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AN ASSESSEMENT OF AGRICULTURE CANADA'S ANAEROBIC DIGESTION PROGRAM

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FOREWORD

From 1973 to 1986, Agriculture Canada supported research and development of methane digesters for Canadian farms. Funding originated from the federal energy R&D budget managed by the Interdepartmental Panel on Energy Research and Development. The work was carried out through research contracts with engineering firms and universities; 28 contracts having a total value of $3,389,700 were undertaken. This report is a review of the progress made and an overall assessment of the technology to determine the present opportunities for Canadian farms. Background and some design detail are provided as an introduction to understanding anaerobic digestion and to assist in making preliminary assessments for specific applications. Further detailed information is available in the final reports resulting from the individual contracted out projects (see page 67). It is concluded that application of this technology to Canadian farms cannot be recommended since it is not profitable.

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EXECUTIVE SUMMARY

Anaerobic digestion technology was taken from the laboratory and developed at the pilot and farm-scale levels over a thirteen year period through the Departments' contracting-out program. Utilization of methane for space heating, electrical generation and mobile power were the main energy aspects examined. This was supplemented with work on reducing the pollution potential of manure and food processing waste disposal and on protein and nutrient recovery for refeeding. Emphasis was initially given to the study of anaerobic digestion rather than designing systems for agriculture. Full scale digesters were then designed, constructed, operated and monitored at the mesophyllic temperature range of 20 to 45ºC on several swine, beef and dairy operations.

It was found that anaerobic digesters can he operated year round in Canada's cold climate and the biogas produced can readily he used for space heating or generating electricity. Sufficient biogas is produced to provide supplemental heat to maintain the digestion process in the winter and for a farm to he almost self sufficient in the production of electricity, especially if the peak electrical demand loads can he reduced. However, for small to medium sized Canadian farms anaerobic digestion is not feasible and cannot he economically justified because it is too labour and capital demanding. Canada enjoys relatively inexpensive gas and electrical supplies making biogas economically attractive only where it must compete with petroleum based electrical generation and where the cost of heating is relatively high.

Fairly complex digestion system designs were developed. Manure screening is almost essential to prevent plugging and reliable components such as circulation pumps, heat exchangers and temporary biogas storages are essential. Current systems lack reliability and have high maintenance requirements not compatible with

Designs must be simplified and be more compatible with the needs of the farmer if anaerobic digestion is to be adopted. Systems should also be designed as an integral component of the farm production systems, not as an afterthought.

The recovery of protein was one of the main justifications for continuing the program as it was for refeeding animals obvious that energy alone could not justify farm scale anaerobic digestion. The protein aspects fell short of expectations. It is a low value protein and refeeding resulted in reduced animal feed intake and reduced rate of gain or production. A centrifuge costing $65,000 (1983) is required to recover and concentrate the protein. A comprehensive knowledge of animal nutrition is required to use the protein effectively. Although the recovered material is called single cell protein it also contains undigested feed. To what extent the protein is microbial was not established and a low level of this converted component may account for the poor performance in refeeding. Animal nutritionists have been reluctant to become involved as they see little opportunity for significant benefits from a material that the animal has already tried to digest once. Other concerns include RNA and virus levels and heavy metal buildup in feed supplied via the process.

A full scale poultry system was not developed as laboratory tests of several designs on diluted manure showed that protein recovery using developed methods would not work. Without protein recovery it is a foregone conclusion that the system would not be economic in poultry applications.

Through close cooperation with the National Research Council, a low cost digester packing material was developed. This packing was used in farm systems to scale up the Council's new fixed film technology. The enhanced rate digestion technique was fairly successful on screened swine manure but its success with cattle manure was limited due to plugging with accumulated animal hair.

A mobile test facility which included three fully instrumented pilot scale reactors was built and tested. As the expertise to consider the application of the technology is now fairly advanced the main contribution of this facility will be in the demonstration of treatment of waste streams for pollution reduction. The facility has therefore been placed under the auspices of Environment Canada.

