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BIOGAS PRODUCTION FACILITIES ON FARMS
- A 1985 Look At The Recent Experience -

by

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1.0 INTRODUCTION

Production of biogas by anaerobic digestion of organic materials is not new. The fact that combustible methane gas is produced by anaerobic digestion was recognized as early as the 1600's. The anaerobic process has been used since those times whenever energy was in short supply and for municipal sewage treatment in many countries.

The idea of on-farm production of biogas in Canada was first promoted in 1974 by Lapp et al as a method of energy self sufficiency. Momentum was sustained by significant increases in conventional energy costs. By 1978 both the federal and most provincial ministries of agriculture and energy were prepared to spend research dollars to determine feasibility of biogas technology utilization. The urgency was a response to demands from farmers for relief from escalating fuel costs.

It must be remembered that biogas is not as clean a fuel as natural gas or other liquid fuels. Biogas normally contains 60 - 70% methane (CH_4), 30 - 35% carbon dioxide (CO_2) and a number of other gases including water vapor, in small amounts. The existence of hydrogen sulphide (H_2S) in biogas is of concern because it can be very corrosive, especially in 'wet` gas. However, biogas can be burned in most gas-fired appliances and internal combustion engines when appropriate adjustments/ modifications have been made.

The anaerobic digestion of animal (including poultry) manure has a side benefit. The odor of the digester effluent is significantly reduced. This is a side benefit that cannot be overlooked as many Canadian animal producers are under significant pressure primarily from urban encroachment.

1.1 Study Objectives

This report is not intended as a "how-to" guide. Digestion system design parameters are well documented by: Lapp et al, 1978; Persson et al, 1979; Bartlett et al, 1980; Timbers and Marshall, 1981; MacDonald, 1982; Jewell et al, 1982; Pos et al, 1985; and particularly Parsons, 1984.

The primary objective of this report is to bring together and evaluate the on-farm experience of anaerobic digester users in Canada. Most (eight) of the farm-scale units are in Ontario, two are in Quebec and one each in PEI and Alberta. In addition a number of units in the NE United States were evaluated for comparison purposes and to extend the study group to include the simpler `plug-flow' design prevalent there on dairy farms.

Cogeneration, that is the burning of biogas to produce electricity, is a more urgent priority in the NE United States because of higher electrical energy costs than occurs in most of Canada.

Many Canadian anaerobic digesters were built on the premise that capital cost could be justified by the recovery of protein feed supplements from the digester effluent with electrical and/or heat energy providing a secondary revenue source. Anaerobic digesters reduce the volume of manure that must be stored by very little (2 - 5%), thus no storage avoidance cost can be considered. The digester effluent, whether separated or not, must be stored to permit effective use on cropland. The treatment does not make it suitable for discharge into watercourses.

The second objective is to recommend further research or field experimentation that should be undertaken to enhance or encourage anaerobic digester system designs for, or on Canadian farms. Economic viability must be the ultimate criterion upon' which installation is based. Few farmers can afford the luxury of a major investment for tax credit and/or social status alone.

2.0 TERMINOLOGY

For readers not familiar with the anaerobic digester and related terms a glossary is provided. See Section B.G. A simplified schematic of the anaerobic digestion process is provided as Figure 1. It is also imperative that the three basic types of digesters currently in use be described for reference purposes. See Figure 2 for schematic drawings.

2.1 Types of digesters

2.1.1

The tunnel type, or plug-flow type as it is often referred to, consists of a relatively long horizontal channel. See Figure 2a. The channel is usually of concrete with a flexible cover. The influent slurry is introduced continuously or intermittently at one end and the effluent is simultaneously discharged at the other end. The retention time (RT) is determined by loading rate, channel section, and channel length.

Theoretically the influent moves as a plug, thus the name. In practice, if slurry separation occurs or temperature differentials exist, plug flow is not likely to be continuous.

Slurry heating to maintain digester temperature is normally achieved by locating a black iron pipe heat exchanger in or near the floor or side walls of the tunnel. Digester heat losses are relatively high because of a high surface area to volume ratio. Forced mixing is usually not designed into the tunnel type system.

The tunnel system is working satisfactorily with high strength (high solids content) dairy manure in a number of installations in the NE United States.

2.1.2

The totally mixed digester commonly has a circular silo type configuration. While reinforced concrete is the most common digester tank material, other non corrosive materials are also suitable. Figure 2b shows a common digester configuration. The common design criterion is to have tank diameter equal tank height to minimize surface area to volume, and thus heat losses from the digester.

Digester elevation varies from completely below ground to completely above ground. Soil type and water table are two major factors in determining preferred elevation. It can be argued that the below grade installation is preferable to minimize

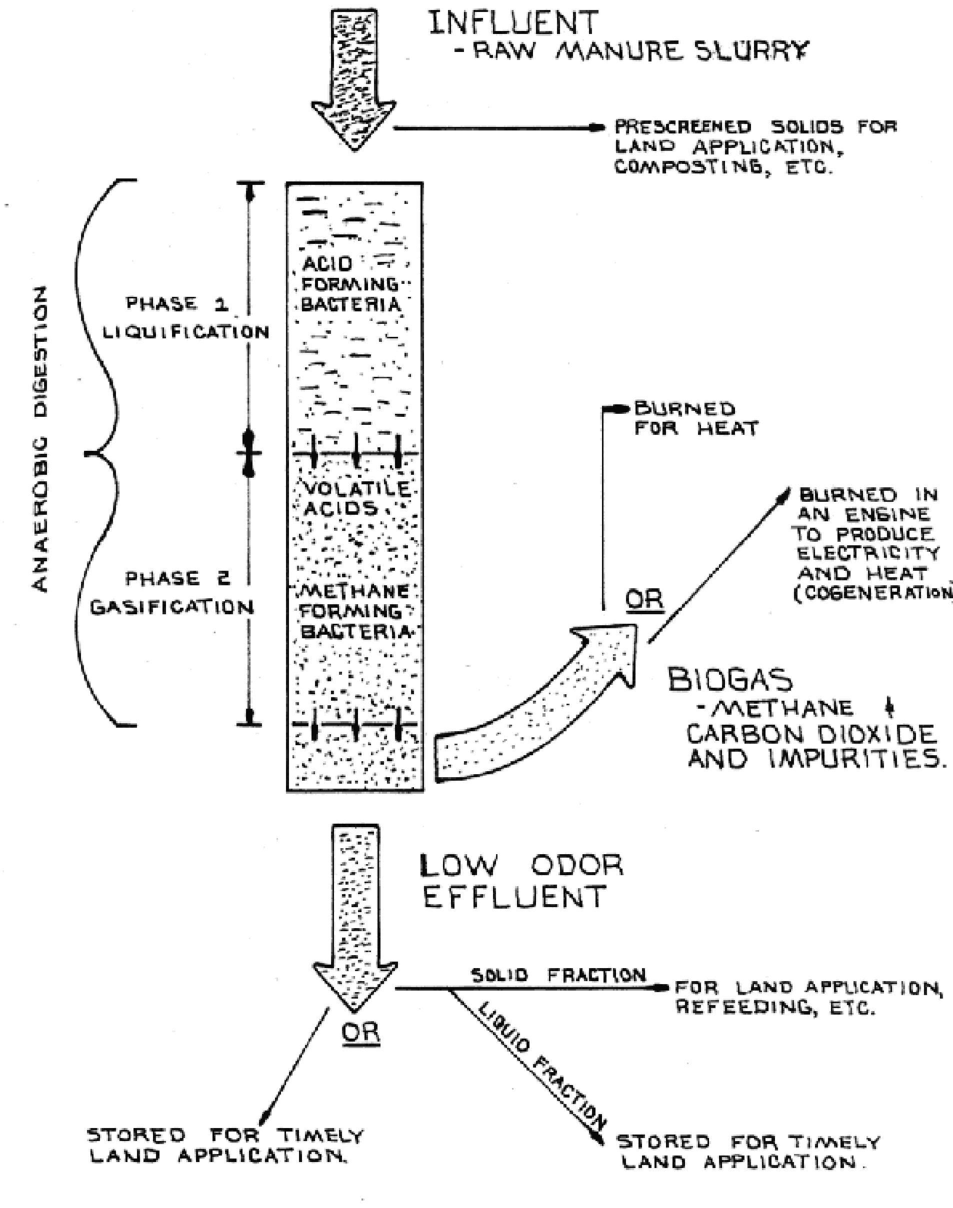

FIGURE 1: SIMPLIFIED SCHEMATIC OF THE ANAEROBIC DIGESTION PROCESS FOR BIOGAS PRODUCTION FROM ANIMAL MANURE.

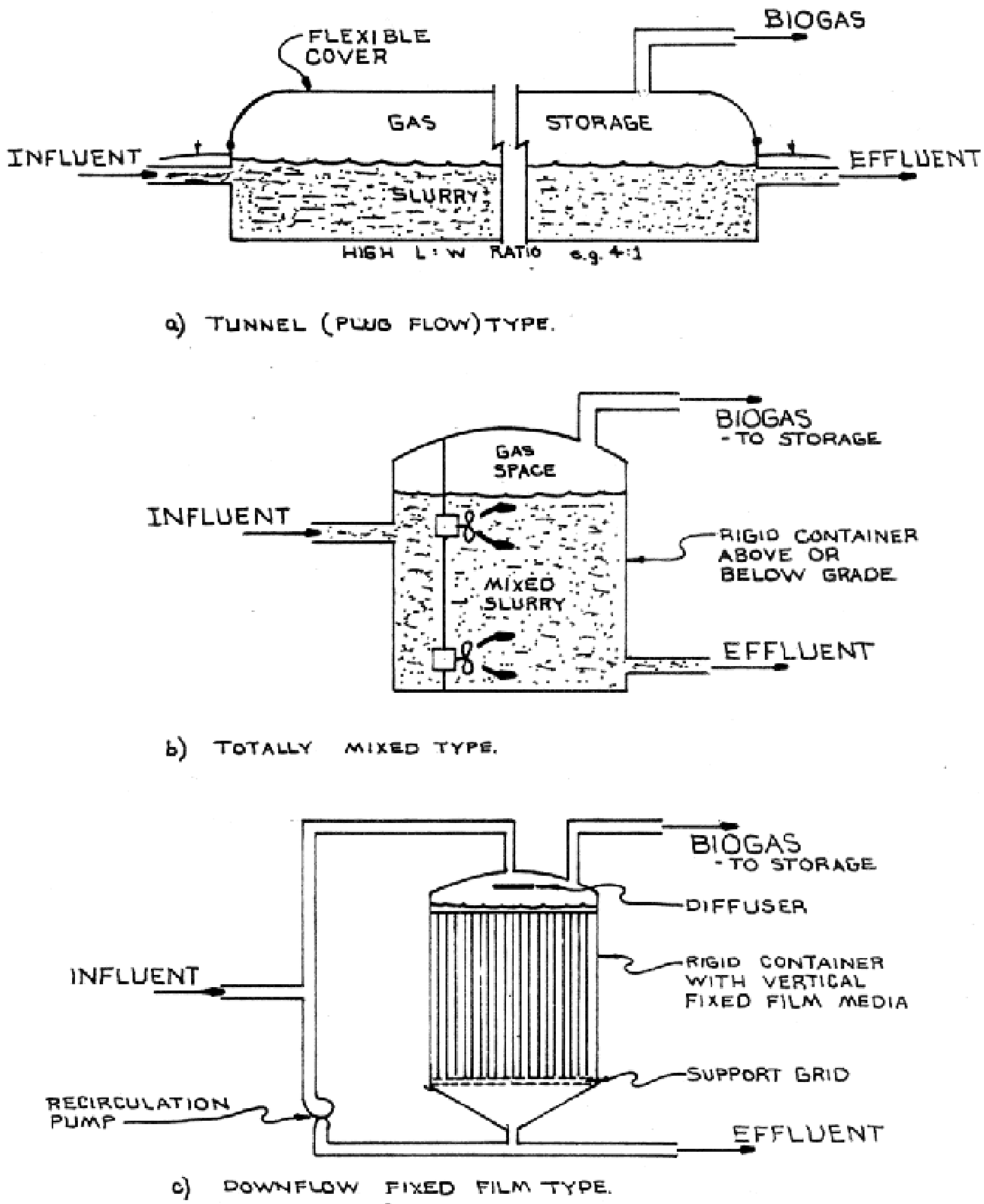

FIGURE 2: SCHEMATICS OF THE THREE COMMON TYPES OF ON-FARM ANAEROBIC DIGESTERS.

heat losses especially in colder climates. However, the relatively small cost of additional tank insulation should be balanced against access for possible sludge removal if desired. The other reason for keeping the digester low, as is the case with some tunnel types, is to permit gravity feed. However, gravity feed and gravity discharge, while highly desirable, are seldom attainable at one site, especially with a vertical digester configuration.

Since the influent liquid manure slurry must be properly mixed (prepared) the same pump can be used to intermittently charge the digester. The displaced effluent can move by gravity or be pumped depending on need/design for effluent processing or storage elevation.

As the type name implies, provision is made in the design to completely mix the digester contents, usually on an intermittent basis to minimize foaming and energy use. Methods of mixing are almost as numerous as the number of digester designers/ researchers. Vertical shaft paddle type mixers have been incorporated. They leave the relatively large motor and gear reduction mechanism exposed on top of the digester tank: for easy servicing. However, since the shaft exits the gas section of the digester tank, maintaining a gas seal has been of concern.

Other designers have utilized external liquid or gas pumps to re-circulate digester slurry or gas as a means of rolling the tank contents and to break up scum and prevent sludge buildup.

A third method is to utilize one or more submersible sewage sludge pumps suspended within the digester tank. Accessibility for pump service can be of concern with this arrangement as servicing would require complete system shut down. However, these pumps, while expensive, are designed for this service application: At present they are only available in relatively large sizes and require regular servicing if operated continuously.

Dissenters of the totally mixed digester system hasten to point out that the retention time (RT) is not consistent, because a portion of mixed slurry is displaced with each feeding - often once or twice per day. Jewell et al, 1982, for example, show better performance of tunnel digesters than totally mixed - with dairy manure.

The totally mixed digester can be divided into two compartments if desired to provide a two-stage digestion process. Persson et al, 1979, have developed a modified two-chamber totally mixed digester that should be effective in slowing down the discharge of recently introduced influent without adding significant cost to the digester system. They use gas miring which is flexible.

Most totally mixed digesters have gas headspace but no storage capability. Gas pressure regulation in the digester is of paramount importance to eliminate damage (lifting) of the rigid top. If the biogas is to be used, external provision must be made for temporary gas storage. Gas storage is relatively expensive and various types observed will be noted.

2.1.3

The fixed-film digester is the third type operating in Canada. The fixed-film concept was first developed by National Research Council of Canada and is described by Van den Berg and Kennedy, 1983: Timbers and Marshal, 1981: and Matt, 1984. A schematic drawing is included as Figure 2c.

The technology is similar to that of the totally-mixed digester with one major difference. The digester tank is filled with vertical 100 mm diameter PVC tubes with internal cross webbing. See Figure 3. The tubes and webbing have mechanically grooved surfaces - four grooves per mm. The vertical tube bundles are supported on a grid to provide for slurry movement below and gas space above. This fixed film media provides a surface area of 100 m^2/m^3 of digester for bacterial attachment. The purpose is to prevent bacteria 'wash out' and provide for a much higher specific gas ratio while reducing the RT.

The fixed film anaerobic digester can be significantly smaller than other digesters and thus have reduced surface heat loss. The fixed film media and support cost must however be weighed against the capital-cost reduction in downsizing the more conventional totally-mixed digesters.

3.0 FIELD VISITS

At the request of the Ontario Ministry of Agriculture and Food (OMAF), Agricultural Energy Centre, and the Ontario Ministry of Energy in cooperation with Agriculture Canada, the authors visited a number of on-farm and research digesters. The purpose was: to assess first hand the performance of and problems with anaerobic digesters that had been in operation for a period of time: to determine if the systems were meeting expectations of the operators: and to recommend further support and/or research to improve performance and/or economic viability from an energy standpoint. For the latter objective, utilization of digester by-products would be assessed from the indirect energy savings point of view.

3.1 Visits - Tunnel (plug-flow) systems

3.1.1 Mason-Dixon Farm - Gettysburg, Pa.

(a) Input

Flushed dairy manure from a 1000 cow milking herd (and replacements) is screened from a settling pond so that about 12% TS material is pumped to the digesters.

(b) System

Originally a mesophilic 600 m^3 tunnel type digester with a nylon reinforced flexible cover for gas storage and an RT of about 12 days was installed. A steel framed structure protected the flexible digester cover from wind and snow. In 1981 an additional unroofed digester was added to accommodate the manure from an increased herd and increase the RT.

Cogeneration is by a large natural gas engine generating all the power to run the massive milking/dairy operation. (Milking was on a 20 h/d basis when visited in August 1985.) Engine heat warms the digesters using 75 mm cast iron pipe as heat exchangers or is dumped to the atmosphere via radiators when not needed.

(c) Comments

The system is working well and has been in operation since 1979. Signs of degeneration are evident but the high level of dedication and expertise available by the extended Waybright family are always available to take corrective actions.

Problems have been experienced with scum accumulation requiring shut down and accessing the digesters with a large PTO agitator. This may be partially due to the use of flushed manure (Chen et al, 1984).

Consideration was also being given to the use of a rigid cover to eliminate problems with the flexible covers. This change would require separate gas storage and designed-in agitation (mixing).

(d) Benefit perception

Utility energy displacement had made the project worthwhile. The use of separated digested solids as bedding had been abandoned because of high moisture content (about 75%) and associated bacteria growth.

