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A FARM SCALE ANAEROBIC DIGESTER PHASE 1. CONSTRUCTION START UP AND OPERATION

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A Farm Scale Anaerobic Digester
Phase 1. Construction Start Up and Operation

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1.0 INTRODUCTION

Increasing energy costs and the concentration of livestock production, combined with the needs for energy on the farm and to reduce the environmental problems caused by the disposal of animal wastes, made it logical to explore the usefulness of the anaerobic digestion process. The construction of a farm scale anaerobic digester was the logical outcome of research which suggested that the production of biogas from livestock manure was technically, although not necessarily economically feasible. The economic question of whether the net energy yield when combined with the environmental benefits from the digester would justify the construction and operating costs can only be properly evaluated through construction and operation of a farm system. The usefulness of digesters depends to a large part on the labour requirements as well as the technical expertise required for operation. Comparisons with Europe, Asia and Africa (Lapp et al, 1975), where weather and labour conditions are different from the North American situation are only helpful to a limited extent. The success of a digester on a North American farm could not be predicted without practical experience at the farm level.

In the fall of 1977, Agriculture Canada awarded a research contract to John Fallis an Ontario farmer for the construction and operation of an anaerobic digester to process the manure produced by the swine on the farm which he and his father operate.

The purpose of this report is to describe the basic design and construction features of this digester and review the operational procedures and problems involved in this particular farm scale operation.

2.0 DESCRIPTION OF DIGESTER

2.1 Sizing

The two man operation at the Fallis Farm is a 95 sow, farrow to finish operation. An estimated 7,000 L of liquid manure are produced daily, without the addition of water to dilute the manure prior to loading the digester. Selection of a suitably sized digester was based upon a fifteen day retention time.

Figures for the volume of manure produced were adopted from the Canada Animal Manure Management Guide, Agriculture Canada Publication. 1534.

2.2 Physical Details

The digester was constructed of reinforced concrete employing the techniques commonly used for concrete farm silo construction. The digester (Figures 1 and 2) is circular with a flat bottom and conical roof, with an internal diameter of 6.1 m and liquid height of 3.7 m which gives a total operating volume of 107 m^3 (Figure 3). Rubber waterstop seals were installed at the roof and bottom construction joints (Figure 4) to provide a suitable seal and allow for operation at pressures up to 2.5 kPa.

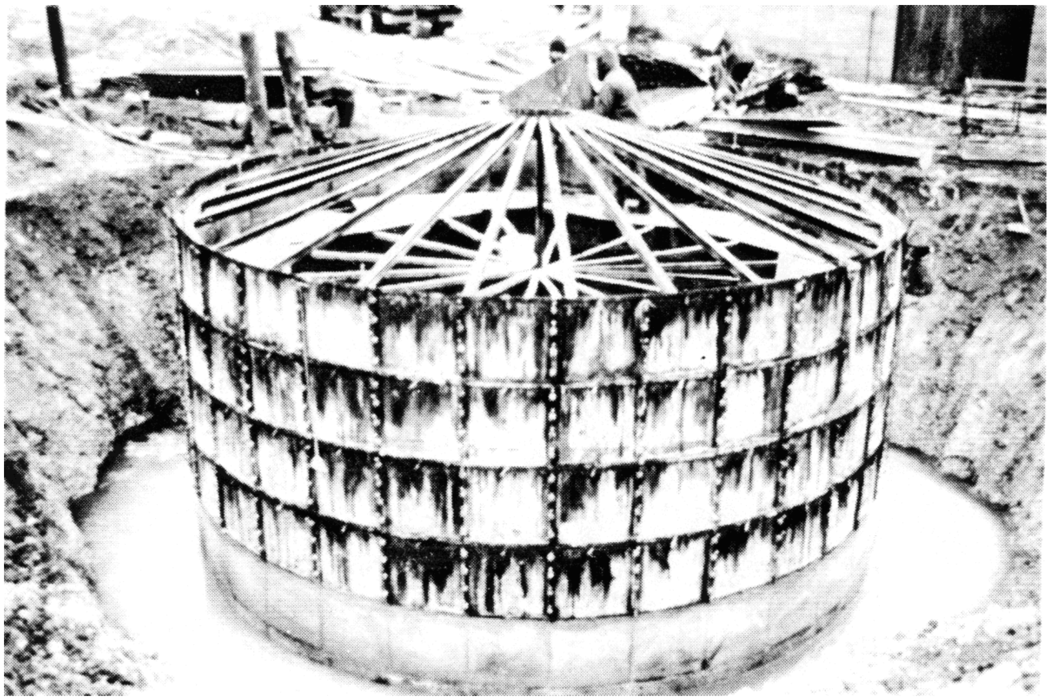

Figure 1. Construction of digester walls showing forms and removable roof form supports.

Figure 2. Placement of roof forms prior to installation of reinforcing material and pouring of roof.