Overall, a good attempt was made in applying and evaluating anaerobic digestion technology for Canadian agriculture. A definite reduction in odor was observed with digested manure and anaerobic digestion should be considered as one of the treatment techniques when odor control or reduction is critical to the economics of large scale operations. Canada now has suitable expertise in the private sector and systems can be designed and built. The known economic and technical benefits do not warrant further government support in its application. Results of research completed to date show that even when the technology is fully integrated into a farming operation involving energy production and recovery of protein, the energy and feed cost savings do not justify in economic terms the large capital investment, operating costs and management time that the farmer must supply. Thus at the present state of technological development, methane production systems cannot he recommended for use on Canadian farms since they are not profitable.

INTRODUCTION

Anaerobic digestion is a naturally occurring process found in swamps, waste lagoons and the digestive tracts of animals or anywhere where there is organic matter and oxygen is excluded. It is a microbiological process, in which several species of microbes break down organic matter into methane and carbon dioxide. The methane digester provides a suitable environment for the growth and functioning of the microbes. Three of the main variables to be controlled are the temperature, pH and food supply.

Anaerobic technology has received much recent attention because it can be operated relatively simply without requiring an extensive knowledge of microbiology. Many digesters have been built in Asia and function using simple construction and operations. One of the products, methane gas, is a source of energy that is already used extensively in the form of natural gas. Anaerobic digestion has been looked upon as a means of disposing of unwanted organic matter, such as animal wastes, while reducing the odour problem. More recently the digestion process has been investigated for providing animal protein feed and nutrients.

In matching these characteristics with the needs and opportunities of Canadian agriculture, anaerobic digestion has deserved and received extensive research, development and demonstration support from the federal government. Canadian farmers have organic matter (e.g. manure) to dispose of, can use a protein and nutrient supplement in their feeding operations, frequently have odour and pollution problems caused by animal wastes and are highly dependent on energy to run their operations.

