D. Fulhage, Swine Waste Digester at the University of Missouri, Columbia, University of Missouri, Columbia, Agricultural Experiment Station, August, 1978.

32. Forest, T. H., Mixing for High-Rate Digestion, Advances for Sewage Treatment Design, Manhattan College, 1961.

33. Fischer, J. R. et. al., Design and Operation of a Farm Anaerobic Digester for Swine Manure, Transactions of the American Society of Agricultural Engineers, Vol. 22, No. 5, 1979.

34. Duckworth, G. L. and J. H. Geddes, "Natural Gas Desulfurized by the Iron-Sponge Process," reprint from The Oil And Gas Journal, September 13, 1965 edition.

35. Taylor, D. K., "How to Desulfurize Natural Gas," reprint from The Oil and Gas Journal, November 5 and 19, and December 3 and 10, 1956 editions.

36. Iron-Sponge Price List of Connelly-GPM, Inc., Chicago, Illinois, January, 1981.

37. Personal Communications, J. Warrington, Franco Equipment Company, Dallas, Texas, January, 1981.

38. 1980 Concrete Reinforcing Steel Institute Handbook, CRSI, Chicago, Illinois, 1980.

39. Personal Communication, J. Williard, Dove Plastic Manufacturing, Inc., Austin, Texas, January, 1981.

40. Personal Communication, Farrell Angel, Cameron, Texas, December, 1980.

41. Personal Communication, James Fischer, University of Missouri, Columbia, Missouri, January, 1981.

42. Personal Communication, Operator, Samsom & Sons Dairy, Webberville, Texas, January, 1981.

43. J. R. Fischer, et. al., "Producing Methane Gas from Swine Manure in a Pilot-Size Digester," Trans of ASAE, Vol. 22, No. 2, p. 370-374, 1979.

44. KOEHLER Liquid Cooled Gasoline, LP Gas, Natural Gas, 7.5 KW Set Brochure, The Koehler Company, Koehler, Wisconsin 53044.

45. S. Neyeloff and W. W. Gunkel, "Performance of a CFR Engine Burning Simulated Anaerobic Digester's Gas, 1980 ASAE National Energy Symposium Proceedings, No. 12, pp. 324-329.

46. Hashimoto, D. G., P. R. Chen, and R. L. Prior, "Methane and Protein Production from Animal Feedlot Wastes," Journal of Soil and Water Conservation, 1979, 34:16-19.

47. Lindley, J. A. and H. J. Hirning, Phase I Design & Analysis Report, DOE Contract #DEEC-01-08CS-40377.

48. Industrial Fermentations, Vol. I and II, L. Underkofler and R. J. Hickey, Editors, Chemical Publishing Co., NY. 1954.

APPENDIX

SumX Corporation

07 November 1980

Mr. Harvey Davis
Executive Director
Texas Department of Water Resources
Capitol Station
Austin, Texas 78711

Dear Mr. Davis:

SumX Corporation is under contract with the United States Department of Energy (DOE) and the Texas Energy and Natural Resources Advisory Council (TENRAC) to demonstrate the feasibility of producing and utilizing methane gas produced from swine manure as an alternative energy source. The confined feeding swine operation to be used in this demonstration project is the Del Valle Hog Farm located just east of Highway 71 - Onion Creek bridge in Travis County.

At the present time, Mr. Dan Berdoll, owner/operator of the Del Valle Hog Farm holds a "Certificate of Registration of a Site for Commercial Swine Production Waste Control Facilities" issued under provisions of Articles 7621d-1 and 4477-7, Vernon's Texas Statutes, by the former Texas Water Quality Board. Construction and operation of this proposed demonstration project will result in a modification to Mr. Berdoll's current waste management program.

Currently, Mr. Berdoll, in compliance with the Certificate of Registration, collects swine manure in a large concrete holding tank underneath slotted feeding floors. Liquids from the tank are drained to a 0.85 acre-foot evaporation pond and solids are pumped from the tank periodically for land spreading on grazing lands. Under the demonstration project, the liquid manure from the concrete tank will be removed daily and loaded into an anaerobic digester for waste stabilization and methane production. The stabilized waste will be discharged to a new waste retention pond adjacent to the existing evaporation pond. This new waste retention pond is designed to contain greater than one-year's production of stabilized waste considering environmental factors.