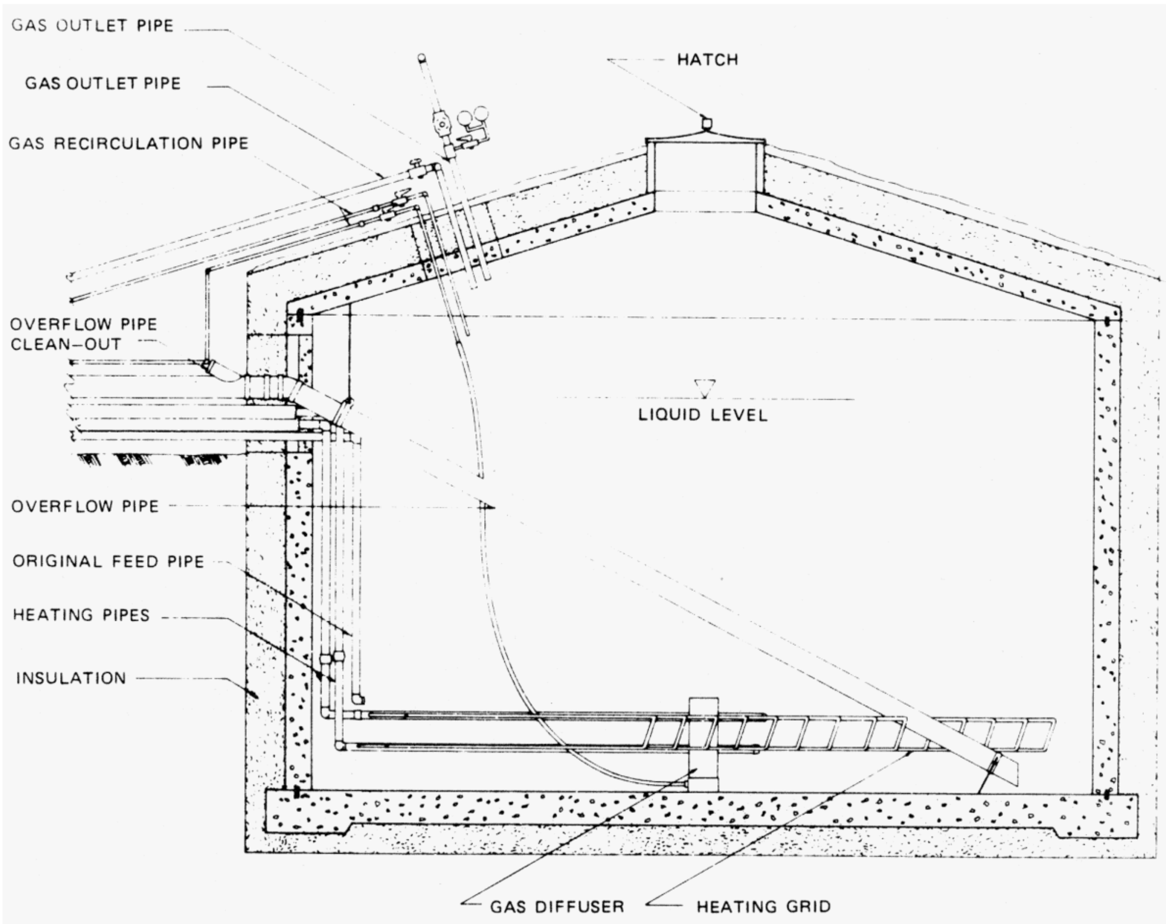

Figure 3. Interior of tank (elevation)