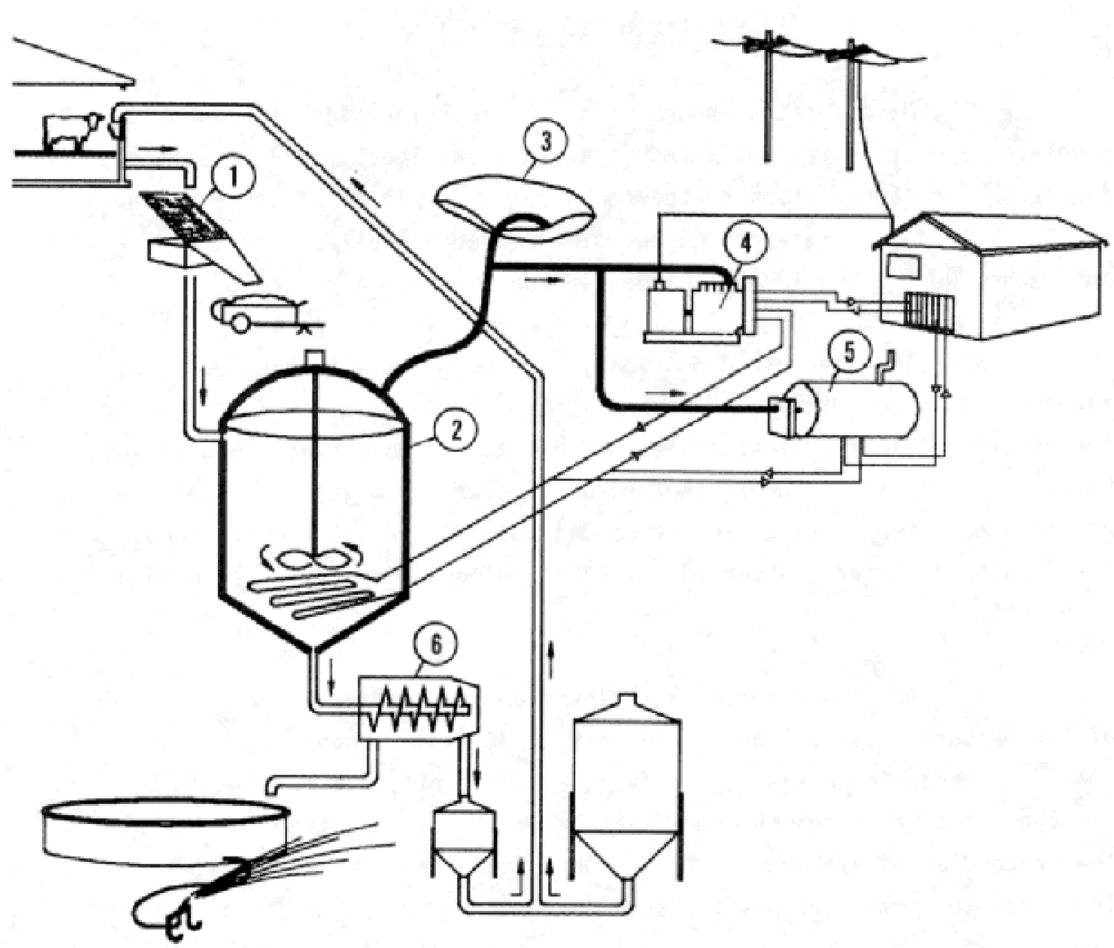
ANAEROBIC DIGESTION PRINCIPLES

Descriptions abound on the basic principles of anaerobic digestion and are often quite technical and detailed. Since this report focuses on the application of the technology, only a brief description (van den Berg, 1984) is presented to help the reader appreciate why various approaches were taken in Agriculture Canada's research program.

In anaerobic digestion, organic matter is broken down into methane and carbon dioxide in a process that can be described as two stage fermentation. In the first stage, organic compounds are broken down into volatile organic acids where the organic matter is converted to fatty acids by one group of bacteria. In the second stage (methane fermentation), these fatty acids are converted by another group of bacteria to methane and carbon dioxide.

As in any fermentation process the feeding and reproduction of the bacteria must be controlled or they will over populate, consume all the feed, producing a waste, and eventually die off. An example of this is the production of wine; the sugar in the grapes is converted to alcohol and the process stops either when the alcohol concentration is too great for the yeast to survive or all the sugar has been used up. This is an over simplification, but it is essentially the same process that can occur in a methane digester.

The acid forming bacteria reproduce quickly and are not particularly sensitive to changes in their environment. However, the second group, the methanogens, grows much more slowly, taking one to four weeks to double their mass and require relatively little energy to convert the acids to methane and carbon dioxide. The slow growth of the second group of bacteria has presented the greatest challenge.



1. Screening of waste prior to digestion
2. Digester
3. Inflatable storage bag for biogas
4. Engine generator
5. Biogas boiler
6. Centrifuge for recovering protein

Figure 1. Schematic of a typical farm scale anaerobic digestion system

If the acid forming bacteria population exceeds the methane forming population, the digester contents will become too acidic, hampering the methane forming bacteria. Again, if too many methane forming bacteria are removed with the effluent from the digester, an imbalance will be created. Obviously, not as much care has to be taken with the acid forming bacteria as they will reproduce quite quickly. Related to this is the fact that, because of the low energy requirement of the methane forming bacteria, little energy is needed to keep them alive.

Successful operation of a digester requires a balance between the two bacteria populations to provide an environment in which they are complimentary.

A digester does not reach full production capacity instantly. It takes time for enough bacteria to grow and to handle all the organic matter. If too much organic matter is added, the acid forming bacteria will become dominant and the contents too acidic for the methane bacteria. The trick is to feed into the digester just enough organic matter so that the fatty acids produced by the acid forming bacteria just match the needs of the methane forming bacteria.

Several factors can therefore upset or hamper the activity of the bacteria in the digester such as:

- the temperature can he too low
- the supply of organic matter can he too high
- a lack of essential nutrients for the bacteria
- too many bacteria removed with the effluent
- antibiotics in the feed.

Our research was therefore aimed at developing an optimum design for the fermentation process, maximizing the contributions of the digester in the overall context of contributing to the operation of the farm.