Reduced neighbor objection to manure disposal was a definite asset.

3.1.2 Foster Bros Farm - Middlebury, Vt.

(a) Input

Dairy manure from 330 cows and 270 replacements was being hauled to the digester when visited in 1982.

(b) System

The anaerobic digester was a mesophilic 600 m^3 paralleled tunnel type digester with flexible membrane cover for gas storage. The total digester was covered by a pole frame metal covered building to protect the digester cover from wind and snow. Planned RT was 20 days. Figure 4 shows the partially inflated gas storage and cover building.

Cogeneration was provided by a natural gas engine and synchronous generator that could produce 150 kW. All electrical energy was being put into the utility grid between 7:00 and 19:00 h at a premium value of $0.09/kWh (1982). Again, engine heat was being used to heat the digester and manure receiving pit via pipe heat exchangers as well as an adjacent solids separation area housing the large hot water tank as a heat sink.

Solids separation from digested effluent was being achieved by screening and a single roller press. The solid portion was being aerobically composted. The total system cost was about $250,000 (1982 US).

(c) Comments

The system was working well after about one year of operation. Again extended family expertise appeared as a major factor in the total system operation.

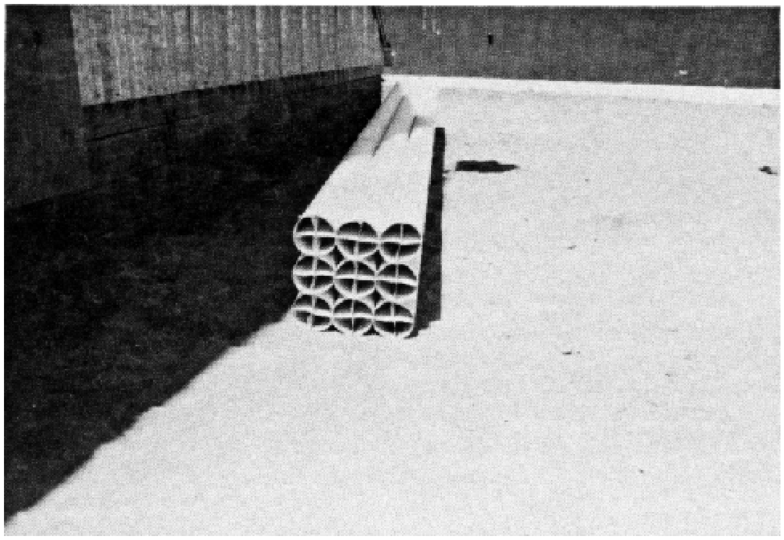

Figure 3. The 100 mm diameter fixed film media tubing used in anaerobic digesters

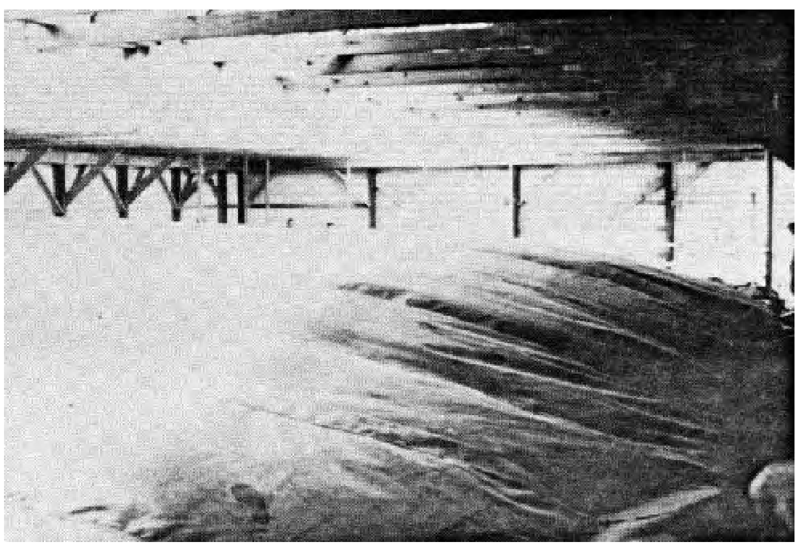

Figure 4. The partially inflated gas storage over a tunnel type anaerobic digester with building protection

In this installation the gas storage and cogeneration equipment were both upsized in order to take advantage of the peak demand premium being paid by the utility (12 h/d). The anticipated electrical revenue was $32,800 per year. If generation had been intermittent or continuous at a lower level the revenue would have been reduced to $18,200 (1982 US).

(d) Benefit perception

The electrical revenue exceeded cost at the farm. (Because of direct connection the generator could not be utilized for standby power.)

They planned to use the composted solids as bedding or to sell them.

Manure odor was reduced and storage/spreading was less offensive.

3.1.3 Shugah Vale Farm - Claremont, NH.

This farm was not visited but credible information was obtained from Gilman, 1985.

(a) Input

Scraped dairy manure from 350 milk cows and replacements combined with milking center wash water provides a daily input in excess of 34 mJ.

(b) System

Two tunnel digesters are precast concrete with hard covers, the third has a flexible membrane top to provide gas storage. The total working volume is 750 m^3 providing an RT of 22 days. A 45 m^3 heated reception pit incorporates a chopper/mixer unit for slurry preparation.

Cogeneration is provided by a Caterpillar gas engine coupled to an 85 kW induction generator. All electrical energy produced is supplied to the utility at a buy-back rate of $0.078/kWh - more than consumer price in 1985. Again, rejected engine heat is provided by hot water piping to the reception pit and digesters or is dumped.

Solids separation from digester effluent is being undertaken with a screw press. Separated solids at 30 to 50% m.c. are being air dried in windrows on a concrete pad, weather permitting, with possible use of waste engine heat in the future. The total system cost was about $200,000 (1984 US).

(c) Comments

Startup in the spring of 1984 encountered a number of difficulties, such as foaming and resultant low. gas production. By April of 1985 many problems had been resolved. The April gas production as metered was 15,805 m^3 and electricity sold was 26,160 kWh with peak: power outputs at 80 kW. This translates into a specific gas ratio of 0.70 m^3/ m^3/d and a conversion rate of 1.66 kWh/m^3 of biogas. Improved biogas production rates are being sought.

Difficulties were encountered with the separation equipment. More expensive equipment requirements are likely to result. As of August 1985 only 1/4 of the digested manure had been separated.

(d) Benefit perception

The owners are still hoping to increase gas production to bring revenue from $68/d to $100/d. Separated and composed solids as bedding with potential sales of 50% to greenhouse growers as a soil mix inqredient have not materialized to increase revenue.

Odor reduction was considered a positive side benefit.

3.1.4 Gasser Farms Ltd. - Pike River, PQ.

This is the only known tunnel type (plug flow) digester in Canada.

This system was monitored through a contract with Agriculture Canada. The digester and associated equipment were built and/or paid for by the farm.

(a) Input

Scraped and gravity flow dairy manure from 350 cows is the primary source, with wash water from the on-site dairy facilities being added, thus reducing the manure to about 9% total solids (TS).

The digester was sized for up to 700 cows and this is further aggravated by the cows being field exercised during the summer. Consequently manure has been trucked in during the summer to supplement supply and maintain gas production. Prior to our visit in early September 1985, some of the incoming manure was from a swine operation.

The `winter' slurry throughput is about 24 m^3/d.

(b) System

This tunnel type anaerobic digester has many design variations when compared to the preceding simpler systems. This installation might be described as a 'sectioned, mixed, plug-flow, anaerobic digester`. In fact one is really hard pressed to call it a plug-flow digester at all.

This four section, U-shaped, continuously mixed, anaerobic digester was designed and built in 1981-82 and came into production in 1982.

The 600 m^3 working volume digester is in the shape of a U, and is a concrete tank. 11 m wide, 20 m long and 4 m deep - to allow gas space. The digester has a longitudinal dividing wall with a gap for a weir at the U end. Two shallow cross walls, 0.3 m below normal slurry level, are located to also act as weirs at mid length, thus giving the digester a four stage arrangement.

Prepared slurry is pumped into a receiving pit, heated, and then moved by gravity through all four sections before entering an effluent section. The effluent is then pumped, without separation, to a large 3.6 m by 41 m diameter outside holding tank. to await field application.

Biogas is pumped continuously to diffusers in each of the four sections to provide agitation and prevent scum and sludge accumulation.

The total digester is below grade with insulated concrete walls and a reinforced concrete cover. An insulated building over the digester provides warmed space for the cogeneration equipment and a machinery storage/workshop. Figure 5 provides an overview.

Biogas storage was initially provided by a 150 m^3 flexible bag inside a vented steel tank providing wind and snow protection. Five additional exposed 28 m^3 storage bags of various materials provided by Agriculture Canada were also being tested. It was evident that only one or two were likely to remain as part of the storage system. The gas pressure in the digester and storage was limited to 1 kPa to prevent system damage.

Cogeneration - A Waukesha natural gas engine was driving a 60 kW induction generator. See Figure 6. The 60 kw generator would not meet peak milking time demand (831 kW), thus the system is interconnected to the Hydro Quebec grid but backfeed is not practised or desired. A PTO standby alternator is maintained to provide system excitation in the event of utility power failure.
When visited, the cogeneration system was being operated for up to 14 h/day

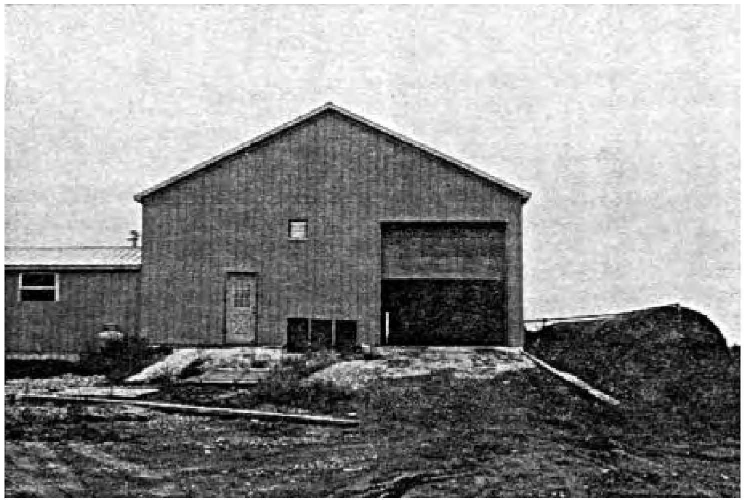

Figure 5. An overview of the Gasser digester with farm shop/cogeneration building and flexible biogas storage protection tank

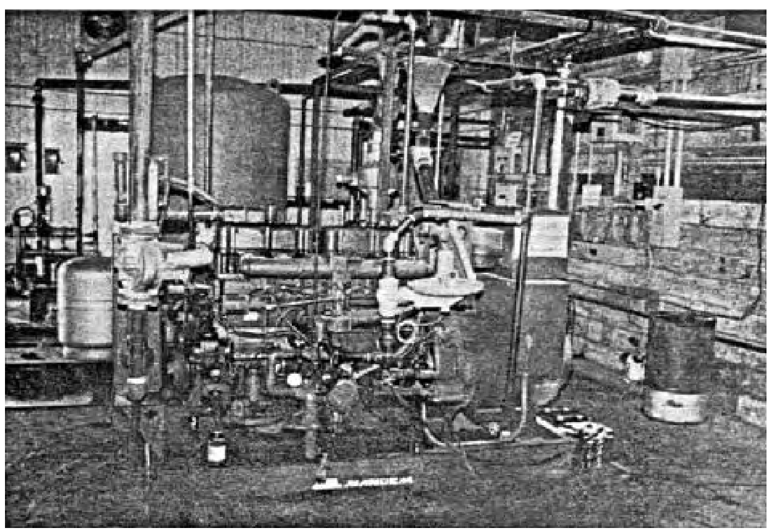

Figure 6. This picture shows a well maintained cogeneration system providing 60 KW but requiring significant biogas storage

and shut down at night when demand was low. The intermittent operation created the need for large gas storage volumes. The operators indicated they used about 425 W of biogas per day. Based on this figure the specific gas ratio is about 0.71 $m^3/m^3/d$. As indicated previously the digester capacity is under utilized at present with an RT of about 25 days vs the design criterion of 12 days. Cournoyer and Chagnon, 1984, showed gas production of 575 m^3/d for winter conditions with a more consistent influent. This higher ratio would increase the specific gas production ratio to 0.96 $m^3/m^3/d$.

Engine coolant and exhaust heat are utilized to preheat slurry, maintain digester temperature and heat the workshop and other areas of the barn. A backup dual fueled boiler (biogas or LPG) was installed to facilitate startup and maintain digester temperature in the event of engine failure. Total system cost, including cogeneration, was about $200,000 with much of the construction work undertaken by the owners.

(c) Comments

The owners/operators were pleased with the performance of the system to date. It has been operating since April, 1982. However, some scum accumulation was beginning to appear in the digester section corners, possibly because of the use of swine manure which has a greater tendency to segregate. As a result they were questioning the choice of the concrete digester cover which provided very limited access.

If and when the digester is shut down for clean out, an evaluation of the accumulation of sludge, possibly due to inadequate mixing near all digester walls, will be of great interest for future designs of this style of digester.

The operators are very conscious of water accumulation in the biogas lines. Initially PVC piping was used. Line sag caused condensed water to restrict gas flow. All lines were changed to large diameter steel and appropriately sloped to water traps which are drained manually each day. Parsons, 1984, covers line selection and sizing in great detail.

Because of no buy-back arrangement with the power supplier, the owners are attempting to generate as needed. However, because of the lack of self sufficiency to meet peak daily demands they had already invested more money (approx. $20,000), to priorize the farm electrical service than would have been necessary for direct interconnection.

The attempt to generate electricity only as required also resulted in the need for relatively large gas storage which added significantly to capital cost.

The percentage of kWh generated on this farm was not always reflected as a reduction of the monthly electrical power bill. Hydro Quebec presently maintains a free 35kW demand rate structure. If the cogeneration equipment is out of service for even 20 minutes during a peak demand time (such as milking) a significant monthly demand charge is applicable and has residual consequences in other months. Cournoyer and Chagnon, 1984, showed potential farm self sufficiency of 83% for this farm when only kWh were considered. In practice the yearly power bill is only likely to be reduced by about 50%. This comment is a general one as all electrical utilites operate on a demand (kW) based rate system which is a justifiable measure of their supply cost to the consumer.

(e) Benefit perception

Again this is an extended family farm operation with exceptional evidence of pride of ownership. On-farm skills are readily available for routine engine maintenance and other tasks.

The owners did not indicate that environmental pressure had been a major deciding factor, but odor control was definitely apparent at the site.

Energy self sufficiency had been a primary motivating factor in deciding to cogenerate. Refeeding of digested solids had been planned but not implemented and was not now high on the priority list.

3.2 Visits - Totally mixed digesters

3.2.1 Cattleland Ontario - Petersburg, Ont.

(Formerly Rosyln Park Farms (RPF))

This unit was built with partial funding from Agriculture Canada in cooperation with Environment Canada in an effort to determine pollution abatement potential of anaerobic digesters.

(a) Input

Beef animal manure without bedding from approximately 4000 head is pumped from under slats to the digester complex. Most of the time coarse solids are removed for composting prior to digestion of the liquid fraction.

This beef manure is lower in TS than most because of the high moisture content of many of the feedstuffs being utilized. A significant portion is by-products from the food processing industry, such as whey, cull potatoes, etc.

(b) System

This anaerobic digester was the first large scale, on-farm unit to operate successfully in Canada. The digester was started in 1980.

The above grade, vertical, cast in place reinforced concrete tank is 9.1 m in diameter and 11 m high with a domed concrete roof. The tank is externally insulated and covered with steel for mechanical protection. This digester tank provides for a 636 m^3 working volume. The slurry is mixed as required, and specifically during feeding, by a 10 kW motor operating a vertical shafted stirrer.

Slurry is recirculated from the digester to a heat exchanger to maintain digester temperature. This heat is provided by engine heat reclaiming. The influent is also pre-warmed by the effluent using a separate heat exchanger.

Cogeneration was never given serious consideration because of the relatively low on-site power requirements and the low buy-back ratio offered by Ontario Hydro. Their 1985 rates are $0.033 kWh if the monthly generator capacity factor is 65% or greater.

Engines have been operated on biogas for other on-site purposes. Initially three old gasoline engines were operated to provide hydraulic power via pumps and motors. More recently one slow speed, dual fuelled diesel engine replaced the gasoline engines. The engine(s) provided power to operate raw manure and digested manure centrifuges while heating the digester.

The digested manure centrifuge was used to provide residue of anaerobic digestion (ROAD) for refeeding as partial protein supplement to the beef animals. The practice has been recently discontinued and the centrifuge removed.

A back up biogas fired boiler is available for digester heating and will probably be used during the winter of 1985-86.

Most of the biogas is being dumped (flared) but two used petroleum tanks (about 10 m^3 each) are in place to provide low pressure surge capacity to operate the large diesel engine which will still be required to operate the raw manure centrifuge for the composting operation.

Digester effluent is moved to a large earthen storage for holding until utilized for irrigation onto crop land.

The total system cost, including separation equipment, was about $477,000.

(c) Comments

Initially the digester was operated in the thermophilic range to increase throughput and destroy pathogens. When it was established that mesophilic conditions would permit the desired 10 day RT the temperature was dropped back to save biogas.

Present biogas production estimates are unavailable as monitoring has been discontinued. Prior production rates and equipment costs are available (MacDonald et al, 19B3).

(d) Benefit perception

The digester has been and will continue to be operated to reduce environmental impact and permit the large feedlot to coexist with urban encroachment.

Cogeneration would be considered if the utility buy back rate was high enough to justify the capital expenditure.