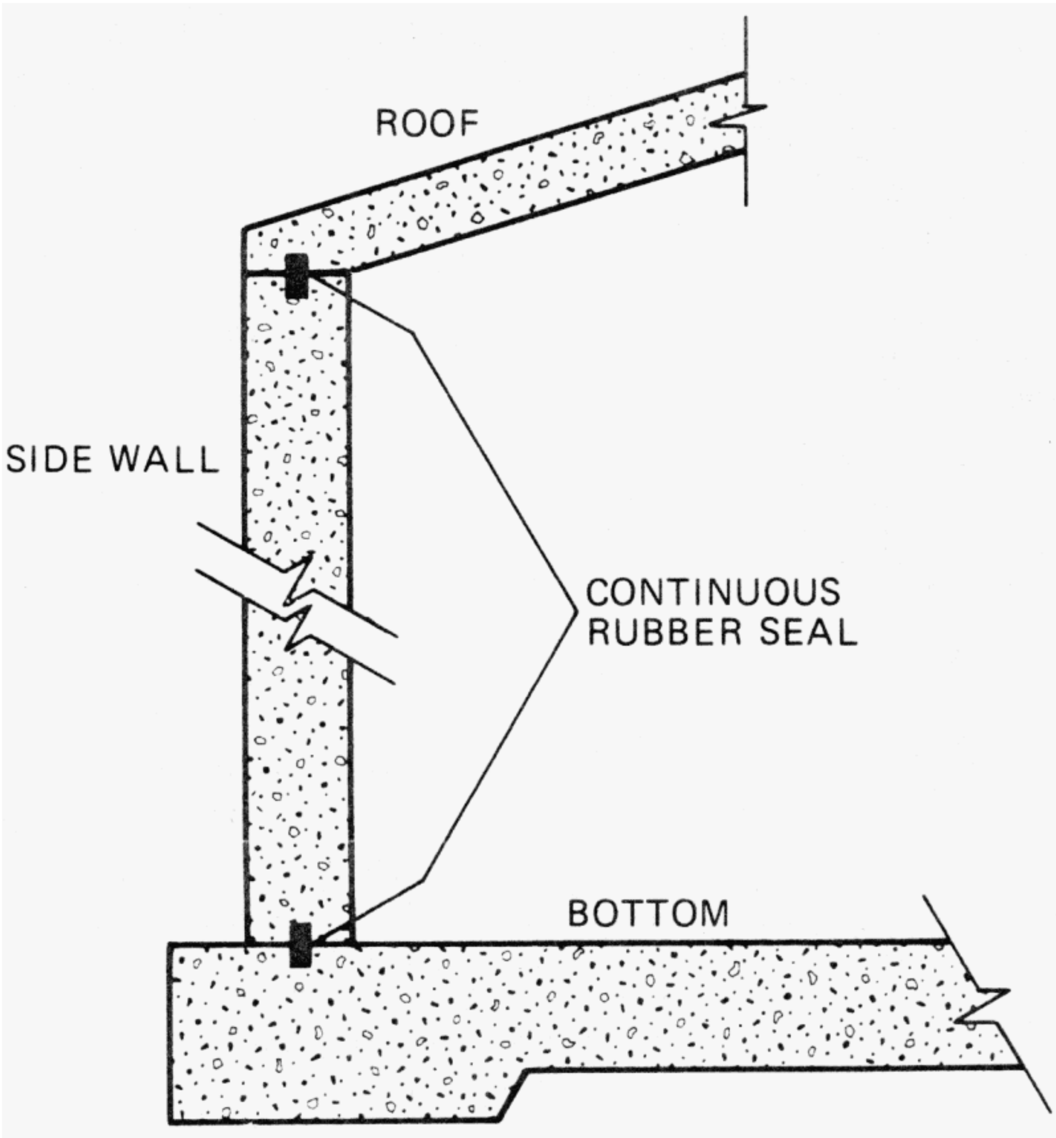

Figure 4. Construction joint with continuous rubber waterstop seal

To provide better insulation, thus reducing the energy costs of maintaining the digester at an operating temperature of 35°C, the unit was constructed below grade with only the roof above ground. Thermal losses were further minimized by adding poly-styrene insulation to a thickness of 50 mm, 150 mm and 200 mm on the bottom, sides and roof respectively. A hinged 600 mm diameter hatch is located on the roof of the digester to provide access to the interior. This hatch is provided with a circular rubber gasket and a mechanical locking device to ensure a tight seal under operating conditions. Through the roof of the digester are four connectors which serve as an outlet for gas removal to a suitable user site, an inlet and outlet for the gas recirculating mixer and an outlet for the pressure regulator. This regulator is a liquid sealed manometer which allows the biogas to vent to atmosphere while still sealing and maintaining pressure within the digester.

2.3 Heating System

To achieve and maintain the required elevated temperature in the digester, a heating grid was installed 50 mm above the floor. This grid is made of nominal 25 mm black iron pipe arranged in a series of 14 return loops. Each loop is approximately 8 m long and is connected to a main 50 mm header pipe (Figure 5). This header is connected to the 142,000 kJ/h propane fired boiler system (Slant Finn G175-P) located in the adjacent boiler building 7 m from the digester (Figure 6). A glycol mixture is used as the heat transfer fluid. A controller (Honeywell T954) incorporating a filled bulb sensor is used to control the heating cycles of the boiler. A duplicate control system was also installed to serve as a back-up in case of breakdown. This boiler system includes a surge tank, continuous duty circulating pump, thermal overload protector and two pressure temperature indicators.

A strip chart recorder was used to record the temperatures within the digester (Honeywell Electronic 16). The recorder was also located in the boiler building a 2.5 m x 3 m wooden frame structure with a metal exterior.