1300 E. Broker Ln. • P.O. Box 14864 • Austin, TX 78761 • (512) 835-0330

Additional information is enclosed for your review which more fully describes swine feeding operation and the proposed modifications. Soil samples will be collected from the proposed site of the new waste retention pond and analyzed for particle size distribution and Atterberg limits. These results will be forwarded to your office when available. If additional information is needed for your files, please call or write.

Sincerely,

David Malish

David A. Malish, P.E.

DAM:kf

Enclosures

SUPPLEMENTAL INFORMATION DESCRIBING PROPOSED MODIFICATIONS TO DEL VALLE HOG FARM WASTE MANAGEMENT FACILITIES

Description of Existing Facilities

Mr. Dan Berdoll operates a confined sow farrow-to-finish swine facility near Del Valle, Texas. The general location of this facility is shown in Figure 1. At this facility 800 to 1,000 head of swine, weighing approximately 100,000 pounds, are fed daily in the finishing pens. The swine production facility includes four segregated operations which are breeding and gestation, farrowing, nursery, and finishing.

The breeding and gestation pens are located in covered barns with sloped concrete slab floors. These slab floors are cleared periodically, but no attempts are made to collect and/or remove the manure in these pens.

The farrowing pens are raised above a concrete slab floor which is washed daily. The manure slurry gravity flows through a 10" plastic pipe to an existing 0.85 acre-foot evaporation pond.

The nursery unit and the finishing unit are constructed with concrete slotted floors above a 20' x 215' concrete liquid manure pit. The liquid level in the pit is maintained approximately 6" below the top of the tank by a liquid overflow drain system designed to gravity drain excess liquids to the evaporation pond. Solids are periodically pumped into an irrigation system for spreading on approximately 10 acres of Bermuda. Liquids from the evaporative pond are also used for irrigation as necessary.

Facilities for the demonstration site will include a concrete anaerobic digestion system and a new waste evaporation/retention pond. The new waste retention pond will be located adjacent to the existing pond and is designed to provide approximately 1.5 years of storage of digester effluent