3.2.2 Selves Farms Ltd - Fullarton, Ont.

This system was designed and built with partial funding from the Ontario Ministry of Energy (OME), directed through the OMAF Agricultural Energy Centre.

The installation was funded to permit on-farm evaluation of energy self sufficiency and the refeeding of digested solids to replace protein and mineral supplements in feed rations of swine.

(a) Input

Liquid manure from a 375 sow farrow-to-finish operation is processed through the system. Only the 1000 head finishing barn and gilt holding barn are at the digester site. The remainder of the manure is tank trucked in from other farm locations. (The tanker moves digested effluent to holding tanks on the other farms to minimize wasted trips and energy.)

Total manure production of approx. 13.5 m^3/d with 4.5% TS at 65% VS are mixed and pumped into the digester. The digester is fed twice per day - just prior to peak electrical demands (pig feeding time).

(b) System

The total system cost about $225,000, and went into full operation in June, 1983.

The digester tank is completely below grade. (This was possible due to a low water table at the site.) It is cast in place concrete 6.6 m in diameter and 6.2 m high and has a domed reinforced concrete top. The digester is externally insulated. The working volume is about 210 m^3.

Two submersible pumps are run continuously to maintain a homogeneous slurry. (Swine manure of low TS content tends to separate readily.) One pump is near the bottom to minimize sludge accumulation, the other near the top to prevent scum formation.

Three series loops of 50 mm low carbon steel pipe are located in the digester to facilitate use of engine heat to maintain digester temperature.

Two 23 m^3 underground storage tanks only provide for 1/2 to 3/4 h surge capacity for the engine when precharged to 40 kPa by a low pressure gas blower. Some excess gas is vented to prevent damage to the digester or storage tanks.

Cogeneration - a Caterpillar natural gas engine burns biogas to power a 90 kW (kVa) synchronous generator. After installing an electronic governor the operators have had success in maintaining 60 Hz. With judicious load management, primarily because of minimal gas storage, the cogeneration unit is providing all the electrical power on site which includes feed preparation, a shop and two residences. However, the main barn is naturally ventilated and the farrowing and over one-half the pigs are finished off site in more conventional fan ventilated buildings.

Building private power lines to the other farms was considered but abandoned for cost reasons. Another alternative is a `wheeling' agreement with Ontario Hydro. One such agreement is in place with a conservation authority generating hydro electric power at a dam.

At present standby power only is provided by Ontario Hydro. Grid connection is now considered desirable and is under consideration.

The present biogas production is about 310 m^3/d for a specific gas ratio of about 1.5 m^3/m^3/d.

An increase in the swine herd to 425 sows is anticipated and should also increase daily gas production. The present RT is about 15.5 days which should tolerate some reduction. MacDonald et al, 1984, indicate that this digester could be operated successfully at RT of 7.5 days without `washout' of the methanogenic bacteria population.

The engine heat is presently adequate to heat the digester, the farm shop and office area as well as two residences. Excess summer heat is dumped by the conventional radiator with thermostated electric fan technique.

Solids separation - No pre-separation is practiced at present. After digestion the effluent is pumped to a vibrating screen separator (Figure 7). Coarse fibrous material is removed for field spreading as a soil conditioner /fertilizer. The liquid portion is then centrifuged, (Figure 8) after the addition of a coagulating polymer, to separate out the ROAD.

The spent liquid is then stored in conventional tanks (pits) for field application. The ROAD is blended with the finishing hog ration to replace some protein supplement and mineral premix.

(c) Comments

This digester system is operating very effectively - again with expertise of a number of competent family members and dedicated staff.

While this system has experienced a few technical problems such as the failure of pressure relief valves that precipitated two digester tank top separations, the tank has been repaired and the gas pressure relief system revised to incorporate the popular U-tube liquid filled safety discharge.

Early failure of the exhaust gas-to-water heat exchanger initiated the design of a more durable and economical stainless steel unit by the consultants (Canviro Ltd, 1985). It has been field tested and incorporated into more recent installations as well. The volatile solids production rate of 2.6 kg/1000 kg live weight was well below the predicted rate of 4.8 (Canviro Ltd, 1984). This has resulted in less than the design biogas production rate. Present biogas production rates are in excess of the site electrical needs but certainly short of the total farm electrical needs. The synchronous generator is only operated at 1475 rpm but could be operated at 1800 rpm if electrical demand or utilization was readily available. The decision not to interconnect to the Ontario Hydro grid had been made based-on the low, cost of generation, buy-back: rate of about $0.017/kWh in place at the time.

Because of the reduced generator speed, to extend electrical energy availability without increased biogas storage, some difficulties were encountered in starting the large 15 kW motor on the HM corn silo unloader. This was overcome by special wiring changes to reduce inrush (starting) current.

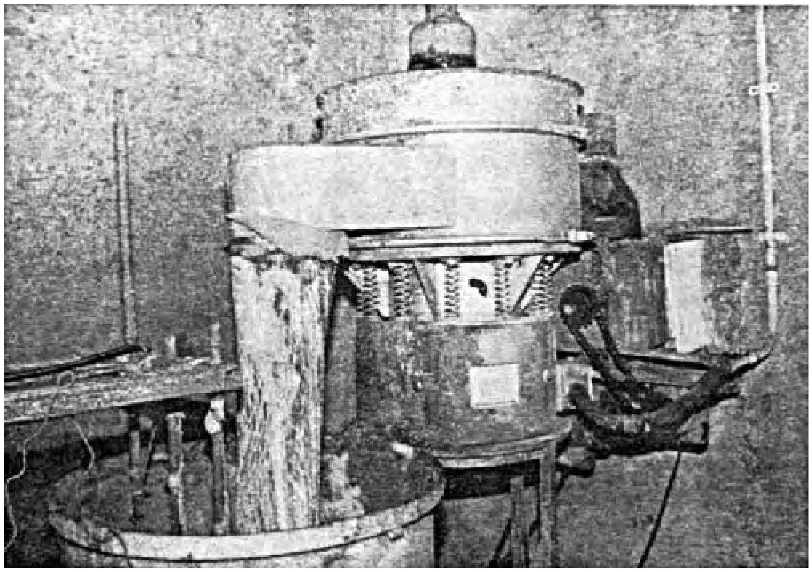

Figure 7. Digester effluent is being scalped of coarse fibrous material

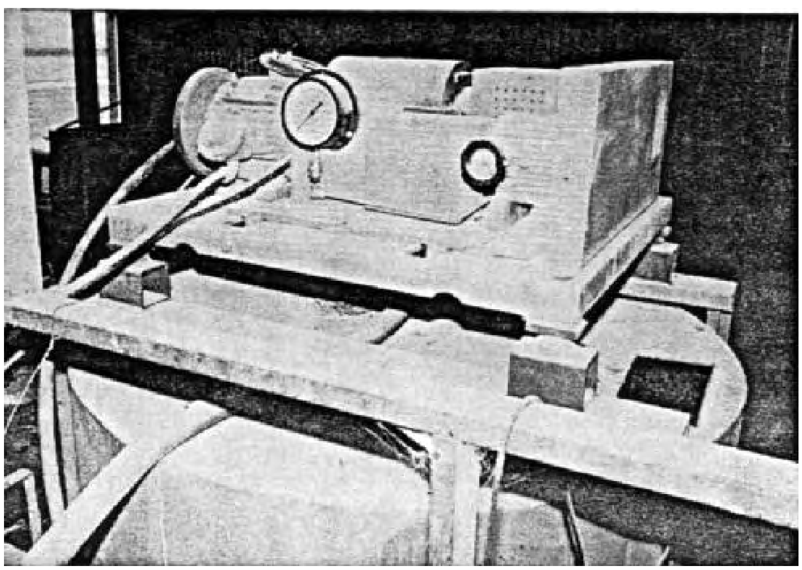

Figure 8. The scalped digester effluent is centrifuged after the addition of a polymer, to provide ROAD

The cogeneration system is producing 850 kWh/d from 480 m^3 of biogas for a conversion of 1.77 kWh/m^3 of biogas. The estimated electrical energy savings are about $4000/year when calculated as displaced purchase at $0.041/kWh_(Canviro Ltd, 1984).

The biogas produced is of high quality, being about 70% CH_4 (MacDonald at al, 1983). Indications are that the biogas must also be low in sulphur. Crankcase oil changes have been extended to 2000 hours following extensive oil tests for presence of low pH or other contaminants. This experience is in marked contrast to the experience of Jewell at al, 1985, with biogas from dairy manure. One is left to speculate at this time about the influence of many variables such as animal or digester type, feed ingredients, or digester bacteria on the quality of the biogas produced.

The high quality of biogas at this site has also permitted the use of regular (relatively cheap) spark plugs as compared to the expensive specially plated electrode plugs recommended by the engine manufacturers. The feeding of specially prepared ROAD is continuing to replace a portion of the protein and some of the minerals. The manager is presently expressing some doubt about continuing unless palatability can be improved. Feed cost reductions are certainly not consistent with the predictions of 'return calculation' put forward by MacDonald et al, 1984.

At this time one can only speculate on the advantages of putting unscreened manure into this digester. If the agitation is not close to optimum one might predict a sludge buildup primarily from undigestible fibrous or gritty materials. This will only be known after a longer period of use.

There is of course some justification for putting the total manure into the digester. With prescreening, some volatile solids will undoubtedly be removed with a resultant specific gas ratio reduction. Benefit vs operational problems should continue to be monitored at this site.

(d) Benefit perception

The farm manager stated that the primary motivation for the digester with cogeneration had been energy self sufficiency. In predicting a recovery of capital, refeeding value of ROAD was given a significant rating. He also indicated that odor control was definitely enhanced but that it had not been a priority factor in the initial justification.

The other desirable feature was the separation of solids and liquids. While a dual handling system was required, the solids portion could be spot applied on eroded knolls and other places requiring organic matter.

3.2.3 Pittens Farm - Cambridge, Ont.

This system was designed and built with partial CREDA funding provided by the Ontario Ministry of Energy, and Energy Mines and Resources Canada, under their bilateral agreement. The funds were directed through the OMAF Agricultural Energy Centre which provides project supervision.

This installation was funded to permit on farm evaluation of totally mixed digester technology with dairy manure. Cogeneration will be put in place to utilize the biogas.

Refeeding of ROAD to dairy animals could be evaluated later but separation equipment was not initially included.

(a) Input

Plans call for utilizing the dairy manure as collected from slotted floor pits serving 250 milking animals and calves. (The heifers are raised on a separate farm.) The slurry will be mixed and pumped as required to the anaerobic digester.

(b) System

The anaerobic digester 5.3 m above ground, is a vertical concrete tank insulated and sheathed with steel for mechanical protection. The 7.3 m diameter tank 7.3 m high should provide a working volume of about 285 m^3. This typical totally mixed digester is shown in Figure 9. The slurry will be mixed as required by two submersible pumps, one located near the bottom to prevent sludge accumulation, the other near the surface to prevent scum formation.

The digester tank contents will be heated to mesophilic temperature with engine coolant and exhaust heat using internal low carbon steel pipe loops.

Cogeneration will be practiced at a proposed rate of 60 kW using an induction generator to facilitate power grid connection.

The digester effluent will be piped to a relatively new 3.7 m by 27 m diameter circular concrete tank for holding prior to land application.

While separation of ROAD and refeeding are a possible consideration, equipment was not initially being installed.

The system cost is about $225,000. ROAD recovery equipment would cost add another $100,000.

(c) Comments

This is a well managed family farm operation relying on hired help for milking and other tasks.

When visited, and at the time of writing, the digester system had not been commissioned primarily due to delays in acquiring cogeneration equipment and the services of skilled tradesmen.

The owners, as entrepreneurs, have taken advantage of the opportunity to reduce purchased energy. They are interested in refeeding ROAD but are hesitant to commit capital until more research and data are available.

(d) Benefit perception

The owners hope to reduce energy costs while reducing odors. The large dairy operation is relatively close to an urban center and some odor complaints during spreading are inevitable.

While they are interested in the possibility of refeeding they have no plans to consider separated solids for bedding the free-stalls.

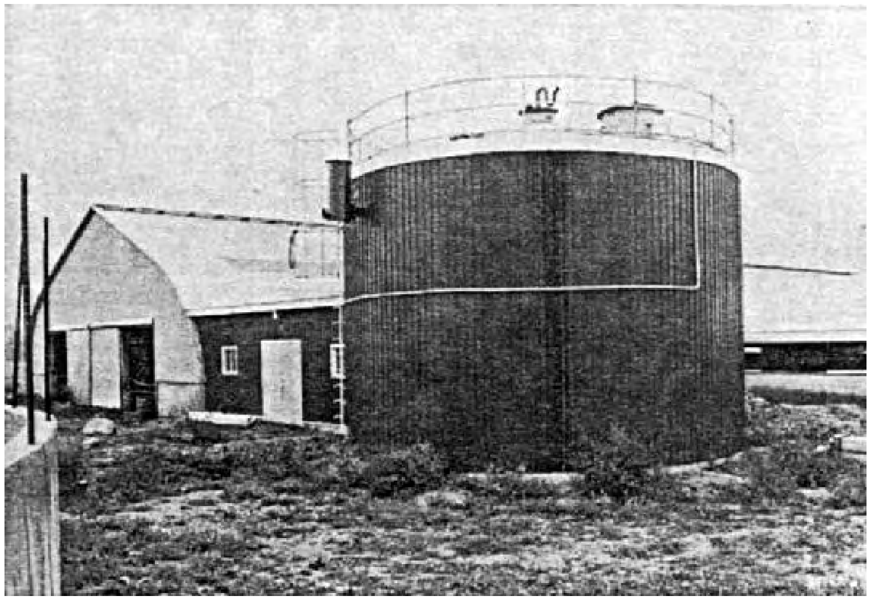

Figure 9. A typical circular, above-grade, totally mixed anaerobic digester

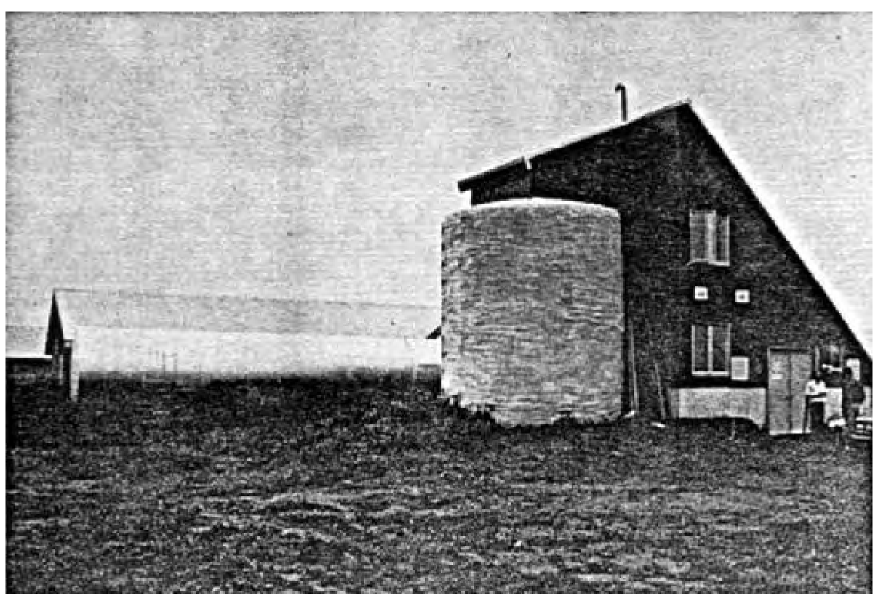

Figure 10. A typical (50 m^3) circular fixed-film anaerobic digester with large horizontal steel tank in background to protect the gas storage bag

3.2.4 Linden Lee Farms - Cornwall, PEI.

This system was designed and built with partial funding from Energy Mines and Resources Canada under a CREDP program. Electrical energy costs to the consumer in PEI are the highest in Canada.

(a) Input

From Jan 1984 to June 1985 the input was swine manure from on-site housing for 1400 animals (15 to 100 kg). This was supplemented with piped in manure from a neighboring farm housing 450 finishing pigs and 7500 laying hens.

During the summer of 1985 the swine facilities were depopulated and the digester shut down while the on-site facilities were being upgraded to a 225 sow farrow-to-finish operation.

The manure from the starter barn and neighboring farm was pumped weekly to a holding tank located at one end of the finishing barn. The mixed slurry was pumped from there to the digester once each day.

During a monitoring period (Canviro Ltd. 1985), the average input rate was 16.2 m^3/d of manure having an average TS of 3.57.. The RT was 18 days, well above the design minimum RT of 9.5 days.

(b) System

The vertical circular concrete digester is 7.3 m in diameter and 7.3 m high with 5.3 m above grade. The digester operating volume is about 285 m^3. The digester tank is insulated and covered by a UV barrier top coating.

Total mixing is provided by two, 2.2 kW submersible pumps, one located near the bottom to prevent sludge buildup, the other near the surface to prevent scum formation.

Loops of low carbon steel pipe are located in the digester tank to utilize engine or wood stove (backup) heat to maintain mesophilic temperature in the digester.

The interesting difference with this installation is that the digester is about 84 m removed from the gas storage and cogeneration equipment located in the farm shop. The biogas line and hot water lines run underground. This arrangement puts the engine generator closer to the electrical load and heating center of the farmstead.

Cogeneration is with a natural gas engine capable of running on biogas or LPG connected to a 40 kW induction generator.

Biogas is temporarily stored in a rigid 23 m^3 tank having an effective storage volume of 9 m^3 created by gas compression when pressurized to 40 kPa. When gas pressure drops below 7 to 10 kPa cogeneration ceases or the system automatically switches to LPG until biogas pressure is returned to the 28 to 35 kPa range.