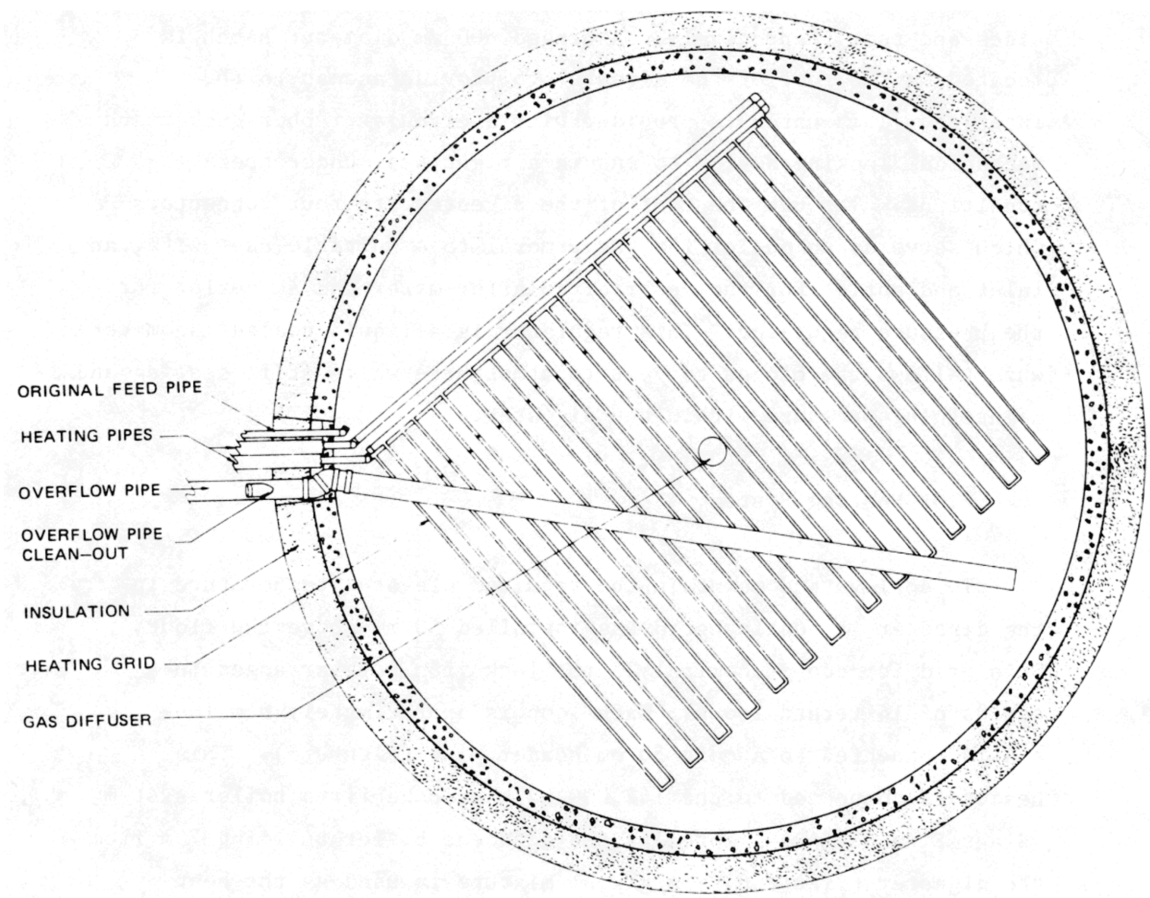

Figure 5. Interior of tank (plan)