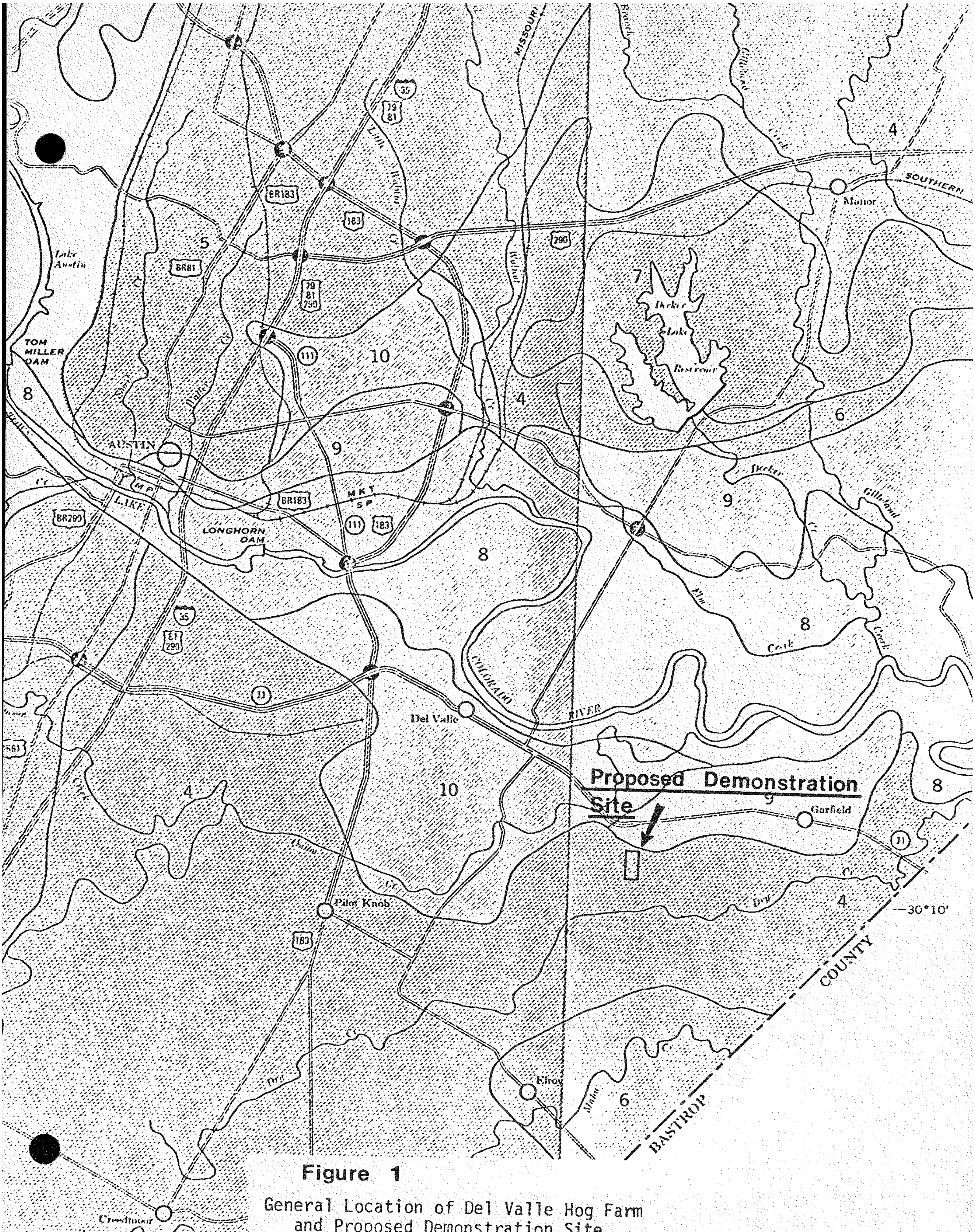


Figure 1

General Location of Del Valle Hog Farm and Proposed Demonstration Site under normal environmental conditions. This pond will have a surface area of approximately 16,000 square feet and a depth of 8 feet. A big gun sprinkler system will be permanently provided with the system for waste management flexibility. Effluent will be periodically removed from the pond for irrigation on coastal Bermuda or milo as necessary. The site has access to over 50 acres in the immediate area of the facility on which effluent can be applied. The new waste retention pond is situated such that it will not receive natural runoff.

Preliminary soils information for construction of the facilities was obtained from the soil survey for Travis County as provided by the U.S. Soils Conservation Service. Figure 2 shows the approximate location of the proposed demonstration site and Sheet 77 of the Soil Survey maps. This soils map indicates that the soils in the area are of the Houston Black series which are described by the U.S. Soils Conservation Service as follows:

> The Houston Black series consists of deep, moderately well drained clay soils. These soils have developed in calcareous marls, alluvial clays, and chalk, under a prairie of tall grasses. Slopes are smooth and single or complex; the range is from 0 to 8 percent.
>
> In a representative profile, the surface layer is very dark gray clay about 24 inches thick. The next layer is dark-gray clay that reaches to a depth of about 38 inches. The next lower layer, to a depth of about 80 inches, is grayish-brown clay. The underlying material, to a depth of 104 inches, is mottled clay.
>
> These soils crack when dry and are very slowly permeable when wet. The available water capacity is high.
>
> Houston Black clay, 1 to 3 percent slopes (HnB). This gently sloping and gently undulating soil occupies smooth ridges or foot slopes. Slopes are both single and complex. Areas range from long and narrow to broad and irregular in shape and from 20 to 150 acres in size. This soil has the profile described as representative of the series.