It should always be remembered that the profitability of the farm must take precedence over operating the digester. This is frequently overlooked by people caught up in the enthusiasm generated when introducing a new technology.

Virtually all the byproduct organic matter produced by Canadian agriculture could be anaerobically digested. However, our research concentrated mainly on animal wastes and therefore so does this report.

Canadian agriculture has moved to intensive livestock housing creating with it a concentration of animal wastes on farms. Any agriculturalist realizes that animal wastes that fall where animals graze is best left where it is. It is natures "balance/system" and the cost of gathering and transporting this material would he prohibitive. Therefore, only wastes from confined animal housing should be considered as suitable for digester operations. Even under intensive production conditions it is frequently impractical to gather all the wastes. Nevertheless, Canada has a substantial amount of animal wastes that could be processed anaerobically and the potential energy production well warranted the research. Over 150,000 tonnes of waste per day needs to be utilized or disposed of in Canadian agriculture. It is generally accepted by agriculturists that the best use of agricultural wastes and particularly manure is utilization as a fertilizer and for maintaining organic matter in the soil. Thus manure is in reality a valuable commodity important in soil conservation.

ADVANCED TECHNOLOGIES

New technologies designed to increase the conversion rate and stability of digesters have been developed in the laboratory. The program sponsored the scale up and application of some of these technologies.

The actual conversion of fatty acids to methane and carbon dioxide does not take a lot of time; it is the reproduction of the bacteria that takes the time. Bacteria are not very mobile, consequently it is necessary to ensure that they have good access to the organic matter. Adequate mixing of the digester contents is the natural choice and the report will discuss various methods that have been tried and developed.

In most digesters where the contents are mechanically mixed, every time material is removed, some of the bacteria will also be removed. The methane bacteria take one to four weeks to reproduce, consequently unless the material is in the digester for the same length of time, the bacteria population will tend to steadily decrease. Enzymes and cultures can be produced elsewhere and added on a routine basis. However, this would greatly complicate the operation and was never really considered in the program. Similarly, the number of bacteria removed with each discharge must not exceed the number of bacteria reproduced in the entire digester. An alternative is to remove the effluent but retain the bacteria inside the digester. Fortunately, the bacteria will grow on and cling to surfaces inside the digester, so that if enough internal surface area can be provided for the bacteria to cling to, the organic material throughput can be substantially increased. The surfaces for the bacteria can he either installed rigidly or maintained in suspension through various techniques. This concept has a good potential to reduce the size of the digester, because more bacteria can he maintained in a given digester volume

RESEARCH DIGESTERS SITES.

Credit for the original work on anaerobic digestion for farm applications in Canada belongs to Prof. H. Lapp of the University of Manitoba. His work was underway for about one year before Agriculture Canada started to provide financial support and initiate its program. A pilot plant at the Faculty of Agriculture's Glenlea Research Station was constructed. The research facility is located near a ,complex of four swine barns holding approximately 800 head. The pilot plant has the capacity to digest the manure from about 75 hogs. It was a good location to assess the effect of the Canadian winter climate on an anaerobic digestion system as this was one of the main objectives. Work at the University of Manitoba was conducted over a period of five years and this pilot scale work studied many parameters of interest.

Two projects to scale up the University of Manitoba work were undertaken in 1978. At the Langille farm, about 3 (1 kilometers from Winnipeg, a system was installed but was never fully operational as the farm ceased swine production shortly after construction of the facility. At the Fallis farm near Peterborough, Ontario, several years were spent attempting to achieve a low cost practical unit. This was a 100 sow farrow-to-finish family-run operation, very typical of Canadian swine operations.

All the initial program work was on swine waste. The first cattle facility was constructed in 1979 on Roslyn Park Farm at Petersburg just west of Kitchener, Ontario. The facility was built through fu~,ding from an Environment Canada program to address a pollution and odour problem. Agriculture Canada used this opportunity to expand its program and examine the benefits of refeeding the digester effluent to help justify the system cost. Several projects were carried out with this facility until the feedlot stopped operation.