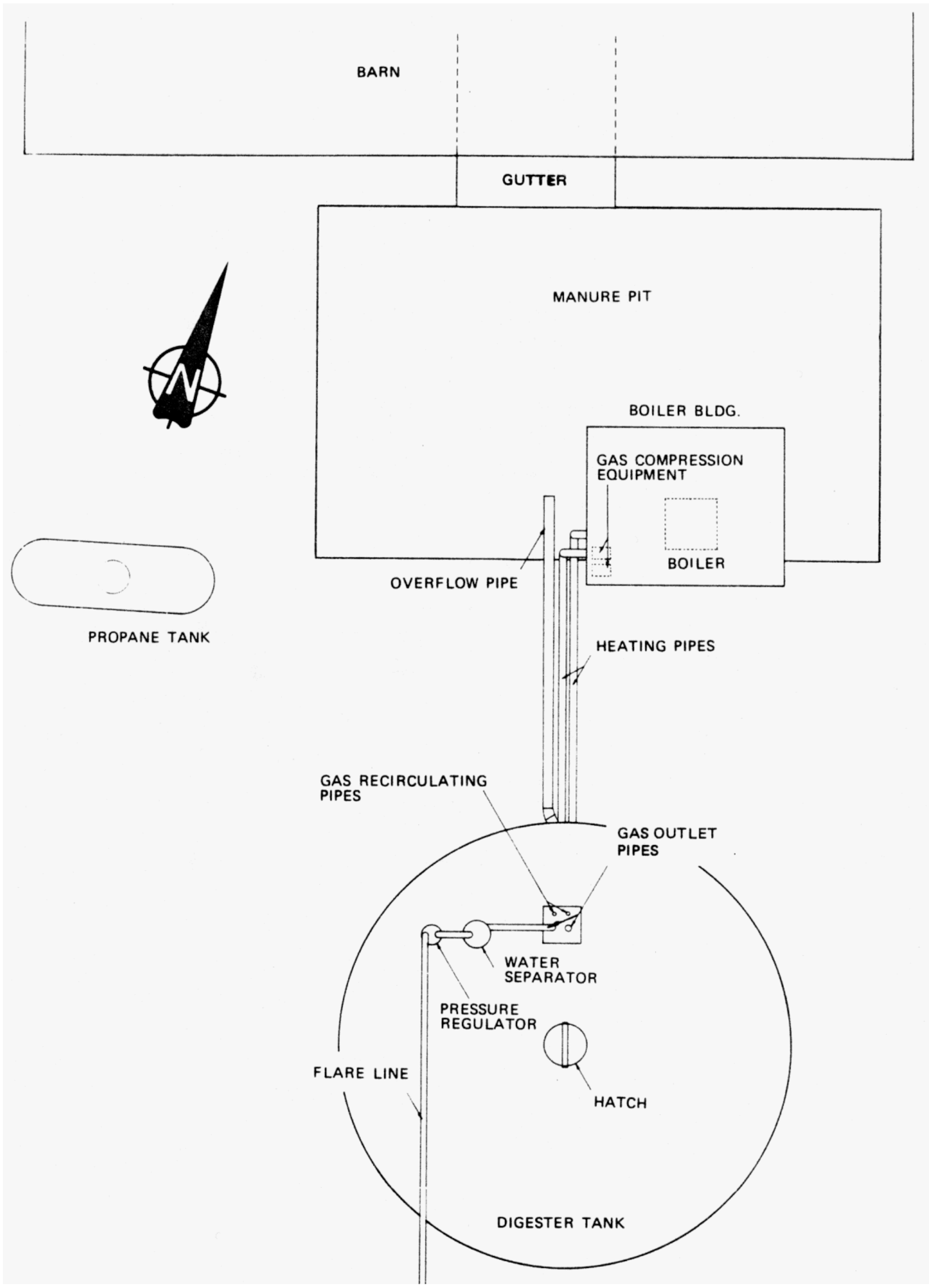

Figure 6. Equipment layout excluding manure pump and feed line.