The induction generator system was chosen to facilitate grid connection via an import/export control system. The control system can be set as desired to regulate both the import during peak farm demands and the export desired during low need periods.

Engine heat from coolant and exhaust gases can be supplied to the digester tank when required or stored in a 27 m^3 hot water storage tank. If the engine return water becomes too hot the conventional radiator system with electrical fan is thermostatically energized to dump heat to the workshop.

Hot water from the storage tank can also be used to dry grain or heat the farm residence as required, using hot water radiators at each location.

No separation of digester influent or effluent is being practiced. The effluent is discharged to a large earthen pond for timely land application.

The capital cost of this system was about $166,000.

(c) Comments

While not entirely unique among innovators using anaerobic digesters, this farm operator certainly excels in the entrepreneurship of ‘making the system work'.

Biogas production averaged 180 m^3/d when adequate manure was available for digestion. The methane content of the biogas averaged about 60%. As noted earlier, the RT of 18 days is higher than desired and is likely to be adjusted downward when the revised hog production system attains full capacity.

Preliminary monitoring (Canviro Ltd, 1985) indicates a much lower specific biogas production rate than for the Selves Farms Ltd unit which is of the same design. The average was only 0.30 m^3/kg VS/d compared to 0.70 m^3/kg VS/d at the Selves unit (Canviro Ltd, 1984). It is speculated by the consultants that the feed rations might account for the significant difference in manure digestibility. Selves Farms Ltd feeds a HM corn and soybean meal ration while Linden Lee Farms feeds a barley or wheat and heat-treated soybean ration. Another observation is that some of the Linden Lee manure is held longer before movement to the digester tank. This might account for some degradation due to aging. Fresh manure does have a higher digestibility (Jewell at al, 1982, Persson et al, 1979).

Follow up monitoring of the Linden Lee Farms digester should be undertaken - probably in 1986 - when the digester is more effectively loaded to ascertain possible effects of feed ration differences.

From November 24, 1984, to February 28, 1985, the 40 kW cogeneration system produced only an average of 102 kWh/d as compared to the average farm consumption of 235 kWh/d or 43% of need. Remembering that off-farm manure was being utilized it becomes doubtful if the farm can be self sufficient unless the digestion rate of available VS can be improved significantly. However, when the displaced energy cost exceeds $0.10/kWh and the buy-back rate exceeds $0.05/kWh the cogeneration potential is a great deal more attractive than for the much lower rates in most other Canadian locations.

Separation of the digester and cogeneration equipment has not caused any insurmountable problems and points the way for flexible system design to meet the site specific requirements of various farmsteads.

In preparation for a fall 1985 restart, the cogeneration equipment has been downsized in an attempt to match the lower than expected gas production rate.

The generator has been replaced with a synchronous 20 kW unit. The same engine is being used at a reduced speed - 1200 rpm rather than the previous 1800 rpm. More continuous cogeneration is anticipated with less power factor problems than encountered with the induction type system.

The operator is interested in trying ‘digestive additives' but only after he is assured of positive benefits by suppliers or researchers.

d) Benefit perception

The initial stimulus for involvement was to reduce purchased electrical and heat energy for the farm.

The secondary realized benefit has been odor control, not because of previous pressures from neighbors, but because the less odorous effluent has permitted `controlled' top dressing on cereal crops at a more convenient management time - in June.

Refeeding of ROAD has not been given priority because the operator perceives his operation, when expanded, as too small to justify the capital investment. He is also growing and roasting soybeans with perceived savings in protein and feed energy costs when compared to the purchase of equivalents.

3.2.5 Olds Agricultural College - Olds, Alta.

This anaerobic digester installation was not visited by the authors, but the information provided by Larry Arvay of Olds College is intended to broaden the scope of the report.

The totally mixed system was partially funded by A.O. Smith Harvestore to evaluate some of their components and permit evaluation of other benefits by College personnel.

(a) Input

Two sources of manure are available: flushed manure from a 110 sow farrow-to-finish operation and scraped manure from a 50 cow milking herd.

The rations for all animals are barley based and some barley straw also enters the digester from the free stall dairy unit.

The influent rate was varied by choice from 9.0 m^3/d to 11.7 m^3/d. Neither TS nor VS values were reported.

The influent is prepared with a chopper pump and pumped into the digester once per day without preheating. The influent is made up of a combination of swine manure, dairy manure, and some recycled effluent/raw manure from the storage tank - to reduce RT.

(b) System

The totally mixed digester had been in operation for 11 months when shut down in November 1985 for evaluation and clean out.

The digester tank is double-walled glass-lined steel to accommodate insulation. The above grade circular digester is 7.6 m in diameter and 8.5 m high providing a working volume of about 300 m^3.

Stirring (mixing) was done by the use of an external 5.6 kW pump providing recirculation of digester slurry at one or more of three jet locations in the digester. The pump was operated for 30 minutes every three hours - not continuously.

The digester slurry was heated to mesophilic temperature by a natural gas fired hot water boiler and heat exchange piping in the digester.

The biogas has not been used. Plans are to run a small cogeneration system for demonstration purposes, to fuel a dead animal incinerator, and to fuel furnaces for support facilities heating.

No system costs are available.

(c) Comments

The system worked well but accumulation at the overflow weir indicated the existence of scum formation, including straw, on the liquid surface.

The RT has been in the range of 26 to 3 days even with some recycling. The operators would like to bring the RT into the 12 to 20 day range if and when input rates can be increased. The once per day loading, but not everyday, was also the result of limited staff time far digester attention.

The gas quality at 62% CH_4 is good. Equipment is in place for scrubbing the gas of H_2S but no data was provided on levels or performance.

The biogas production rate averaged for 220 digester fed days is 92 m^3/d. If taken for the elapsed days of 256 the averaged gas production is 79.1 m3/d. This provides specific gas ratios of 0.307 $m^3/m^3/d$ and 0.264 $m^3/m^3/d$ respectively. These values are low but likely to improve if feeding times are increased and RT decreased. This digester is being fed from cereal grain based rations which may be suppressing biogas production rates.

(d) Benefit perception

The primary objective of the anaerobic digester installation was to control odor from the animal housing units and provide digested manure for refeeding trials. Plans are underway to reconstitute straw using digester effluent and to install a separator. No feeding trial reports are available

The secondary objective was for biogas utilization demonstrations.

3.3 Visits - Fixed film digesters

3.3.1 Folkema Farm - Ingersoll, Ont.

This system was designed and built with funding from Agriculture Canada under the ERDAF program. The objectives were to: evaluate on a field scale the downflow fixed film digester concept (Vanden Berg and Kennedy, 1983), using hog manure, while assessing the potential for refeeding and cogeneration.

(a) Input

Flushed manure from 100 sows and weanling pigs on site was the basic input to be supplemented by manure from finishing facilities located on another farm.

The on site production was anticipated to be 3.6 m^3/d while the system was designed to handle a maximum rate of 6.8 m^3/d.

(b) System

Raw manure at 5 to 7% TS is conveyed from a stirred holding tank to a gravity screen separator. The larger solids at 70 to 80% mc are removed for refeeding to the gestating sows.

The passed liquid portion with 3 to 3.5% TS is held in a second tank. When required for digester feeding twice per day, the liquid influent is preheated in a large plate-type heat exchanger tank.

The digester tank is double-walled glass-lined steel to permit insulation. The cylindrical portion, 3.5 m in diameter and 4.4 m high is over an inverted cone bottom supported above grade by a concrete wall. The operating volume of the digester is about 38 K. The cylindrical portion of the digester is filled with the fixed-film, tube bundles. See Figure 3.

No heating occurs in the digester. If the slurry temperature falls below the desired mesophilic temperature an external pump circulates slurry through the same preheat heat exchanger.

No mixing equipment exists in the digester. Influent from the top (downflow) and biogas movement upward through the fixed film tubes as well as low temperature induced circulation are intended to provide sufficient mixing. The conical bottom was used to eliminate sludge accumulation. Effluent is removed at the cone bottom.

Effluent is transferred to a circular concrete tank for holding prior to land application.

Biogas is pumped to an outside flexible 80 m^3 bag covered by an A frame structure. Maximum bag pressure is 2.5 kPa.

Cogeneration - Biogas is taken from the bag and compressed to 5 kPa to supply a 25 kW Waukeshau engine driving a 15 kW induction generator. The cogeneration system is connected to the Ontario Hydro grid to permit power exchange. During operation the buy-back rate was about $0.017/kWh. If necessary a small PTO driven alternator at the farm service disconnect would permit the cogeneration equipment to provide standby power.

Heat from the engine coolant and exhaust were available *for* heating water as a heat sink for the digester. Plans were to also use hot water in the nursery facilities and the farm residence.

Separation - The predigested solids have been fed to gestating sows. Centrifugal separation of solids from the digester effluent has not been attempted at this installation.

(c) Comments

After numerous delays in acquiring the fixed film media the digester went into operation in December 1983. Biogas of good quality (65% CH_4) was produced at rates varying from 35 m^3/d to 100 m^3/d depending on feeding rates and availability of manure (Matt, 1984). These rates would give specific gas ratios of 0.9 to 2.6 m^3/m^3/day. This indicates the potential of the fixed film digester to provide relatively high specific gas ratios.

Unfortunately no long term electricity production figures are available. The operator stated that production of 70 to 80 kWh/d had been produced with the generator operating as long as six to seven h/d. He believed that the flexible gas storage bag was able to provide three to four h engine runs without the frequent shut downs often encountered with compression storages.

Some observations on the benefits of refeeding the undigested separated solids were made but no factual data are available to support the hypothesis.

Engine heat or LPG was used to heat the digester slurry via the plate heat exchanger. A large hot water storage tank was also designed into the system to act as a heat sink.

The complete digester system has been shut down since March 1985 due to an engine exhaust heat exchanger failure and a significant reduction in available manure to operate the system.

(d) Benefit perception

Odor control was a definite benefit when the system was visited during an open house in August 1984.

The digester system performed well on the low TS content influent.

3.3.2 CRIQ - Ste Foy, PQ.

Laboratory testing had been carried out at Centre de Recherche Industrielle du Québec prior to building a prototype and then a full scale farm unit near St Henri.

The total project was funded by Agriculture Canada to ascertain fixed film digester suitability for reducing COD and producing biogas, with swine manure.

(a) Input

The farm scale digester was designed to handle the manure from 1400 feeder pigs with an RT of five days.

The objective was to remove 75% COD of the influent. The digester was being fed three times per day at various daily loading rates to measure the performance.

The on farm digester went into operation in April/May 1985.

A vibrating screen separator with 20 mesh screen was used on the prepared influent. The screened solids were bypassing the digester and going directly to the effluent storage.

The raw swine manure contained 5 to 6.8% TS with 70% being VS. The prepared feed delivered to the farm was believed to be cereal grain based.

(b) System

The 3.7 m diameter by 6.1 m digester tank was of concrete with exterior UV protected insulation and set partially below grade. See Figure 10. The four m long fixed film tube bundles were supported above a sloped digester floor leaving a 1.5 m head space for gas. Access for sludge removal from the sloped floor was available.

The digester slurry was being recirculated 10 to 12 times per day by an external pumping system set to operate intermittently e.g. 15 min every 30 min.

The working volume of the digester was 50 m^3. The fixed film tubes (see Figure 3) provided a fixed film area of 100 m^2/m^3 for a total of approximately 5000 m^2 of surface area for bacterial adhesion.

An 80 m^3 flexible bag storage in an unsealed metal tank was available for biogas storage. See Figure 10.

(c) Comments

Preliminary tests had given yields of only 40 to 45 m^3/d of biogas relatively high (0.2%) in H_2S. The specific gas ratio was less than one which indicated a low digestibility of VS. These results are consistent with experience at Linden Lee Farms (PEI) where the hog ration is also cereal grain based.

Because of the high H_2S content of the biogas, CRIQ personnel were working on a revised formulation of FeO in anticipation of cleaning the gas prior to use in an internal combustion engine.

Cogeneration - When visited (Sept 1985), a 10 kW induction generator unit was being installed for test purposes.

Instrumentation was also being put in place to monitor the gas bag fill (height) within the steel tank. The sensors would provide start/stop control of the cogeneration system, hopefully at lower gas pressure differences than have been experienced by other operators using compression type storages.

The farm site chosen offered another interesting use of the biogas. The farmer has been composting separated manure solids as a secondary business. He also has two greenhouses in which off season tomatoes, etc. are grown. The greenhouses are in close proximity to the digester and provide an excellent opportunity for use of biogas directly as heating energy.

(d) Benefit Perception

The farm owner indicated that he was not under pressure to reduce odors. However, the proximity of a number of residences to the large swine operation would indicate that odor reduction could be desired, Cogeneration was not high on the priority list as Hydro Quebec provides relatively cheap electrical power with no buy-back arrangement as of Sept 1985. Permission had been obtained for interconnection on an experimental basis. Use of all power generated by the 10 kW generator was likely to occur on that farm to offset purchased power.

The probable use of ‘waste' heat in the greenhouses should be monitored with interest in the next year or two.

3.3.3 Kemptville College of Agricultural Technology - Kemptville, Ont.

A relatively small fixed film research oriented digester was funded by the Ontario Ministry of Energy directed through the OMAF Agricultural Energy Centre. Agriculture Canada provided funds for monitoring the system performance.

The main objectives were to provide a farm scale digester that could be used to treat wastes from different types of animals under closely controlled conditions. The College location also provided an interdisciplinary pool of experts to facilitate testing of directly related benefit theories such as refeeding ROAD to animals and crop utilization of treated effluent.

(a) Input

For the first testing period the liquid fraction of beef manure from 160 adjacently housed animals was the influent. The manure availability rate varied from 0.9 to 1.36 m^3/d, with a mean of 1.28 m^3/d. The manure was separated using a vibrating screen separator at three to four day intervals and diluted to a desirable TS level of approximately 70 kg/mJ. The influent was blended with recirculated slurry in the ratio of about one to three for prewarming prior to entry at the top of the digester.

This influent was used from startup in November 1983 to May 31, 1984 and for further testing after digester revisions prior to shut down during our visit in September 1985.

(b) System

The digester was designed as a vertical above grade digester 3.5 m in diameter and 5 m high providing an operating volume of about 30 m^3. The tank is a coal tar epoxy-lined steel tank vertically packed with supported 2.9 m bundles of 100 mm tubes as fixed film media. See Figure 3.

Unlike the other two units provision was made for mixing of slurry internally. A vertical steel tube containing a reversible, submersible pump was located at one side. This pump could be operated to move slurry up or down through the tubes continuously or intermittently.

A pipe type water-to-slurry heat exchanger was located horizontally below the media support. The tank bottom is conical to facilitate sludge removal. Separation - A vibrating screen separator removed coarse solids (screenings) from the influent for direct land spreading. A polymer feed pump introduced a precipitating polymer into the effluent prior to the high speed centrifuge used to produce 18 to 20% dry matter cake (ROAD) for refeed trials.

The centrate (liquid fraction) from the centrifuge is directed to a large circular concrete storage tank for holding prior to land application.

Biogas production/storage/use - The biogas is pumped to a medium pressure steel storage tank at 35 to 70 kPa. Biogas is presently being used in a dual fuelled hot water boiler to heat the digester or discharged when not needed.

Cogeneration - Provision was made to install an engine generator set for demonstration purposes. It has not been installed.

Total system cost was about $195,000.

(c) Comments

Initially the digester system worked well. At the mean loading rate of 1.28 m3/d the digester produced 34.3 m^3/d of biogas, the RT being about 23 days. This gave a specific gas ratio of 1.1 m^3/m^3/d. It should be noted that the beef animals were being fed a high energy corn based ration.

Biogas quality was somewhat lower than desirable however, having only 51% CH_4.

Near the end of the 149 day test period, as reported by MacDonald et al, 1984, the mixing pump was turned off. Gas production fell sharply, indicating that the digester was acting as a totally mixed system-only. Digester access revealed that fixed film media tube bundles had floated up into the gas head space. Further inspection revealed that several tubes were clogged with undigested manure solids. The trapped biogas then caused them to be buoyed up out of the liquid.

This type of clogging and gas entrapment has not occurred to date with either of the other fixed film digesters operating with swine wastes. It was concluded that even after coarse screening the beef manure influent had too high a TS content.

During the summer of 1984 the fixed film media was removed for cleaning and the digester restarted without the fixed film media. The digester has operated successfully as a totally mixed system on the screened beef manure.

Nitrogen changes during digestion - Some very preliminary field tests with the liquid centrate at Kemptville indicate a possible reduction in nitrogen availability for crop utilization.

This hypothesis may be supported by results given by MacDonald et al, 1984. They show that the total Kjeldahl nitrogen (TKN), that is the organic nitrogen plus ammonia nitrogen, is conserved through the digestion process. However, the ammonia nitrogen component increased while the organic nitrogen component decreased during digestion. Since ammonia (NH_3) nitrogen is volatile it may well be lost from the effluent storage prior to land application.

The possible loss of available plant nitrogen should be researched further since it has always been assumed that no loss of plant nutrients occurs during the anaerobic digestion process. This assumption had traditionally been based on TKN or total nitrogen content.

Refeeding - No research data or opinions on refeeding of ROAD were put forward at the time of visiting the digester in September, 1985.

(d) Benefit perception

This is a research installation, thus the same criteria are not applicable.

The unit was designed to be versatile for testing purposes but close enough to farm-scale to be useful for demonstrating the technology to visiting farmers and other groups.