The Ontario Ministry of Energy provided funding through the Ontario Ministry of Agriculture and Food for the construction of an anaerobic digestion facility at the

This was a 350- sow farrow-to-finish operation run by an outstanding farmer. Agriculture Canada supported work at this facility to evaluate and develop a system for recovery and feeding of protein and nutrients from the digester effluent.
At Ingersoll, 20 kilometers east of London at the farm of G. Folkema, a fixed-film digester was built for a 120-sow farrowing operation. This was the smallest scale and first attempt at operating a full scale fixed film system for swine. The use of screened solids from the manure for refeeding prior to digestion was also investigated in this project.

The program also provided support for a small unit installed at the Kemptville College of Agricultural Technology by the Ontario Ministry of Agriculture and Food. This was also funded by the Ontario Ministry of Energy. It was a joint project to evaluate the fixed film digester technology for beef cattle manure from 150 steers housed in a slotted-floor barn.

At Pike River, south of Montreal a combination plug-flow/ mixed digester for 300 dairy cattle was built by Les Fermes E. Gasser et Fils Limitées. Monitoring, development of controls and study of the durability of biogas storages were supported by Agriculture Canada. This facility appears to he the only large one in Canada that was not built with public funds.

In Quebec, the Centre de recherche industrielle du Quebec operated a pilot scale unit for several years and constructed a full scale fixed film facility at St-Henri-de-Levis, about 50 kilometers south of Quebec City. This farm owned by Buteau and Tremblay maintains about 1400 finishing hogs.

The University of British Columbia operated several laboratory scale units using dairy manure scraped from a barn housing the confined Holstein dairy herd. This work was originally started under a National Sciences and Engineering

A mobile test facility to evaluate the applicability of anaerobic digestion was built in Waterloo, Ontario and operated for one year at a Schneider meat processing plant in Kitchener. It was subsequently relocated to Portage la Prairie, Manitoba to study the digestion of wastes from a food processing industry complex.

REVIEW OF CONTRACTS

A short review of the progress and findings of each contract follows. Some of the findings in the original contracts are now well known, however, much of this work was fundamental to the progress of the program which should be thus credited. Also these reviews discuss some of the initial problems that have now been overcome.

After reading the review on each contract, the reader should be able to determine whether or not to obtain the full report. Reports are available only in the original language (see Reference Section for a complete list and where to obtain copies).

Contract No. 4-0260, 5-0019, 6-0516, 7-0719 and 8-1805

A study of the feasibility of using methane gas produced from animal waste for energy purposes. University of Manitoba, Lapp, H.M. 1975 to 1979.

The work at the University of Manitoba was done through a series of annual contracts (for administrative reasons) which have, therefore, been grouped together in this report.

During the first year of operation the pilot plant operating on swine waste was remodelled and expanded to include four 3194 litre digesters. Energy inputs to the plant were in excess of the energy value of the biogas, due to energy used in mechanical mixing and temperature maintenance during the winter. This directed future work to look at intermittent mixing, increasing the loading rate and reducing the digester temperature. A half-ton truck was modified to operate on methane gas as a prelude to biogas production. Preliminary work on scrubbing and compressing the biogas for mobile applications was initiated. It was also found that the digester could

In the second year, lower temperature digester operation showed a corresponding lower biogas production. Mixing energy was found to be minimal for high rate digestion. Odour reduction was studied and found to be most effective at the higher operating temperature of 35ºC. Fertilizer assessment trials of the effluent were initiated using barley as a test crop. Theoretical digester heating requirements were calculated and compared to the measured electrical energy consumption indicating that heat transfer theory could be satisfactorily used for system analysis and design.

In the third year process operating temperatures were investigated to achieve an optimum energy output input ratio. Use of gas recirculation demonstrated that gas mixing could be a viable alternative to mechanical mixing. Fertilizer plot trials were continued. A computer model was written to theoretically optimize energy production.