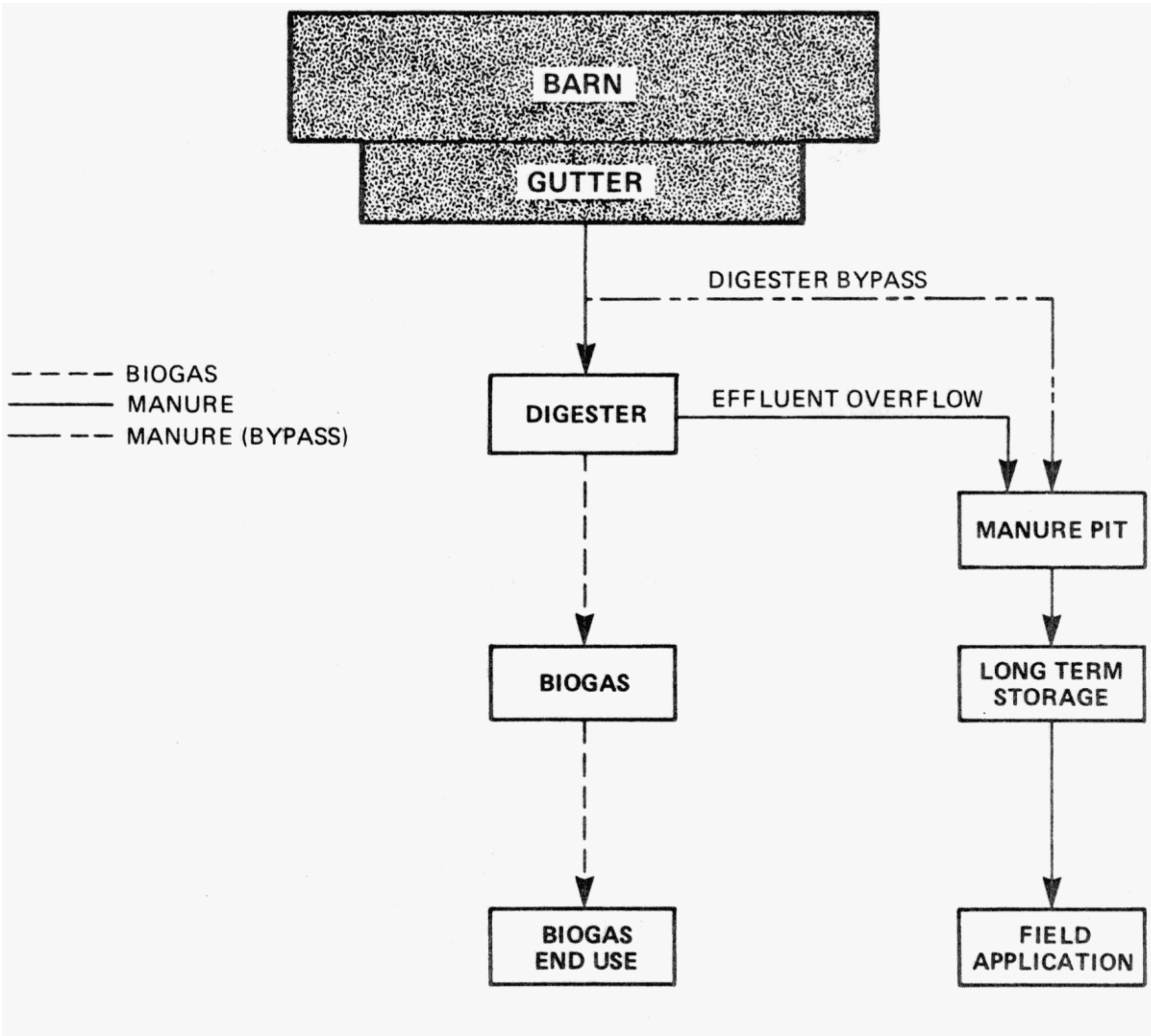

Figure 7. Flow schematic (manure-biogas)

2.4 Liquid Level and Mixing

Reaching diagonally upwards from the vicinity of the heating grid to the side wall plate is a 15 cm dia. pipe. This overflow pipe maintains the liquid height in the digester at 3.7 m. Manure is fed through a 5 cm dia. pipe running vertically from the side wall plate to a point adjacent to the heating grid. A Myers 0.6 kW centrifugal pump is used to transfer the liquid manure from the barn gutter to the 5 cm feed pipe and into the digester (Figure 7). Mixing within the digester is accomplished using an "aerator" (RAMCO 20 cm) which is basically functioning as a gas lift pump. Gas taken from the head space above the liquid manure is recirculated via a 0.375 kW compressor (Conde 3SCC) back to the "aerator". This flow of gas lifts liquid in the tube and spins propellers in the "aerator" which permits the continuous mixing of the digester contents. Thorough mixing of the manure is essential to provide temperature equilibration in the digester and to ensure maximum nutrient availability to the microorganisms.

3.0 OPERATING PROCEDURES

3.1 Initial Start-up

When construction work was completed, approximately 50,000 litres of water was added to the digester, providing enough liquid depth to cover the heating grid and the boiler sensors. Heating of this water was commenced using the propane fired boiler system. This initial heating period lasted four days with the boiler system running continuously to achieve a 35°C temperature. To ensure anaerobic conditions the head space in the digester above the water was purged for one hour using the exhaust from the farm's diesel tractor. Outlets on the roof of the digester were sealed, the manometer system was set to 15 cm of H_2O and the digester was considered ready to accept manure.

Partial filling with water, heating and then adding manure was the initial start up procedure adopted to ensure a rapid start to the digestion process. Experimental work at the University of Manitoba (Lapp et al, 1975) indicated that this start up procedure provided the best results. Before daily operations could take place using the manure from the barn gutter a source of feedstock was required as seed material to start the digester. This seed was taken from the bottom of the adjacent manure pit at the rate of 1000 L/day. Agitation of the digester contents at this time was performed daily only when feeding.

Initial planning of the daily operations took into account the fact that this particular operation was to be a farm scale system. Discussions with the farmer indicated that approximately one hour per day could be allowed for these duties. Normally this would be done on a regular basis in the morning after the barn chores were completed.

3.2 Proposed Daily Operations

The daily operations were to include transferring manure to the digester, checking the temperature and manometer as well as observing the operation of the agitator and the unloading tube. Daily operation on a regular basis was not satisfactorily achieved in the first 28 months of operations. Various breakdowns, blockages and delays prevented the digester system from achieving its optimum daily loading and resulting gas production rates. Section 5.0 of this report will review the various problems encountered and some of the solutions attempted to achieve a stable daily operation.

4.0 DIGESTER PRODUCTION RATES

4.1 Biogas Production

A residential natural gas meter (Rockwell Series 250) was installed in the gas outlet line three months after the digester had been started. Monitoring of this meter over a 10 day period indicated biogas production rates just below 70 m^3/day.

4.2 Chemical Analysis

Chemical analysis was conducted on manure and effluent samples by the Ontario Region Chemical Laboratories of Environment Canada in Ottawa. Test 1 was conducted three months after startup, and test 2 samples were taken four months after start up. These results are shown in Table 1. Additional readings of pH were done at the digester site with a laboratory pH meter (Fisher Accumet 120). Further detailed testing was not continued due to operational problems with the digester system.