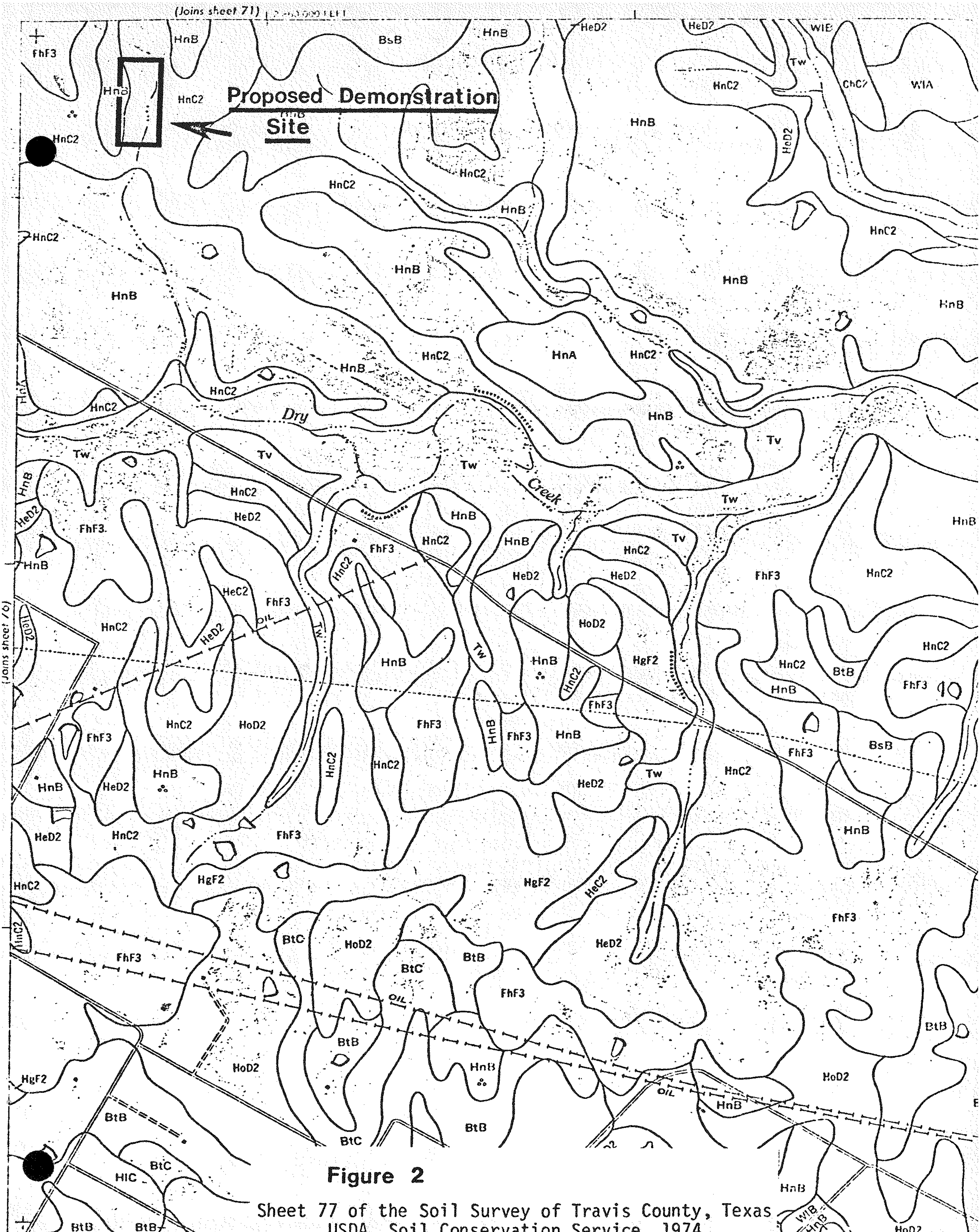


Figure 2

Sheet 77 of the Soil Survey of Travis County, Texas
USDA, Soil Conservation Service, 1974

The hazard of erosion is moderate. In a few areas erosion is caused by runoff from higher lying adjacent soils.

This soil is well suited to cultivation. It is also well suited to growing native range grasses.

Houston Black clay, 3 to 5 percent slopes, eroded (HnC2).

This gently undulating soil occupies areas that are mostly long and narrow. Areas of this soil range from 25 to 100 acres in size.

This soil has a surface layer of dark-gray clay about 30 inches thick. The next layer, to a depth of 70 inches, is gray clay that has yellowish mottles in the lower part.

The hazard of erosion is moderately severe. Most areas are gullied and rilled. Gullies, stabilized into parabolic shapes, are 10 to 20 feet wide.

This soil is suitable for crops, but requires careful management to control erosion. It is well suited to improved pasture, hay, or native grass range.

Field observations confirm that soils in the immediate area of the demonstration site are of the Houston Black series.

Physical characteristics of the Houston Black series as reported by the U.S. Soils Conservation Service are shown in the following table.

SOIL CHARACTERISTICS OF PROPOSED DEMONSTRATION SITE ACCORDING TO U.S. SOIL CONSERVATION SERVICE, SOIL SLURRY OF TRAVIS COUNTY

MAP SYMBOL	MAPPING UNIT	% PASSING NO. 200 MESH SIEVE	ATTERBERG LIMITS: Liquid Limit (%)	Plasticity Index
HnB	Houston Black Clay, 1-3% Slope	90-98	67-69	41-49
HnC2	Houston Black Clay, 3-5% Slope			

These physical characteristics indicate that this soil can be used for construction of the waste retention pond and adequately control seepage of contaminated waste water into ground water. This physical cahracterization will be field verified through analysis of samples collected from the immediate area of the proposed site.