Emphasis in the fourth year was placed on preparing design data for scaling the digestion system up for actual farm applications. Biogas handling and utilization was investigated and several techniques of scrubbing the biogas were looked at. It was concluded that scrubbing CO out of the biogas did not sufficiently improve engine performance to he justifiable.

Fertility trials did not show that digester effluent or chemical fertilizer improved crop yield, because it was found that the soil fertility level of the test plots was too high to permit any response. A procedure for designing an anaerobic system for farm applications was presented. A trip report of a visit to several digesters in the mid-west United States giving related advantages and problems associated with their methane digesters is included in the annual report.

The final contract determined that gas mixing had no detrimental effect on the production of biogas over mechanical mixing. It became apparent though that if the

The safety aspects of methane gas were discussed and a recommendation for further work was suggested. An internal combustion engine operating on biogas worked quite well but availability of gas from the pilot plant limited the hours of test operation. It was concluded that scrubbing CO was a low priority, unless the gas is used in a mobile vehicle.

Overall it was concluded that the technology was technically feasible for Canadian farmers.

Synopsis of Work at University of Manitoba.

During Agriculture Canada's support period at the University of Manitoba, numerous technical and scientific papers were produced. The papers and contract reports contain valuable information on many aspects of anaerobic digestion such as biogas scrubbing, fertilizer trials and odour reduction. These preliminary findings gave valuable information in directing subsequent research support by Agriculture Canada. Many of the conclusions reached by other researchers have not differed greatly from those of Lapp at the University of Manitoba. Perhaps subsequent researchers have not adequately reviewed Lapp's work.

Contract No. 7-0751

Farm scale anaerobic digestion, W. Langille, 1980.

The objective was to scale up the pilot work done at the University of Manitoba and place it on a commercial farm operation to determine potential problems under real farm conditions. An existing liquid manure system was retrofitted to make an anaerobic system by insulating and covering the manure tank to form the digester. It was found that this was not a suitable way to proceed. Construction material left in the tank caused problems and the farm operator lacked sufficient time to properly address the problems that arose. During the course of the contract the

Contract No. 7-0752

Design Operation and Demonstration of Farm Scale Anaerobic Digester for the Production of Methane from Hog Manure. Fallis, J. 1985.

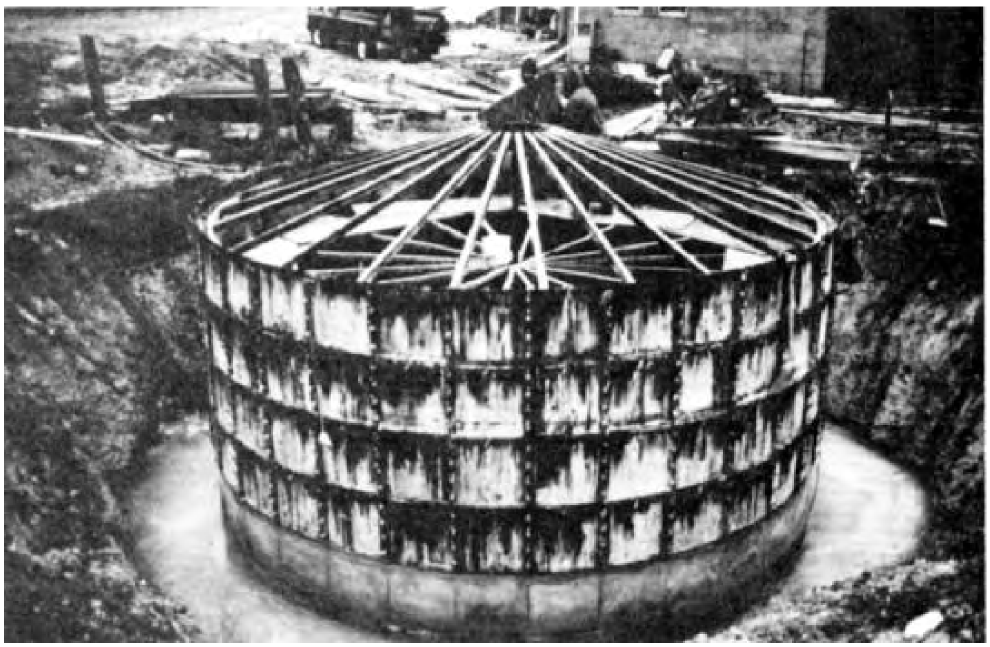


Figure 2. **Construction of a digester on the Fallis farm using silo slip form construction techniques.**