Table 1. Chemical Analysis on Manure and Digester Effluent

	Test 1		Test 2	
	Manure Inlet	Effluent	Manure Inlet	Effluent
C.O.D. (mg/L)	63200	6760	56500	5900
T.S. (mg/L)	30300	7860	55800	7400
ALK (mg/L)	8140	5520	6960	7580
T.V.S. (mg/L)	20500	3810	40000	3700
pH	6.5	7.4	6.2	7.4

5.0 OPERATIONAL PROBLEMS

No major problems were experienced in the first three months of operation. This time period covered the initial heating of the water in the digester and the addition of manure at the rate of 1000 L/day. However, when the loading rate was increased to 3,600 L/day during the middle of the third month, a series of problems occurred. The first problem was with the compressor for the mixing system. A temperature gradient was detected in the digester. Because this indicated a lack of mixing action inside the digester the compresser was disconnected from the gas recirculating system and tested separately. No compression was occurring and upon inspection, i.e. dismantling the compressor, a build-up of corrosion was found between the steel rotor and the carbon vanes. This prevented the vanes from sliding freely in the rotor causing a loss of compression action and in turn decreased mixing of the digester contents. It was felt that the corrosive nature of the biogas was causing this build-up. The compressor was cleaned, reassembled and put back into service. Performance of the mixing system was adequate until the sixth month of operation when additional maintenance was required. A second problem related to the gas lift mixer system arose due to plugging of the gas diffuser pipe in the bottom of the mixer. This blocking, or partial blocking, of the gas diffuser resulted in increased back pressure in the gas line between the compressor and mixer and the subsequent activation of the by-pass pressure relief valve causing a cessation of mixing. The Conde compressor could not generate adequate pressure to clear the blockage when the safety relief valve was manually overridden. A 413kPa(60psi) portable compressor was finally used to clear the line and restore mixing.

Lack of agitation was believed to be partly responsible for another problem with the unloading system. During the fourth and fifth months a lag time of up to six hours was noticed between the feeding (loading) and unloading procedures. This delay was observed by the farmer during his daily monitoring of the digester operations. Failure of the digester's gravity overflow unloading caused a gradual increase in the volume of manure housed inside the digester which also reduces the volume of the head space above the liquid. Concern was expressed about the possibility of causing the roof to lift off the digester or to cave in due to negative internal pressure changes when the digester did unload.

This ongoing problem of unloading was believed to be due to the settling of solids at the bottom of the digester around the inlet to the unloading tube. Because of the inter-related problems of mixing and unloading the decision was made to shut down the digester in the sixth month and remedy the mixer problems. Overcoming the mixing problems would also alleviate settling and unloading problems. Removal of the mixer from the bottom of the digester was not an easy task because no allowance for maintenance had been made in the original design. There were no cables or chains in place to allow the unit to be removed and inspected. The digester had to be drained, vented and entered to manually remove the mixer. With the aid of suitable safety equipment, namely respiratory protection and safety harnesses, the digester was entered and the mixer removed. Examination of the unit showed that the outlet holes were plugged with a mixture of manure solids and hog hair bristles. After cleaning, the mixer was fitted with a cable system to allow for removal.

The seventh and eighth month of operation were spent on maintenance of various components at the site. The terminals of the temperature recorder were corroding. A cleaning and refurbishing had to be done at this time. Another component suffering from corrosion was the in line gas meter. Meter operation was impaired by corrosion build up on the internal components as well as the continual formation of condensate in the base. The gas recirculating compressor was also serviced at this time. Due to the various equipment problems and the fact that winter was starting, the decision was made to leave the digester empty and out of service for the three winter months.

Undiluted manure pumped directly from the adjacent manure pit was used to fill the digester in the twelfth month of operation. A submersible pump (Flygt 3085) was installed to replace the troublesome compressor-mixing system. It was still felt that a continuous mixing operation would eliminate the settling and cure the unloading problems. In addition to the continuous mixing, a modification was made to the unloading tube at the exterior of the digester wall. An elbow and cap were fabricated to allow a plumbing snake to be introduced down the unloading tube to the bottom of the digester in the event of a blockage. This snake would be used to break up any solids collecting in the tube. A polycarbonate lid (Lexan) was also fabricated and installed on the digester hatch to allow for observation of the mixing action at the digester surface.

This modified system worked continuously for approximately one month before the submersible pump failed. Installed with suitable cables, the pump was removed and shipped to the factory repair shop in Ottawa for repair. A bad bearing was diagnosed as the problem. No charge was made for the repair, but operating time was lost. Delays in the unloading cycle were again being experienced and a further modification to the unloading tube was made. Fabrication of a sealed end plate at the tube exit point above the manure pit allowed the unloading tube assembly to be flooded with water between each loading/unloading cycle. This flooding was done to prevent the possible drying out of the manure in the tube and prevent clogging due to caking of manure in the unloading tube. It was evident after a few weeks of operation that this modified procedure did not eliminate the problem and it was later abandoned.

During the next six month period the digester was operated intermittently. The submersible pump failed on two other occasions. One notable failure was due to the collection of hog hair on the main shaft between the lower bearing housing and impeller. This caused the main shaft to stall and mixing to cease. Still the mixing and unloading problems persisted and during the 19th month of operation the submersible pump was removed and replaced with a modified compressor system. The compressor was now equipped with phenolic blades and an "in-line" drip pocket and lubricator assembly. This technique of adding lubricating oil to the vanes of the gas recirculating compressor had been tried and proven successful at Pennsylvania State University (Persson 1979). Trouble free operation of the compressor over the following months indicated that the problem with this installation has also been solved.