3.4 Visits - other anaerobic digesters

3.4.1 Fallis Farm - Peterborough, Ont

The construction of this digester, probably the first farm scale unit in Canada, was started in 1977. Agriculture Canada provided funding at a time of rapidly escalating energy costs to determine if a relatively low technology system could reduce energy dependency.

(a) Input

The farm presently has a 95 sow (arrow-to-finish operation on site. All the manure was collected in a concrete tank at the end of the barn and transferred to the digester by a pump.

(b) System

A 6.1 m diameter by 3.7 m high insulated concrete silo was built below grade with only the insulated concrete roof protruding. This unit provided a working volume of 85 to 90 m^3. The influent was pumped in via a pipe below the liquid surface thus causing effluent to be displaced though a 150 mm pipe - later changed to a 300 mm pipe.

The digester design was obviously based on the experimental Penn State digester (Persson et al, 1979), but did not incorporate the dividing wall.

The digester slurry was to be heated by a black iron pipe system in the digester supplied by hot water from a dual fuelled (LPG and biogas) boiler. Mixing was to be accomplished by pressurized biogas and diffusers) located at the bottom of the tank.

No biogas storage was ever put in place.

(c) Comments

Due to inadequate mixing, sludge accumulation became a serious problem. The effluent pipe was eventually shortened to 1.2 m below the liquid surface to get the intake end out of the sludge and prevent plugging.

Biogas production never stabilized sufficiently to permit its use in the hot water boiler - or to heat the farrowing/nursery units.

The system was continually modified until the heat exchanger pipes corroded and started to leak in 1984. At this point the system was abandoned.

(d) Benefit perception

The farmer had hoped to be more energy self sufficient by providing biogas to heat the farrowing/nursery units.

He had also realized the benefits provided by odor control and is still very positive about the future of anaerobic digestion. However, he is not prepared at this time to invest the amount of money required for the more sophisticated systems being tested. If technology developments reduce capital costs he will likely try again.

Interestingly enough, to avoid odor problems, he had recently located a large 24.4 m diameter by 3.7 m high concrete manure storage literally half way back the farm. Once per week he pumps manure from the holding tank underground via 100 mm PVC pipe to the big storage.

3.4.2 LEL Farms Ltd. - Guelph, Ont.

This digester was built at the expense of the owner, primarily to control odors from an extensive swine complex. Poultry facilities are also located on the farm.

(a) Input

Only a portion of the swine manure is being put through the digester. The manure is flushed from some of the barns to a mixing pit from which it is pumped into the digester. The present throughput rate is about 12.3 m^3/d with an RT of 31 days. If the total farm manure production was put through the digester the operator estimated the RT would be reduced to the five to six day range.

A high capacity centrifugal separating pump had been purchased to remove solids prior to digestion but was not operating in August 1985.

(b) System

The below grade tank type digester has been in operation for three years. A rectangular 9.1 by 12.2 by 3.7 m deep concrete insulated tank with floating insulation panels (0.6 m by 2.4 m by 50 mm) makes up the digester.

The entire tank is covered with a flexible membrane cover to provide gas storage. The digester and cover is not covered for wind and snow protection. See figure 11. The operator attempts to maintain mesophilic digester temperature by burning biogas in a modified gas boiler and supplying heat by a water piping system within the digester.

If and when biogas production is adequate, plans call for supplying hot water heating to the furrowing/nursery units.

(c) Comments

While the digester system is very rudimentary it does work - primarily because of true operator commitment and ingenuity.

If the wind blows when the flexible cover is not fully inflated, air is blown in to prevent billowing. The addition of air (oxygen) is probably a cause of low quality biogas. Problems have been encountered in maintaining combustion in the hot water boiler. The biogas is expelled when digester heating is not required.

The addition of a rigid frame cover over the digester unit should be a priority to prevent cover damage and eliminate the need for air addition. Adding air (oxygen) will have an adverse effect on the anaerobic bacteria.

(d) Benefit perception

The major reason for operating the anaerobic digester is odor control. If digester utilization is increased to treat all the manure produced, the additional capital and operation cost will have to be at least partially justified by energy recovery for heating.

Cogeneration, being capital intensive, is not being given serious consideration at this time.

3.4.3 OMAF Research Station - Arkell, Ont.

Extensive research facilities are in place with research funds from the Ontario Ministry of Agriculture and Food, the Ontario Ministry of Energy and some financial support from the Ontario Pork Producers Marketing Board.

Professor Jacob Pos of the School of Engineering, University of Guelph, has dedicated much time and effort to these facilities and to all of the related research conducted here.

The laboratory scale, pilot scale and farm scale systems have provided a wealth of background information for commercial designers of anaerobic digester systems. An overview of the facilities are given in Figure 12.

For purposes of this report the facilities will not be described in detail. This information is available. See references: Pos et al, 1981; Pos et al, 1984; Pos et al, 1985; and Eszes and Pos, 1985.

The fundamental work that has been conducted however, will assist in many of the conclusions drawn about system design and application.

Present research is devoted to gas cleaning and scrubbing as well as totally new digester designs. This work needs to continue in order to provide answers and trained personnel in the field of anaerobic digestion for Ontario and Canadian farms.

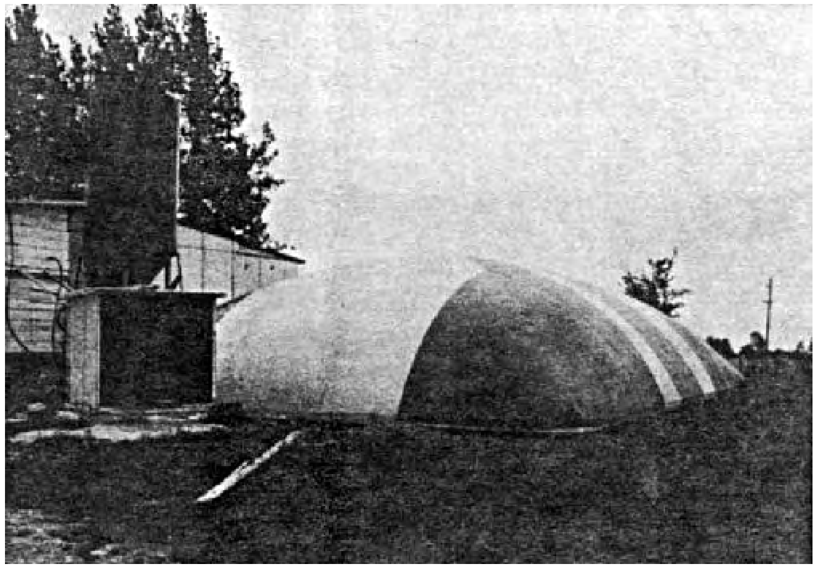

Figure 11. A simple anaerobic digester with unprotected flexible membrane gas storage. Slurry preparation pit and pump are located at left.

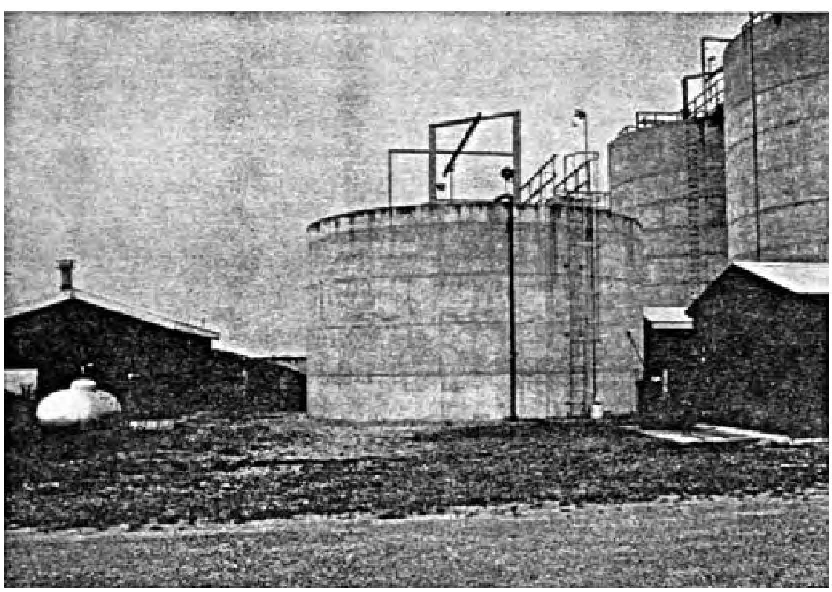

Figure 12. An overview of the OMAF anaerobic digestion research facilities at Arkell, Ontario

4.0 EVALUATION

4.1 Anaerobic Digestion

Based on the visits to farms and discussions with operators there is no doubt that anaerobic digestion of animal manure does indeed reduce odors. That in itself is a very positive factor in continuing the effort to develop on-farm digester technology. Unfortunately odor control offers no directly measurable financial incentive for an animal producer to spend even 20 to 50 thousand dollars.

If anaerobic digestion is to be an integral part of animal production facilities some other benefit or some other interest group must provide the financial incentive. The on-farm benefits result been perceived to be in two categories: direct energy as a result of effectively using biogas; and savings by refeeding a portion of the digester effluent.

4.2 Digester Types and Performance

Based on farm visits and other reference material it appears that present on-farm digester experience is providing some guidelines and bringing forth some additional questions - primarily about available basic data for design and performance predictions.

Indications are that the lower cost, because of potential farm labor use, tunnel type (plug-flow) digesters are only suitable for high strength scraped manure. Flushed manure with less than 10% TS tends to separate rather quickly into three layers. The settled sludge reduces digester volume. The floating scum prevents gas escape. Effective mixing in a long shallow digester would be difficult and energy expensive.

Totally mixed digesters are normally circular and can be built with silo building technology. They appear to offer maximum flexibility of input materials. Separation can still be a problem if total mixing is not effective. Continuous or even intermittent mixing can be energy expensive - utilizing a significant portion of even cogenerated energy. Some of the digesters visited require 4 to 10 kW for mixing.

Research efforts have been directed to no-mix digesters (Ben-Hassan et al, 1985). The success with various influents in large, farm-scale digesters has yet to be proven. Mixing techniques and equipment for farm-scale systems needs further investigation to reduce both initial and operating cost.

Fixed film digesters have been field tested and appear to work well with low strength (TS content) manures. The Folkema and CRIQ units are both receiving prescreened hog manure with TS contents below five percent. The prescreening, while desirable, will undoubtedly remove some volatile solids which become unavailable for biogas production. If the screened solids can be used effectively as at the CRIQ and Cattleland Ont installations for composting and sale then removal would not be a determining factor. If maximum biogas production is the objective then prescreening is undesirable.

Most arguments in favor of the fixed film digester indicate lower digester costs and reduced heat losses. Both of these can be set aside. If the cost of the fixed film media is high ($\$130/m^3$) when combined with other support costs, etc. and considering the mixing/heating restrictions imposed, the initial costs might better be directed to increased digester sire. When digesters are built `square', that is the diameter and height approximately equal, the shell heat losses from a moderately insulated digester are small when compared to the preheating requirement of the digester influents which will be equal.

Fixed film digesters must then be justified by other means such as more gas production per kg of VS added. At this point in time, field experience is not sufficiently supportive of this benefit. Too many other variables appear to be overriding biogas productivity, such as the ration components of the animal feed, and the loss of available volatile solids by prescreening. It is estimated that as many as 20% of the volatile solids may be removed depending on the influent material and the degree of solids removal.

There is no doubt, based on available literature such as Van den Berg and Kennedy, 1983, that prevention of microorganism washout is indeed desirable. However, the fixed film media may have to take on a different configuration and possibly be moveable if it is to work effectively in high strength wastes.

4.3 Biogas Production and Quality

Raw biogas is indeed a useful fuel. It can be burned to produce heat directly or used to fuel an engine to provide electrical power and produce heat from the engine coolant and exhaust. Figure 13 shows biogas fired boilers while Figure 6 shows a typical cogeneration system.

Biogas has a high water vapor content that must be condensed out as early as possible in the handling system. This can be done with some form of cooling heat exchanger on a vertical gas pipe. The condensate collected in water trap(s) must be removed on at least a daily basis.

Biogas will contain CO_2, H_2S and other gases as well as the desired CH_4. At this time it is doubtful that removal of 30 to 40% CO_2 can be justified. While creating a sluggish rate of burn, compensating adjustments in burners and engines appear to permit satisfactory performance. A reduction of storage volume is not likely to justify the purchase and maintenance costs of a CO_2 scrubber unless a very simple system becomes readily available.

All farms visited that were operating stationary engines on biogas were using natural gas engines, except one. When operated on biogas the timing had to be advanced a significant amount to compensate for the slow burning characteristics. The engines also had to be de-rated in power output by 30 to 40% to compensate for the CO_2 dilution of the combustion mixture.

Since biogas has a relatively high octane number, higher compression engines are desirable. One farm (Cattleland, Ontario) and research by Eszes and Pos (1985) both support the concept of using a diesel engine. With the diesel engine the biogas is aspirated into the air stream and the injection of a small amount of diesel fuel initiates combustion. Again the engine output must be de-rated and some (about 10%) diesel fuel is required.

To burn biogas in natural gas or propane equipment, the orifice size must be increased and the air entrainment port(s) decreased. For further information see Pos, 1985, p 43.

The existence of H_2S or other compounds of sulphur can create problems. When combined with water they create acids which are corrosive. Field observations indicated that copper and galvanizing materials are the most vulnerable.

Research efforts are being directed, and should be continued, to find an economical H_2S removal mechanism to enhance the value of biogas as a fuel.

It also appears from the literature and from field observations that the percentage of H_2S produced is variable from less than 0.1% to 1.0%. The general consensus is that levels of 0.1% or less are tolerable and obtainable directly from some anaerobic digesters. A field study combined with laboratory analysis might be able to ascertain the digester conditions affecting H_2S production. This approach might provide a more viable alternative than cleaning the gas if `the condition' can indeed be isolated.

4.4 Biogas Utilization

There is no doubt that biogas is more efficiently utilized as a heating fuel than as a producer of electrical energy (Nemetz, 1984). Unfortunately biogas cannot be practically liquified for long term storage. The energy required and equipment costs for even high pressure compression storages are prohibitive. Thus, biogas must be used - if it is to be used at all - on a daily basis. Even temporary storage involves a cost in gas pumping (Figure 14) and storage. Figures 15, 16, and 17 show three types of low pressure, short term biogas storage units.

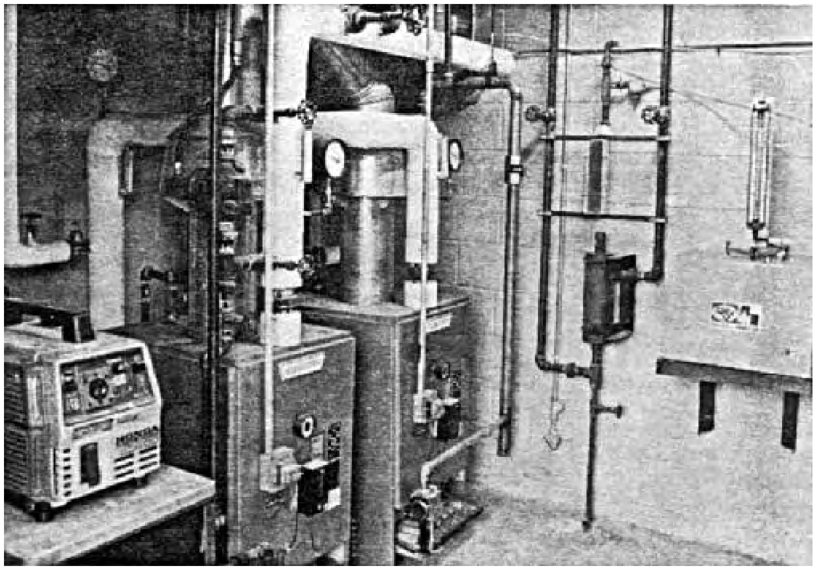

Figure 13. Biogas fired boilers produce heat for digester heating or other applications

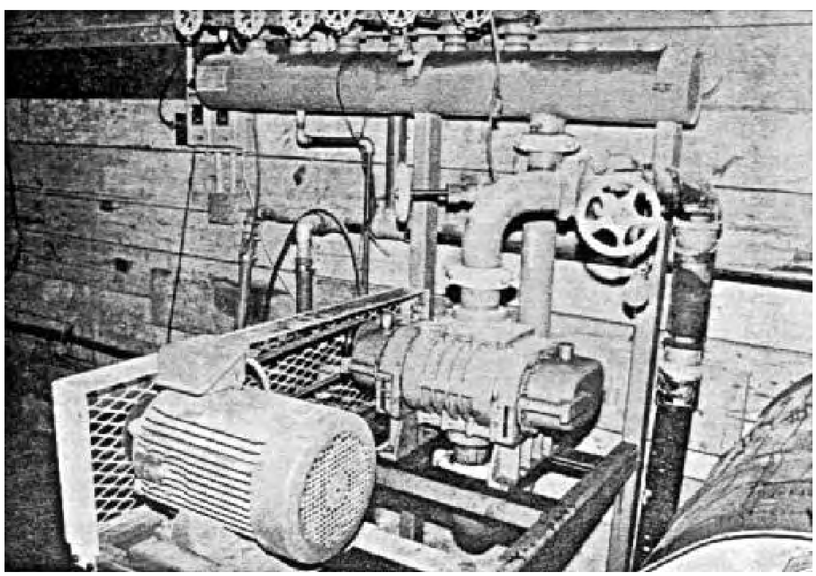

Figure 14. Biogas pumping equipment to circulate or deliver biogas to storage or point of use

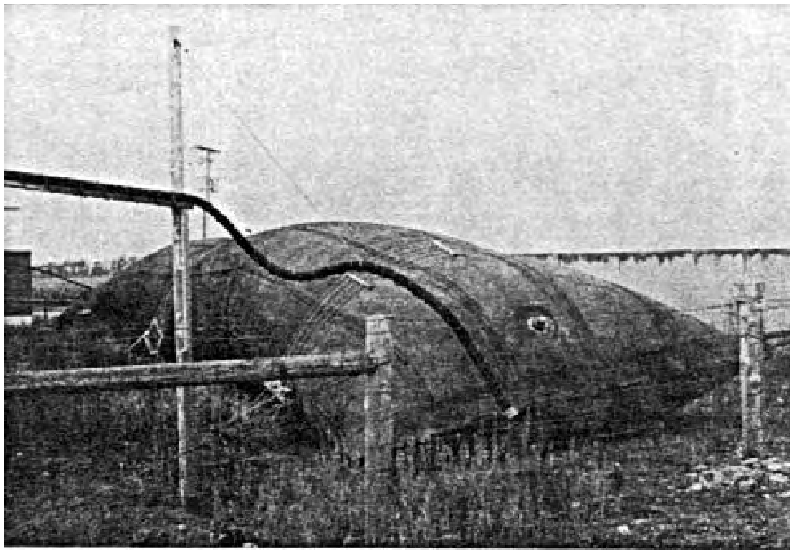

Figure 15. A flexible, unprotected, membrane type biogas storage. Note the three tie downs required for restraint.