TEXAS DEPARTMENT OF WATER RESOURCES
1700 N. Congress Avenue
Austin, Texas

November 19, 1980

Mr. David A. Malish, P.E.
SumX Corporation
P. O. Box 14864
Austin, Texas 78761

Dear Mr. Malish:

Re: Del Valle Hog Farm, Registration No. 20289

We received your letter dated November 7, 1980 concerning modifying Del Valle Hog Farm Waste Management facilities. The primary purpose of the modification is to conduct a U.S. Department of Energy and Texas Energy and Natural Resources Advisory Council demonstration project on the feasibility of producing and utilizing methane gas produced from swine manure as an alternate energy source. Under the demonstration project, liquid manure from the existing concrete tank located underneath the slotted feeding floors will be removed daily and loaded into an anaerobic digester for waste stabilization and methane production. The stabilized waste will then be discharged to a new waste retention pond to be constructed adjacent to the existing evaporation pond. This new waste retention pond is designed to contain greater than one-year's production of stabilized waste considering environmental factors.

Based on the information you have submitted, it is our opinion that no changes in the current registration is necessary, at this time. We are, however, requesting that prior to using the new retention facilities, you submit to the Department the results of soil samples tested. Enclosed please find the requirements and acceptable parameters for pond lining on confined feeding operations.

Thank you for your concern in this matter. If we can be of service, please call on us.

Sincerely yours,

A. E. Richardson

A. E. Richardson, P.E.
Director
Permits Division

JG:dg
Enclosure
cc: TDWR District 3

P.O. Box 13087 Capitol Station • Austin, Texas 78711 • Area Code 512/475-3187

SPECIAL PROVISION FOR POND LINING ON CONFINED FEEDING OPERATIONS

(Includes swine, poultry, dairy operations and beef cattle)

Wastewater retention facilities shall be constructed in clay soils or lined with suitable materials to adequately control seepage of contaminated wastewater into ground waters which are acceptable for use as domestic or livestock water supply. The permittee shall obtain representative samples of the soils forming the bottom and sides of the holding pond. These soil samples shall be tested for the following parameters:

a) Percent passing a No. 200 mesh sieve;
b) Atterberg limits (liquid limit, plastic limit and plasticity index)

Acceptable parameters for a soil to be utilized as a liner shall be more than 30% passing a No. 200 mesh sieve, liquid limit greater than 30%, and plasticity index greater than 15. The results of all tests shall be submitted to the Department for review. In the event that a soil analysis different from that described above is desired to be used by the permittee, the proposed method of analysis shall be submitted to the Department for approval prior to implementation.

SumX Corporation

12 December 1980

A. E. Richardson, P.E.
Director
Permits Division
Texas Department of Water Resources
Capital Station
Austin, Texas 78711

Reference: Del Valle Hog Farm, Registration No. 20289

Dear Mr. Richardson:

Pursuant to your request in a letter dated November 19, 1980, we have performed the necessary soils test on material samples taken from the bottom of the recently constructed retention pond. A description of the construction and intended use of that retention pond was previously presented to you in a letter dated November 7, 1980.

The analytical results on the two soil samples as determined by Snowden & Meyer, Inc. of Austin, Texas are attached. These results are consistent with the requirements and acceptable parameters for pond lining on confined swine feeding operations as identified by the Texas Department of Water Resources.

I appreciate your attention and assistance with a proposed waste handling modification. If you have any questions or need additional information, please call or write.

Sincerely,

D.K. Raley

D. K. Raley

DKR:jt

Attachment

1300 E. Braker Ln. • P.O. Box 14864 • Austin, TX 78761 • (512) 835-0330

SUMMARY OF LABORATORY TEST RESULTS

Job Name: Retention Pond
Job No.: 4264

Sample #	Description	M.C.	Lw	Pw	Iw	-#200 (%)	Classif.	qu	
1	clay, green		70	21	49	97.06	CH		
2	clay, brown		62	23	39	70.88	CH		

NOTES:

M.C. = Moisture Content in place (%)
Lw = Liquid Limit
Pw = Plastic Limit
Iw = Plasticity Index
Classif. = Casagrande Classification System

qu = Unconfined Compressive Strength (tons per square foot)