As mentioned earlier, corrosion of various components at the digester site was common. Inside the boiler building the connections to the boiler controls and recording instruments were also corroded. This had to be attributed in part to the location of this building. Although it was convenient to place this building between the digester and barn, the location on top of the manure pit led the equipment to constant exposure from the various gases emitting from the pit. Corrosion caused numerous problems with the temperature recorder and would have led to eventual failure of the boiler control system. The copper lines for the controller sensors eventually rotted off due to corrosion, however polyvinyl covered thermocouple wires exposed to the same conditions were in excellent condition. Corrosion was quite evident in the hatch area and at the gas outlet pipe connections on the top of the digester.

Very little work was done at the digester site during the winter of the twentieth to twenty-fourth months. Without suitable enclosures and shelter, working outside was difficult and the time commitment by the farmer to his animal operation had to be maintained. Because limited operation was attempted during those four months, the operation was reviewed and the decision made to undertake a major retrofit of the installation. The loading and unloading systems would be modified, the boiler building and contents would be relocated and various other changes were to be completed. After twenty eight months of operation the digester was to undergo a complete overhaul in order to solve the various problems that had been prevalent.

6.0 RECOMMENDATIONS

After 28 months of operation a number of recommendations can be made based on the farmer-operator's comments and experiences at this site.

In many cases, local subcontractors, plumbers, electricians, etc. may be hired to perform much of the initial construction and equipment installation. This will provide the farmer-operator with first hand knowledge about the digester and its basic operation from a person he knows and trusts. For casting of the concrete digester itself, it is preferable, because of potential leakage problems, to use a silo contractor experienced in digester work. Also the costs in both time and money can be cut by limiting the number of outside jobbers if local people have the required expertise. If possible, equipment should be purchased from local suppliers. This may be difficult for some specific pieces but much of the plumbing supplies, pumps and electrical equipment can be obtained locally.

The design of the digester and system accessories should provide for ease of accessibility for servicing of equipment without having to shut down the whole operation. All equipment and systems should be readily accessible for monitoring of performance and maintenance if required. Loading and unloading the digester appears to be a problem area, therefore, the larger the pipe sizes in these areas the better. Pipe diameters of at least 10 cm for the loading tube and 30 cm for the unloading tube are recommended. The loading tube should exit below the liquid surface of the digester and should be as free as possible from elbows and sharp bends. The digester feed stock should be thoroughly mixed before it is fed into the digester. This will ease the problem of pumping into the digester and it will also aid the mixing inside the digester by breaking up many solids that are present. Mixing inside the digester appears necessary. Without mixing, experience shows that a thick scum layer forms on the surface of the liquid and various solids in the manure can settle to the bottom of the digester. The scum layer prevents gas from escaping and solids can block the mixing apparatus causing it to fail.

Safety standards at the digester site should be maintained at a high level. Because the biogas is both toxic and explosive, extreme care should be taken when working in areas exposed to possible accumulations of biogas. No smoking signs should be prominent and displayed in all areas. Explosion proof switches, fixtures, and motors, should be installed in any area where biogas can possibly collect. Safety standards for utilization of digester gas such as CGAB105 and B149 are available from the Canadian Gas Association and should be reviewed and followed where applicable.

The digester site itself should be well maintained. Ditches, uncut grass, wood planks and scrap steel all present safety hazards of one form or another, thus good housekeeping is essential. Corrosion of various components at the digester site was common. Special attention should be paid to the choice of materials used for specific applications where exposure to the biogas is common. P.V.C. and polycarbonate materials should be used where possible. To avoid corrosion any instrumentation or controllers should be housed away from any source of biogas contamination.
These recommendations can only serve as guidelines to aid in the construction and operation of a farm scale digester.

7.0 CONCLUSIONS

The digester operation at Millbrook, Ontario provided Agriculture Canada through its contractor with "hands on" experience in the construction, maintenance and operation of a farm scale anaerobic digester. Total expenditures to install the digester and bring it into operation were $16,385. A breakdown of these expenses is outlined in Table 2.

Additional savings can be realized by employing local subcontractors and using local suppliers for various equipment and material purchases.

Daily operation of the digester was to occupy approximately one hour per day of the farmer-operator's time; however, major time commitments did occur when equipment malfunctioned or when operational conditions dictated a shutdown of the system. The major problem areas of mixing and unloading the digester on a regular basis were not completely solved and it was decided to refit and modify the digester. Subsequent reports will detail the operation and design modifications undertaken to upgrade this digester system.

Table 2. Cost Summary 1977/78

Description	($)
Site Excavation	581
Concrete work	
Hatches, etc.	
Materials and Labour	5382
Insulation of digester	
Materials and Labour	1930
Boiler assembly, Heating grid, controllers, etc.	
Materials and Labour	4549
Aeration System	
Materials and Labour	2377
Myers Pump	350
Water: delivered by truck	184
Electrical Supplies	
Materials, Labour and Inspection	757
Propane installation rental and	
353 gal. liquid propane	275
	16385

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