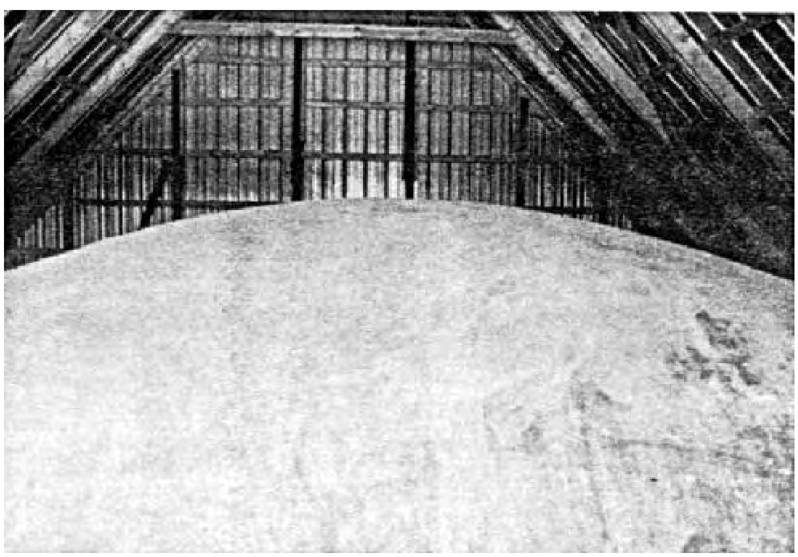

Figure 16. A flexible membrane type biogas storage protected from wind and snow by an A-frame structure

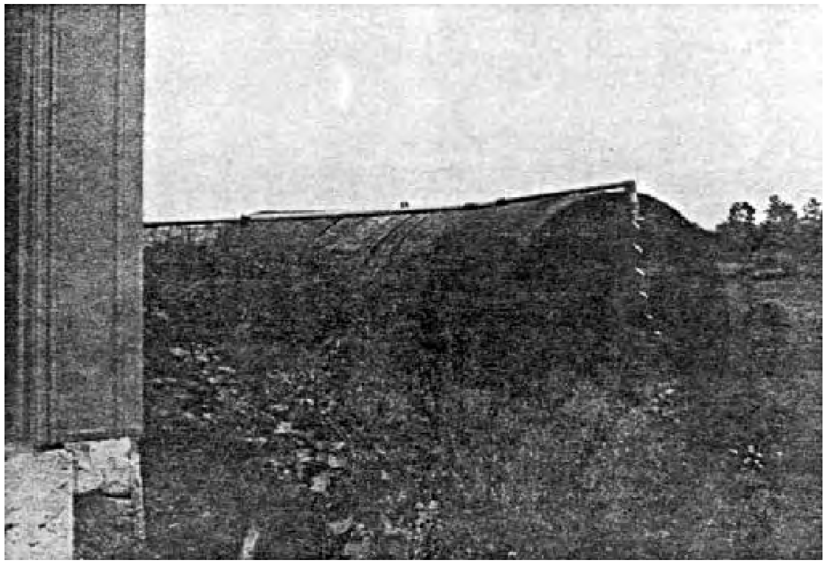

Figure 17. A flexible membrane type biogas storage protected from wind and snow by a used petroleum tank

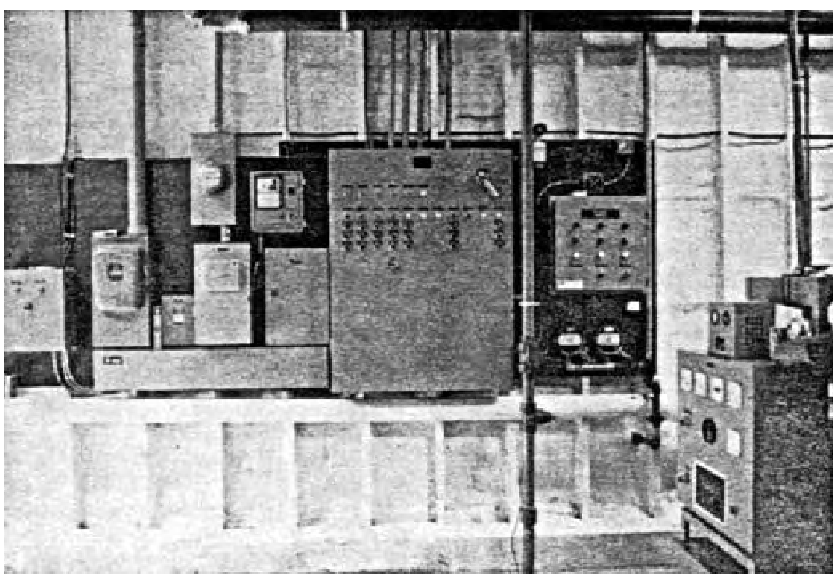

Figure 18. The electrical control system to monitor and interconnect a relatively small cogeneration system in Ontario

With present technology, electrical generation is the only practical alternative for daily biogas use on most farms. While generation of electrical energy is an inefficient use alone (20 to 25 % efficient), cogeneration, where heat is recovered from the engine coolant and exhaust, can bring the combined efficiencies up into the 60 to 80%. range. This is attractive but also has limitations.

Sizing of cogeneration equipment is critical. The biogas demand must approximate production rate. Some reserve capacity can be retained in low pressure storage units but they can add significantly to the capital cost. However, even with storage matching electrical production with time of day demand on most farms is nearly impossible. A rare exception, by virtue of scale, is the Mason-Dixon farms where they milk 20 h/day. Most animal farms have two significant peak demands of about two hours each, corresponding to milking/feeding times.

If the cogeneration systems can meet the daily kWh requirement but not the demand (kW) requirement the system is doomed to economic failure in most Canadian jurisdictions. The cost of equipment to safely interconnect with the utility is high (10 to 30 thousand dollars). See Figure 18. But this interconnection only solves the demand problem for most Canadian locations. The buy-back rate offered by most utilities is well below the cost of production by these relatively small cogeneration systems. The political implications of asking for legislation to provide buy-back at even retail rates, which could support some cogeneration systems, could be very controversial. Figure 19 shows a US interconnection where all power produced is delivered to the utility grid.

If retail rate buy back was legislated for energy purposes only, it could be misconstrued as another farm subsidy bill. If, however, the benefits of anaerobic digestion and associated cogeneration to recover costs were promoted as a means of reducing environmental pollution then the legislation would be much more acceptable. Even this legislation could be questioned. Perhaps animal producers who are forced to use anaerobic digestion (or other means) for pollution abatement, primarily odor control, should be offered a grant-in-aid through the local municipality where the concern is raised.

Figure 20 shows greenhouses adjacent to an anaerobic digester. This is a very site specific opportunity for alternate biogas utilization - but only for a portion of the year. Canadian farmers cannot be expected to diversify and spread management and risk solely for the purpose of utilizing biogas unless the returns justify the means.

Economical and practical short term storage (12 to 24 hours), of biogas would resolve conflicts in cogeneration for many animal producers. The storage systems at CRIQ (Figure 10), Gasser Farms (Figure 17) and Folkema Farm (Figure 16) appear to

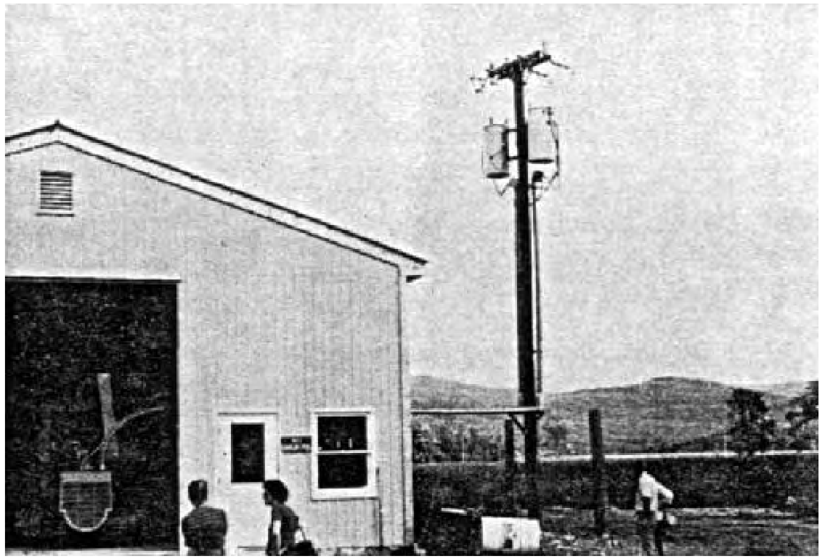

Figure 19. All electrical power produced at this US location is delivered directly to the utility grid. A control system not shown is located in the generation building

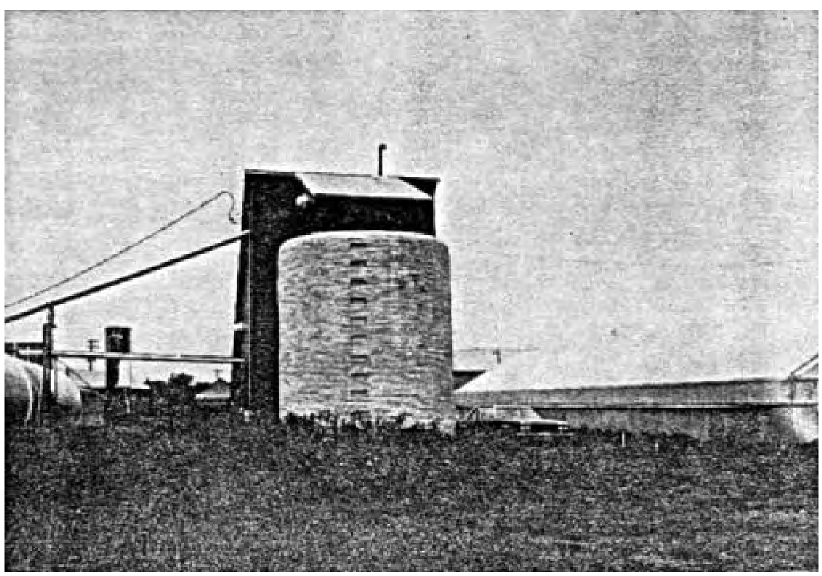

Figure 20. Two greenhouses are located to the right of this digester and will utilize biogas heat directly or through cogeneration

offer the greatest flexibility for short term storage at present. Research efforts should be directed to more cost effective biogas storage systems if energy self sufficiency via cogeneration is to be realized on Canadian animal production farms.

4.5 Digester Effluent Utilization

Without further processing or treatment, digester effluent is probably limited to land application as a means of disposal and a source of fertility or organic matter. The means of application is in this situation no different than the disposal method used on the farm if in fact no digester unit were installed.

Figures 21 and 22 show raw dairy manure and digester effluent respectively. Note the reduction of scum. Odor reduction was also evident during site visits.

The value of the effluent as a fertilizer following digestion is worthy of discussion. General opinion supports the idea that there is very little, if any, nutrient change during digestion. The odor is greatly reduced and part of the total nitrogen is converted to a more volatile form, ammonia. This then means that storage, application and incorporation may be more critical in order to maintain nutrients than with raw manure. Opinion was expressed that because of the change of the form of nitrogen in the digestion process that the effluent was not equal to non-digested manure in held trial applications.

It would appear that there are sufficient differing opinions to warrant further field trials as to the value of digested vs non-digested manure as a fertility source under farm operating conditions.

4.5.1 Effluent Separation

To further use the effluent from an anaerobic digester it is necessary to separate the solids from the liquids. A scalping process before residue of anaerobic digestion (ROAD) recovery (Selves Farms) reduces difficulties in final recovery and eliminates larger, primarily indigestible solids which can be used effectively as soil conditioners. Figure 23 shows the scalped solids provided by the screening unit shown in Figure 7.

The addition of a polymer prior to centrifuging assists in separating out smaller solids of the effluent. This ROAD is a grease-like sticky mass which can be pumped and added to rations to be refed. Figure 8 shows the centrifuge unit.

Other uses of separated solids could be composting or bedding, although securing a product with a low enough moisture content for bedding is difficult. US experience has not been encouraging.

Figure 21. This is raw dairy manure held in a tank prior to land application. Note the scum buoyed by gas production in the tank

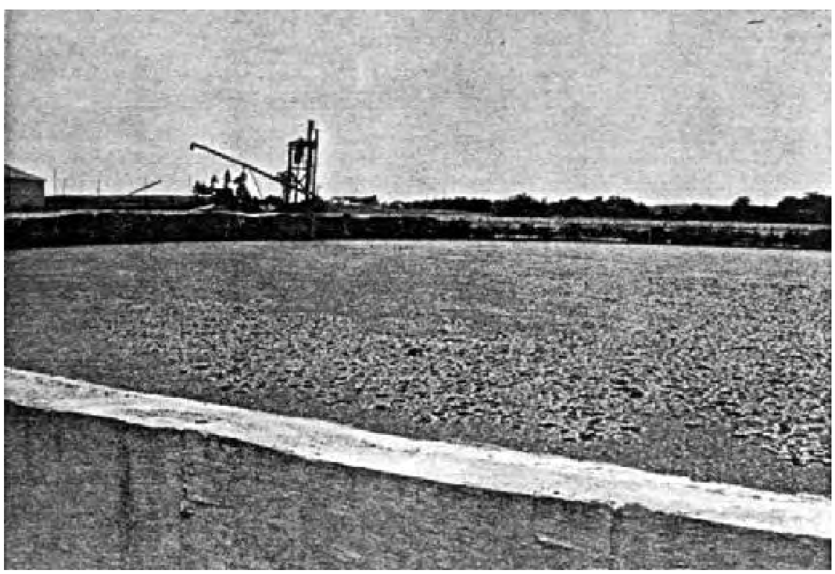

Figure 22. This is digester effluent from a dairy operation held in a tank prior to land application. Scum and odor are both greatly reduced

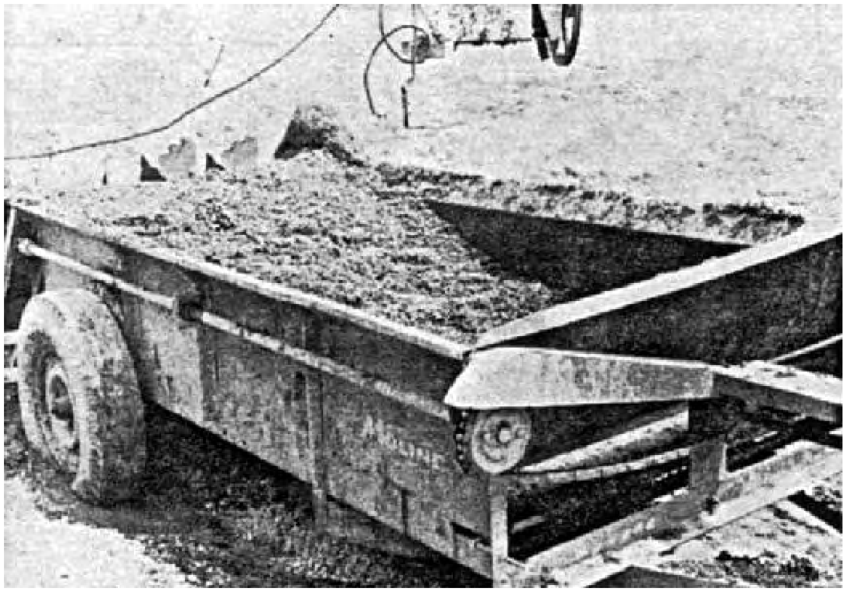

Figure 23. The scalped digester effluent solids are collected for land application as a soil conditioner

4.5.2 Product name

The name of the centrifuged product has been referred to as single cell protein (SCP) or methane fermentation residue (MFR). The product does in fact contain single cell protein as a result of the fermentation process within the digester. It also contains many other components.. The name single cell protein is somewhat misleading relative to other processes designed to produce true single cell protein material. Similarly, the name methane fermentation residue does not accurately reflect the product since methane is only part of the produced biogas.

The product is indeed the residue of anaerobic digestion. Consideration should be given to using this term to avoid conflict in the future. ROAD (residue of anaerobic digestion) for short might eliminate some of the confusion which obviously exists at the present time.

4.5.3 Feeding ROAD

The nutrient composition of ROAD produced from beef cattle and swine digester residue was determined at the University of Guelph (Mowat, et al, 1985). See Table 1. It should be noted that the swine were fed a corn-soybean meal based ration.

Table 1. Nutrient Composition Of ROAD Produced From Beef Cattle And Swine Wastes.

	Mean*		**Range**	
Nutrient	**Cattle**	**Swine**	**Cattle**	**Swine**
Dry matter (%)	20.7	22.6	17.1 - 28.6	19.6 - 25.6
pH	8.3	8.4	8.0 - 8.6	8.1 - 8.6
Composition of dry matter				
Crude protein (%)	24.7	37.5	21.9 - 27.0	33.2 - 42.8
True protein(%)	14.7	18.7	9.4 - 18.4	14.6 - 22.2
NH_4 - N(%)	1.54	2.89	1.16 - 2.09	2.19 - 3.48
NPW - N(%)	1.59	3.02	1.25 - 2.01	2.20 - 3.61
Ether extract (%>	8.9	11.2	5.1 - 12.3	8.5 - 16.1
ADF (%)	27.2	8.9	22.2 - 29.8	8.0 - 10.3
NDF (%)	35.7	22.3	28.7 - 39.9	19.4 - 26.2
Lignin (%)	12.6	4.3	10.1 - 15.0	2-5 - 7.8
ADF N (%)	0.81	0.23	0.65 - 0.94	0.10 - 0.28
Gross energy (kcal/g)	3.0	3.2	2.3 - 3.5	2.7 - 3.6
Ash (%)	36.4	36.4	30.0 - 43.1	30.4 - 42.3
Calcium (%)	6.2	5.5	5.3 - 8.9	3.5 - 6.6
Phosphorus (%)	1.6	5.1	1.3 - 2.2	2.4 - 6.5
Magnesium (%)	1.1	2.1	0.6 - 1.6	0.7 - 3.0
Potassium (%)	1.2	1.0	0.5 - 1.6	0.7 - 1.5
Manganese (ppm)	281	743	241 - 382	240 - 1147
Copper (ppm)	56	500	43 - 67	201 - 786
Zinc (ppm)	240	1356	185 - 300	481 - 2215
Iron (%)	0.38	0.44	0.11 - 0.52	0.15 - 0.94
Sodium (%)	0.55	0.27	0.33 - 0.73	0.20 - 0.31

* Observations per mean with samples taken every two weeks. Adapted from 'Nutritional evaluation of residue from methane fermentation of animal wastes.' Mowat et al. 1985.

Mowat et al (1985) concluded that the ROAD produced from cattle wastes has little, if any, feeding value for beef cattle. When ROAD was the only supplemental protein source, growing cattle had markedly depressed weight gain and feed efficiency. The reduced performance was shown to be due, at least in part, to low nitrogen and energy availabilities. ROAD produced from swine wastes has a much greater potential as a feed source but mainly for beef cattle. The potential was shown to be much greater than cattle ROAD because of the higher crude protein (CP) and energy contents as well as improved CP and DM digestibilities.

This combination of utilization severely limits the farming operations that could make use of ROAD as a feed since there are relatively few large beef and hog operations which are part of the same farm. The idea of selling ROAD as a feed to another operation might be possible. However, in Canada an animal feed must receive federal approval before it can be sold to other producers. At the present time there are no federal standards concerning acceptable levels of heavy metals or antibiotics, nor are there procedures which producers of these materials are required to follow to insure adequate destruction of pathogenic organisms in order for the ROAD produced to be acceptable as a registered feed for sale. Therefore, legally all ROAD produced must be used on the producing farm.

4.5.3.1 Antibody build up

Any refeeding program may result in a concentration of ingredients or components of the material. In the case of antibodies this could have a positive result because of the build up of immunities within individual animals. Such positive results are extremely difficult to quantify because they come under the general heading of preventative medicine. Given that animals are relatively healthy to begin with, the argument for feeding ROAD as an innoculent to prevent disease becomes rather weak. Indeed, the possibility of introducing an undesirable bacteria or antibody in the ROAD is very real, either in spreading a problem within an operation or in introducing a new problem if the ROAD is being fed to livestock in barns other than the one where a problem may have initiated.

4.5.3.2 Heavy metals

The build up of heavy metals within a livestock population being fed ROAD has to be a major concern. Like micro-organisms, the extent of the build up will be in direct relationship to the levels present in other feed components. A significant level of heavy metals in a feed ration will exacerbate the possibility of unacceptable heavy metal concentrations in livestock products.

Research into heavy metal concentrations and acceptable levels is likely to continue in areas affecting crop production and manure or sewage sludge application to soil for crop production. The concern over heavy metal concentration in sewage sludge as it affects crops has been in the minds of many potential producers or users of ROAD as that concern was expressed during on-farm interviews with digester owner/operators.

There is little doubt that this concern is real and would have to be fully addressed before any ROAD feeding program could become general practice.

It is therefore recommended that any projects considered in the future involving the feeding of ROAD include criteria to examine heavy metals that might be present. An alternative would be to expand present research involving the effects of heavy metals in crop production where the concern is primarily with the effect of sewage sludge on land and subsequent uptake by crops grown on that land. It may be possible to correlate present information and levels of safety which would need to be established for ROAD if it were fed to livestock rather than applied to land.

4.5.3.3 Palatability

Results from experimental and field experience indicate that one of the major problems associated with feeding ROAD is intake by the animals. This problem came to the forefront in experiments by Mowat et al (1985), during steer feeding trials conducted at the University of Guelph, in trials conducted by Buchanan-Smith when feeding dairy cattle at the University of Guelph and at Selves farms when swine were fed under practical farming conditions.

As might be expected there were fewer problems, with less rejection at lower levels of substitution, but this rejection became more apparent as increased amounts of ROAD were substituted for normal protein supplements. Efforts to overcome the palatability factor have included a slow change-over rate for substitution of protein in the ration. This is an improvement over sudden feed changes but has presented a problem in the past, and may in the future if a reliable, constant source of ROAD is not available as might occur when the digester is not active, for mechanical or other reasons.

An attempt to entice swine to eat more ration containing ROAD has been underway at Selves Farms with the addition of artificial flavoring. The flavoring used was apple but preliminary results have not shown whether this practice will be either practical or profitable.

The experience encountered with beef, dairy and swine would all indicate that supplying all or even a major portion of the animals' calculated protein needs from ROAD has serious limitations in getting animals to consume the ration.

4.5.3.4 .Minerals

The possibility of focusing the usefulness of ROAD in a ration as a source of mineral rather than protein is worthy of examination. Selves Farms estimated that when 100% of the supplemental phosphorus was coming from ROAD a saving of about seven dollars per tonne could be realized. The ration could be balanced for phosphorus at relatively low levels of substitution for protein which means that palatability problems would be minimized. Selves Farms is concerned with phosphorus levels becoming high in their field fertility and therefore may be unique by not wanting to increase phosphorus levels any more than is necessary.

The economics of establishing a recovery and separating system for mineral purposes is questionable, but taken on a marginal factor basis, may be worthy of examination. A monitoring of the Selves' experience may give an indication as to whether or not additional efforts should be directed towards mineral substitution by ROAD in rations.

4.5.3.5 Philosophic considerations

Support for programs which involve the feeding of animal wastes should not be taken in isolation of the social and political realities which our society will accept. Controversy has existed in the past concerning the feeding of dry poultry manure as a source of protein to beef cattle. Although such a practice may make sense from an economic point of view, the perception from a public point of view has caused at least one major packing company to establish a policy which states that they will not knowingly process beef from a feedlot which is feeding dry poultry manure.

Governments and companies dealing in food products are much more sensitive to perceived concerns by the public than are researchers and primary producers who tend to focus their attention on the real concerns based on facts. It matters little what the real facts may be if the perception by the public is that there is something not right with a feeding program which involves the refeeding of manure or some by-product *of* a manure fermentation or digestion process.

It may be easy to justify and defend the economic reasoning for feeding programs using ROAD but the social acceptability by society of such a feeding program may elude logic.

The political realities of the feeding practice ever becoming an issue, perhaps as the result of over zealous or inaccurate press reports, are fairly obvious. It is doubtful if a politician would defend the use of ROAD as a protein source if pushed to make a choice. It would, for example, be more politically popular and socially acceptable to assure the public that food products are not produced from animals being fed any form of recycled manure. Producers and processors of food such as milk would be ill-advised to allow themselves to be open to any suspicion of unorthodox feeding methods. The fact that food quality may not in any way be affected would be irrelevant should some individual or group take up the cause against feeding ROAD and be successful in stirring up adverse publicity.

4.5.3.6 Summation

We therefore face a dilemma in deciding the direction to suggest in terms of feeding ROAD to beef, dairy or swine. There is no doubt that the construction of a digester unit and separation equipment necessary to recover protein for livestock feed is not feasible if the major purpose is to recover protein. Evidence appears sufficient to suggest that the obtainable protein supplement will not satisfactorily replace most of the protein in beef, dairy or swine rations.

The question then becomes as to whether or not any use can be made of ROAD should the digester be established for another reason such as odor control or biogas production. Because additional processing in the form of separation is necessary, and because capital and operating costs are high and because to date results with feeding ROAD have been negative, it does not appear that this feeding option should be pursued.

Analysis seems appropriate at the present time as to whether or not the recovery of minerals in ROAD is of sufficient value to warrant continued applied research. This work is presently underway at the Selves Farms with the assistance of Canviro and should be supported until a practical conclusion is attained. Phosphorus is seen as the mineral most likely to have enough value to warrant further evaluation of ROAD.

The effluent as a fertilizer for soil application can, after separation, be pumped through irrigation equipment with the solids applied by spreader. Although this may be an advantage, the same advantage exists by using a separation device on undigested manure, because it is primarily a mechanical elimination of solids that may clog irrigating equipment. There is an argument that the solids break down more after digestion, but differences are not likely to warrant using the digestion process solely to make material easier to apply from a mechanical point of view.

It is our opinion that field trials using digested effluent vs non-digested manure-should be undertaken to determine if differences do exist in crop yields.

It is our over-riding opinion that extreme caution be exercised in any research or recommendations involving the feeding of ROAD to livestock. The usefulness of ROAD as a protein supplement is questionable and indeed negative in most research to date. The acceptability of the practice of feeding ROAD may be tolerated at the present time but could be challenged, given an incident or press report bringing the practice to public attention.

The risk of economic loss caused by imposed restriction, whether by government or industry, is considerable and does not warrant general expansion or promotion of feeding ROAD to livestock in Ontario or Canada.

4.6 Economics

Total anaerobic digestion systems including cogeneration and/or protein recovery facilities can be capital intensive. Most systems visited have been designed for relatively large animal population units. One could cost them on a per animal basis but that approach would be very misleading. With present technology and equipment, the specific cost is not proportional. Researchers, designers and users all agree that scaled down units are neither practical nor possible (economically) with present designs.

Nemetz (1984), did an excellent job of projecting, in investment dollar terms, the opportunity for various animal production units by type and size. Unfortunately the availability of volatile solids (VS) per animal and the digestibility used in his model are not consistent with values reported in the field. Canviro (1985, p.37), put together a comparison chart for swine manure from 2000 head of growing-finishing swine. The literature would indicate energy production potential of 9.0 to 11.9 GJ/d. Field experience at two digesters showed a potential of only 4.4 and 4.9 GJ/d due to lower than predicted VS. The differences are significant when excess energy production, above digester heating, is considered as a dollar recovery mechanism.

Further and more serious contradictions start to occur when we focus on protein recovery. Protein recovery has been held up as the `knight in shining armor' riding forth to recover the spent capital. But the horse, or should we say the beef animals, dairy animals, and swine have balked. But all is not lost.

If we look at the summary of capital costs for the Selves Farm unit in Table 2 we get a better appreciation of relative capital costs. This digester/cogeneration/protein recovery system was designed for a 375 sow farrow-to-finish operation. The total system cost was in excess of $250,000. However, note that the digestion system alone cost only $30,600 or 11.3% of the total. The site work cost more, 12.2% of the total. If the digester had been planned into the system initially a high percentage of the site work could have been saved. In contrast, the biogas utilization system and the protein recovery system accounted for 22.9% and 29.4% respectively of the total cost.

Maybe from an `on-farm point of view' we should be moving one and a half steps at a time. Why not just build the digester system and incorporate an oversized biogas fired boiler for hot water? The hot water could be used to heat the digester, and/or pertinent sections of the animal production facilities, along with farm residences or other low heat requirement applications. If and when justifiable, cogeneration could be added - remembering that it might cost as much, 13.5% in this example, as the total digestion system. Preplanning for possible incorporation would be essential.

The preceding proposal is made on the assumption that odor control is a major benefit, which it is likely to be on large farm units with high animal populations. Many of the operators of existing digesters indicated that odor control had become a primary or secondary reason for continuation. Many larger farms are spending amounts of money comparable to first digester cost for the right-to-farm or `code of practice' requirements by covering liquid manure storage tanks or by pumping manure half way back the farm.

The report by Nemetz (1984), was well prepared and provides a useful basic economic analysis format. However, many assumptions of `base case' values are misleading, based on our field observations and other data. The authors would like to urge Agriculture Canada to update this document using more realistic field values and especially to change the emphasis of the 20% conversion efficiency for electrical generation. While this figure is correct, with cogeneration, engine heat is recoverable for other uses, including digester heating.

Table 2. Summary Of Capital Costs for Selves Farms Anaerobic Digestion And Protein Recovery System (July, 1983)*

Description	Cost	% of Major Capital	% of Total Capital
Site Work			
Digging & Grading			
Manure Pumping &	$ 1,413.25	0.7	0.5
Modifications	31,625.25	15.4	11.7
Digestion System			
Digestion Tank c/w Fittings,	$ 26,807.36		
Manholes & Insulation	3,832.50	13.1	9.9
Excavation & Backfilling	.	1.9	1.4
Biogas Handling & Metering	$ 1,491.66	0.7	0.6
Biogas Storage '	4,631.38	2.3	1.7
Electrical Generation	36,562.97	17.9	13.5
Heat Recovery & Utilization	19,194.53	9.4	7.1
Protein Recovery System			
Primary Separator	$ 4,521.32	2.2	1.6
Polymer Make-up & Pumping	7,097.35	3.5	2.6
Centrifuge	64,815.40	31.6	24.1
SCP Storage Bin	2,835.00	1.4	1.1
SUBTOTAL	$204,827.97	100.0	76.0
Digester Control Building	$ 10,919.26	5.3	4.0
Electrical Contract	18,949.82	9.2	7.0
Mechanical Contract	21,716.20	10.6	8.0
Freight	829.43	0.4	0.3
Engineering	12,000.00	5.9	4.4
TOTAL	$269,242.68	31.4	100.0

* Table courtesy of Canviro Consultants Ltd. (Ref. Canviro Ltd., 1984, p. 63.)

5.0 RECOMMENDATIONS

As a result of an expanded (beyond Ontario) look: at anaerobic digester systems on farms, discussions with system designers and researchers, and a review of pertinent literature and reports, the following recommendations are made.

(1) THAT TUNNEL TYPE (PLUG-FLOW) ANAEROBIC DIGESTERS NOT BE RECOMMENDED FOR OTHER THAN DAIRY/BEEF OPERATIONS HAVING SCRAPED MANURE WITH TOTAL SOLIDS CONTENT IN EXCESS OF 10%.

(2) THAT OTHER MEANS OF PROVIDING RETAINED-GROWTH MEDIA IN ANAEROBIC DIGESTERS BE GIVEN FURTHER STUDY AND TESTING IN PROTOTYPE DIGESTERS SUITABLE FOR SCALE-UP USING HIGH STRENGTH ANIMAL MANURE.

(3) THAT A CONTROLLED TESTING PROGRAM BE INITIATED USING A PROTOTYPE DIGESTER TO EVALUATE THE INFLUENCES OF MAJOR FEED RATION INGREDIENTS TO PROVIDE MORE RELIABLE VOLATILE SOLIDS CONTENT AND DIGESTIBILITY DATA FOR SWINE MANURE IN PARTICULAR AND OTHER ANIMAL MANURE IF POSSIBLE.

(4) THAT BASIC MICROBIOLOGICAL STUDIES BE UNDERTAKEN WITH A VIEW TO PROVIDING MORE SPECIFIC INFORMATION ON ANAEROBIC DIGESTION PARAMETERS AND/OR ADDITIONS THAT CAN INCREASE BIOGAS PRODUCTION RATES, IMPROVE BIOGAS QUALITY, AND PARTICULARLY REDUCE H_2S PRODUCTION.

(5) THAT FIELD TRIAL RESEARCH BE CONTINUED AND/OR INCREASED 'TO EVALUATE THE RELATIVE PLANT FERTILITY VALUE OF ANAEROBIC DIGESTER EFFLUENT VS RAW MANURE FROM THE SAME SUPPLY SOURCE. Kemptville College of Agricultural Technology personnel have done some preliminary work. This is one location at which this effort could be continued.

(6) THAT THE PALATABILITY OF ROAD TESTING BE CONTINUED TO DETERMINE THE SUITABILITY AND ECONOMICS OF USING THIS ANAEROBIC DIGESTION BYPRODUCT AS A MINERAL SUPPLEMENT. Some work has been started at Selves Farms Ltd. and appears to be a logical place for continuation with appropriate technical/financial support.

(7) THAT A SIMPLIFIED TEST PROCEDURE, SUITABLE FOR USE BY DIGESTER OPERATORS IN THE FIELD, BE ESTABLISHED TO MONITOR ANAEROBIC DIGESTER CONDITION/STABILITY.

(8) THAT RESEARCH EFFORT BE CONTINUED TO DEVELOP LOW COST, AND LOW MAINTENANCE, BIOGAS CLEANING SYSTEMS FOR H_2S REMOVAL IF LEVELS CANNOT BE REDUCED BY OTHER MEANS.

(9) THAT METHODS OF ELECTRICAL GENERATION AND UTILITY GRID CONNECTION BE STUDIED WITH A VIEW TO STANDARDIZING SYSTEMS TO INCREASE PERFORMANCE AT LOWER CAPITAL COST WITHOUT LOSS OF RELIABILITY AND SAFETY.

(10) THAT RESEARCH BE INCREASED TO IMPROVE THE RELIABILITY AND CAPACITY OF BIOGAS STORAGE SYSTEMS TO FACILITATE AT LEAST 12 HOURS OF STORAGE FOR MORE VIABLE COGENERATION OPPORTUNITY. If heat is the desired and useful energy then insulated hot water storages minimize gas storage requirements.

(11) THAT SOME APPLIED RESEARCH BE DIRECTED TO ANAEROBIC DIGESTION OF POULTRY MANURE. This could probably be done with a prototype digester to ascertain digestibility of various types of poultry manure and establish biogas production rates as well as odor reduction. Poultry manure without litter, as from caged layers, should receive priority.

(12) THAT AN OPERATORS' MANUAL BE PREPARED, IN LAYMENS' TERMS, TO ASSIST PRESENT AND FUTURE ANAEROBIC DIGESTER OPERATORS. This manual should explain basic concepts of anaerobic digestion and provide extensive troubleshooting and corrective action information. It could be used as an instruction manual for operator courses.

(13) THAT RESEARCH BE DIRECTED TO DIGESTER DESIGNS AND OR SLURRY MIXING TECHNIQUES THAT WOULD REDUCE THE AMOUNT *OF* ENERGY REQUIRED, CAPITAL COST AND MAINTENANCE. Such a system should prevent scum formation, control foaming and prevent sludge build-up in the digester while maximizing biogas production.

(14) THAT CONSIDERATION BE GIVEN TO THE EVALUATION *OF* A SMALL SCALE ANAEROBIC DIGESTION UNIT (FOR USE ON A 40 PLUS COW DAIRY FARM OR 50 PLUS SOW SWINE FARM) FOR ODOR CONTROL ONLY. This is perceived to utilize the long term covered concrete manure storage tank with insulation added. The tank might be seeded and purged to remove oxygen, operated as a psychrophilic unit and stirred by submersible agitators.

Many dairy farms are recovering heat from milk in excess of hot water needs. This hot water could be piped through the manure storage.

The manure would have to enter through an air lock system. This is easily achieved with a bottom feed plunger pump (dairy) or a gas trapped liquid system (swine).

The collection or use of biogas is not likely to be worthy of consideration in our colder climate. It would be vented to the atmosphere. Basically this would be a large domestic septic tank system pumped out once or twice per year. This concept should be evaluated by personnel versed in anaerobic digester system design.

(15) THAT ALTERNATE HEAT ENERGY USES COMPATIBLE WITH ANIMAL PRODUCTION BE EVALUATED. It is conceivable that with an adequate labor base provided by an extended family farm operation, the biogas from an anaerobic digester could be used to heat a greenhouse or other crop production facility.

(16) THAT DISCUSSIONS BE INITIATED WITH OTHER MINISTRIES OR DEPARTMENTS TO GAIN SUPPORT FOR A PROCEDURE WHEREBY FINANCIAL ASSISTANCE COULD BE PROVIDED TO ANIMAL PRODUCERS UNDER PRESSURE TO REDUCE ODORS FROM STORAGE AND/OR SPREADING OF UNTREATED RAW MANURE. In many instances a portion of the incremental cost as a grant-in-aid could make anaerobic digestion a viable means of controlling odors and providing renewable energy.

It is perceived that any assistance should be provided by or through the municipality permitting encroachment on animal producers.

6.0 SUMMARY

Without exception, cooperators and operators of all anaerobic digester systems visited are still enthusiastic about the concept. In almost all cases the recovery of capital had fallen short of projections, but this had not deterred enthusiasm primarily because of side benefits such as odor control.

Odor control had provided better relationships with neighboring percipients. In one instance more flexible time management was considered a positive factor because effluent did not have to be incorporated into the soil for odor control. This would also permit effluent to be applied between hay crops, for example.

Most digester operators had hoped for capital recovery by cogeneration and/or refeeding of processed digester effluent. Without exception in the Canadian installations, biogas production for cogeneration had fallen short of the expectation for electrical self sufficiency. This was partially frustrated by the lack of low cost biogas storage to permit generation for maximum farm demand (kW). With the exception of PEI the buy-back rate offered by the utility for constant low kW generation does not provide sufficient revenue to justify the relatively expensive cogeneration equipment and switch gear necessary for grid connection.

Biogas utilization for direct heating would significantly reduce capital investment as compared to cogeneration, but constant uses of the heat have not appeared. One exception is in Quebec where the heat can be used in adjacent greenhouses. Follow up on this installation will be very interesting. Other heat uses, consistent with management interest and capability, should be pursued.

The refeeding of separated digester effluent as a protein supplement had been projected as a very significant source of input cost reduction to justify expensive separation equipment and even digester capital. Both research results and field experience have drawn a very heavy cloud over this projection.

We have the technology and expertise for designing anaerobic digesters. What we need however, is greater emphasis on modest anaerobic digester systems that can be extended when energy prices increase again.

The use of anaerobic digester technology for odor control at this point in time justifies continuing-research and developmental work. Technology advancements, to improve biogas production rates and quality, will be in the best interests of all when renewable energy becomes price competitive.

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8.0 GLOSSARY

ALKALINITY RATIO: (BA/TA) the ratio of bicarbonate alkalinity to total alkalinity of a slurry

ANAEROBIC: living or active in an airless environment

ANAEROBIC BACTERIA: microbes whose metabolisms require the absence of free oxygen

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ANAEROBIC DIGESTION: bacterial digestion of organic material in the absence of free oxygen

BIOGAS: a gaseous product of anaerobic digestion consisting primarily of methane and carbon dioxide

CALORIE (cal): a unit of energy defined as the amount of heat required to raise the temperature of one gram of water one degree C

CARBON-TO-NITROGEN RATIO (C/N): ratio of carbon to nitrogen in organic materials. Anaerobic bacteria produce the most biogas when fed organic materials with a C/N ratio compatible with their metabolic requirements

CHEMICAL OXYGEN DEMAND (COD): oxidation requirement of a slurry in kg/m^3/d

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DIGESTER: sealed tank or container in which the biological requirements of anaerobic digestion are controlled to hasten digestion and optimize biogas production

DIGESTION: process by which complex organic molecules are broken down into simpler molecules - in this case the anaerobic process (fermentation) by which bacteria accomplish this decomposition

EFFLUENT: partially digested liquid manure slurry which exits the digester

GAS YIELD: biogas production in m^3/d or m^3/kg VS added

FERMENTATION: the biological process by which organic material is broken down into simpler constituents by microorganisms. See DIGESTION

INFLUENT: undigested liquid manure slurry which enters the digester

JOULE (J): a unit of energy defined as the exertion of one newton of force over a distance of one meter. One joule = 0.239 cal

LOADING RATE: the amount of volatile solids (VS) fed to the digester daily in kg. (kg VS/d or kg VS/m^3/day). Can also be expressed as kg COD/m^3/d

MANURE: animal feces and urine, but may include wasted feed, bedding, and anti-slip material from the barn and yard

MESOPHILIC: bacteria which thrive in a temperature range of 20 - 35 degrees C

METHANE (CH_4): a combustible gas produced by anaerobic digestion, also the principal component of natural gas

METHANOGENIC: methane producing bacteria

PSYCHROPHILIC: bacteria which thrive in a temperature range below 20 degrees C

RESIDUE OF ANAEROBIC DIGESTION (ROAD): solids removable by screening and/or centrifuging from they digester effluent

RETENTION TIME (RT): the average time that the slurry remains in the digester

SCUM: floating agglomerates in the digester consisting primarily of indigestible feed materials

SLUDGE: separated manure solids and bedding materials which settle to the bottom of the digester

SLURRY: mixture of manure and water processed in the digester

SPECIFIC GAS RATIO: the volume of biogas produced per day compared to digester volume (m^3/m^3/d)

SUBSTRATE: material supplied for microbial action

THERMOPHILIC: bacteria that are most active in a temperature range of 45 to 60 degrees C

TOTAL SOLIDS (TS): the weight of the solid matter remaining after a sample is dried to constant weight at 103 +/- one degree C

VOLATILE ACIDS: intermediate material, low molecular weight fatty acids, produced in the digester by acid-forming bacteria and used by methane-forming bacteria

VOLATILE SOLIDS (VS): organic constituents of manure or the portion of solids volatilized at 550 +/- 50 degrees C: the difference between the total solids content and ash remaining after ignition at 550 +/- 50 degrees C

WASHOUT: the 'significant depression of methanogenic organism (bacteria) concentration in the digester

9.0 REFERENCES

1. Barth, C.L., and R.O. Hegg, 1979. Critical analysis of on-farm digesters. ASAE Paper no. 79-4579 presented at New Orleans, LA, December.

2. Bartlett, H.D., S.P.E. Persson et al, 1980. Biogas generation and uses on livestock farms. NAR-ASAE Paper no. 80-411 presented at Willimantic CT, August.

3. Ben-Hassan, R.M., A.E. Ghaly and R.K. Singh, 1985. Design and evaluation of no-mix energy efficient anaerobic digester. CSAE paper no. 85-408, presented at Charlottetown, P.E.I., June.

4. Bennett, S., 1982. Bioelectric systems: an analysis of the new economics and benefits of anaerobic digesters. NAR-ASAE Paper no. 82-102 presented at Burlington, VT, August.

5. Bentz, L.B., 1980. Manure's biogas powers dairy farm. Soil and Water conservation News, September 1980, pp 6-9.

6. Canviro Ltd., 1985. Final report on the demonstration of energy production and conservation by anaerobic digestion and electrical co-generation of swine manure. EMR demonstration project in P.E.I. Canviro Consultants Ltd., Louisa St., Kitchener, Ont. N2H 5M5.

7. Canviro Ltd., 1985. Final report on the design and development of a gas to water heat exchanger for internal combustion engines operating on biogas. Report for Agricultural Energy Centre, OMAF, Guelph Ont, on behalf of Selves Farms Ltd., April.

8. Canviro, Ltd., 1984. Final report of the demonstration of energy production and conservation by anaerobic digestion and protein recovery at a commercial hog farm. Prepared by Canviro Consultants Ltd. for Agricultural Energy Centre, OMAF, Guelph, Ont.

9. Canviro Ltd., 1983. Farm scale anaerobic digestion of poultry manure for methane and protein production. A proposal submitted to Agricultural Energy Centre, OMAF, Box 1030, Guelph, Ont.

10. Chen, J.S., B.C. Frey and H.L. Brodie, 1984. Scum accumulation in plug-flow digesters - a problem with flushed dairy manure. Technical Notes, ASAE Trans. Vols. 27-28, p. 1694-6.

11. Cournoyer, M.S., U. Delisle et al, 1984. A mixed plug-flow anaerobic digester for dairy manure. ASAE Paper no. 84-4562 presented at new Orleans, LA, December.

12. Cournoyer, M.S., and D. Ferland, 1964. Evaluation d'un digesteur anaerobie. Final report, Agriculture Canada, RDEAA program. Contract DSS no. 48SZ-01843-1-ER19. from Urgel Delisle and Associates.

13. Eszes, S.W., and J. Pos, 1985. Renewable energy utilizing biogas for production of electricity using a diesel engine/induction motor. Final report, School of Engineering, Univ. of Guelph, Guelph, Ont., N1G 2W1.

14. Feddes, J.J.R., and J.B. McQuitty, 1980. The economic feasibility of producing biogas from dairy manure in Alberta. Agriculture and Forestry Bulletin Vol. 4(2) pp 15-20.

15. Gilman, F.E., 1985. Dairy manure processing in New Hampshire. NAR-ASAE Paper no. 85-410 presented at Baltimore, Maryland, August.

16. Gosselin, Y, and P. Vallee, 1985. Le Traitment at la valorisation du fumier dans le programme d'assainissement des eau:;. Conference presentee au assises annuelles 1985 de l'association Quebecoise des techniques de l'eau. Montreal, Que., March.

17. Hills, D.J., and M. Kayhanion, 1984. Methane gas facilities for flush-out dairy farm systems. ASAE Paper no. 84-4559 presented at New Orleans, LA, December.

18. Jewell, W. J., et al, 1982. The feasibility of biogas production of farms. Report no. XB-0-9038-1-10 prepared for the U.S. Dept of Energy.

19. Jewell, W.J., R.K. Koelsch, and R.J. Cummings, 1985. Cogeneration of electricity and heat from biogas. Final report prepared at Agr. Eng. Dept., Cornell Univ., Ithaca, NY.

20. Lapp, H. M., and L. C. Buchanan, 1978. Travel report on a study of methane production from animal manure in the Midwestern United States. Report of Agriculture Canada contract no. OSZ76-00444 prepared at Univ. of Manitoba, Winnipeg, R3T 2N2.

21. Lapp, H.M., D.D. Schulte, and L.C. Buchanan, 1974. Methane gas production from animal wastes. Agriculture Canada, Pub. no. 1528.

22. Lapp, H.M., D. Schulte and M.A. Stevens, 1978. Biogas production from animal manure. A publication produced by the Biomass Energy Institute Inc., Winnipeg, Man.

23. Liao, P.H, and K.V. Lo, 1985. Methane production using whole and screened dairy manure in conventional and fixed-film reactors. Biotechnology and Bioengineering, Vol, XXVII, pp 266-272, John Wiley and Sons Inc.

24. MacDonald, R.D., 1982. Methane production from livestock manure. Factsheet No. 82-067; OMAF Parliament BIdgs., Toronto, Ont.

25. MacDonald, R.D., D. Marshall and J. Barclay, 1984. The Kemptville college downflow stationary fixed film anaerobic digester. CSAE paper no. B4-412.

26 MacDonald, R.D., D. Marshall and R. Chagnon, 1983. Comparative evaluation of five full scale anaerobic digesters. CSAE Paper no. 83-411.

27. MacDonald, R.D., M. Selves, and R. Stickney. 1984. Selves Farms Ltd. anaerobic digester for co-generation and protein recovery. CSAE paper no. 84-414.

28. Maat, D.Z., 1984. Design construction and operation of a full scale downflow fixed film reactor using hogwaste substrate. A report prepared by MacLaren Engineers Inc., 320 Adelaide St. S., London, Ont., N5Z 3L2.

29. Mowat, D.N., G.K. MacLeod and J.G. Buchanan-Smith, 1985. Nutritional evaluation of residue from methane fermentation of animal wastes. Final report, strategic grant #G0978. Dept of Animal and Poultry Sc., University of Guelph, Guelph, Ont., N1G 2W1.

30. Nemetz, I., 1984. An economic analysis of the potential of anaerobic digestion for energy production and protein recovery in Canada. A report prepared by Inputs and Technology Analysis Div., Development Policy Directorate. Agriculture Canada, Ottawa, Ont., K1A 0C5.

31. Parsons, R.A., 1984. On-farm biogas production. Pub. no. NRAES-20 of the Northeast Regional Agricultural Engineering Service, Riley Robb Hall, Cornell Univ., Ithaca, NY., 14853.

32. Persson, S.P.E. et al, 1979. Agricultural anaerobic digesters - design and operation. Bulletin 827, Penn. State Univ., Univ. Park, PA, USA.

33. Persson, S.P.E., and H.D. Bartlett, 1981. Biogas engines for agricultural motor-generators. ASAE Paper no. 81-3585 presented at Chicago, IL., Dec.

34. Persson, S.P.E., and D.J. Meyer, 1983. Preliminary report on energy integrated swine unit with digester odor control and solar assisted heating. NARASAE Paper No. 83-305 presented at Newark, Delaware, August.

35. Pos, J., et al, 1985. Renewable energy biomass digestion (methane). Progress report, School of Engineering, Univ. of Guelph, Guelph, Ont., N1G 2W1.

36. Pos, J., et al, 1984. Renewable energy biomass digestion (methane). Progress report, School of Engineering, Univ. of Guelph, Guelph, Ont., N1G 2W1.

37. Pos, J., et al, 1981. Biogas production. Technical Report no. 126-59, School of Engineering, Univ. of Guelph, Guelph, Ont., N1G 2W1.

38. Pos, J., et al, 1981. Biogas production from animal manure and crop residues. Technical report no. 126-58, School of Engineering, Univ. of Guelph, Guelph, Ont., N1G 2W1.

39. Pos, J., R. Porringa, and D. Eaton, 1982. Construction and start up of a 45 m^3 underground farmscale anaerobic digester. NAR-ASAE Paper no. 82-103 presented at Burlington, VT., August.

40. Timbers, G.E. and D. Marshall, 1981. Biogas as a farm energy source. ESRI Report no. 1-297, Agriculture Canada, Ottawa, Ont., K1A 0C6.

41. Van den Berg, L., and N.J. Kennedy, 1983. Comparison of advanced anaerobic reactors. Proc. Third Int. Conf. Anaerobic Digestion., Boston, Mass., August. NRCC 22613.

42. Walker, L.P. at al, 1984. Anaerobic digestion on a dairy farm: overview. Paper submitted for publication to `Energy in Agriculture.

43. Young, L.G., 1984. Evaluation of methane fermentation residue in diets of pigs. Swine research in Ontario. OPPMB Report pp 133-136. Box 740, Etobicoke, Ont., M9C 5H3.