This prototype digester was one of the first farm scale units built. It was of simple design based on cast-in-place silo construction technology. It was essentially a large holding vat with an agitation system. This project demonstrated that adding a digester to a livestock operation is not easy. Many essential features are common sense but are easily overlooked. The digester although simple suffered from many problems, for example, mixing system plugging and settling of solids, particularly when the mixing system broke down. The accumulation of hog hair jamming the agitator was the main problem. It also became very evident that typical farm operators do not have the time nor the expertise to "nurse" a digester. This is particularly true where their time and capital investment have a greater dollar return elsewhere. The farmer estimated the value of his time at $100 per hour at planting time.

In conjunction with the contract, Engineering and Statistical Research Centre (ESRC) used the facilities to participate directly in the research. The intention was that the farmer would operate the system relying on local tradesmen for repairs and alterations as far as possible. ESRC would provide the technical guidance and assistance as required, thus obtaining first hand information on the operation of the system. The cooperator was responsible for monitoring, loading, temperature control and estimating manure influent.

The manure was not screened and problems with sedimentation soon occurred. Sediment rapidly accumulated on the bottom and this problem was amplified due to the problems with the agitation system. The discharge pipe although installed near the bottom did not remove the sediment and it plugged frequently. It was redesigned with fewer restrictions, but the problem of removing sediment from the bottom was never completely solved. Diluting the contents and increasing the agitation removed a considerable amount, but a concern remained about long-term accumulation. An obvious solution is to screen out the sediment before it enters the digester. However as the farmer quite rightly pointed out, he had a complete liquid manure handling and storage system. To separate out the solids would require the investment and operation of additional manure handling equipment which he really wasn't interested in.

In the fifth year it was observed during a shutdown that groundwater was seeping into the digester and the seal between the wall and the roof was no longer gas-tight. It was repaired because it was felt that if water can leak in, biogas can leak out. It is a problem other digesters will probably also face after several years of operation.

The digester was originally designed with one small manhole. This proved to he grossly inadequate since equipment inside eventually needs to he serviced or replaced. Provision should therefore he made for easily replacing equipment; properly sized manholes should he provided. To rectify some of the problems it was necessary to go into the digester using a respirator. Venting a digester is not always possible or practical each time internal repairs are needed. Fixing and entering a digester is not a safe "one-man" job.

Figure 3. **Corrosion of a gas meter after one year of operation**

Corrosion was a serious problem. The sensors for the heat controllers corroded extensively as did the copper control lines. Also the heating grid in the digester developed a leak. The fluctuating liquid levels inside the digester undoubtedly aggravated the situation. The control shack was originally located above the manure pit for convenience but to reduce corrosion and enhance safety it was later relocated some distance from the manure tank and the digester. The boiler was a potentially hazardous open flame type. Fortunately no accidents happened with the system. Safety is an important aspect to be considered. The farmer or the operator needs some training to he able to operate the system in a prudent manner, and the designer has the responsibility to come up with a safe system.

The project was visited by a large number of farmers, consultants, educators and researchers, many of them actively engaged in the development of farm scale methane technology; it provided an example from which other designs evolved.

Contract 9-1901

Design of a farm scale energy system using agricultural plants and crop residues as energy sources and animal waste to produce raw gas for farm operations. Geobi Inc., F. Benoit, MO.

The intention was to design a combined aerobic and anaerobic system to process both animal manure and plant material. A design was produced, however it was not hacked by sufficient engineering and the operational performance characteristics predicted could not he properly substantiated by preliminary tests or a review of the literature. The quality of the report and design presented were unacceptable to the scientific authority and the work was stopped. There was no final report.

Contract No. 9-1910

Demonstration of Anaerobic Digestion and Single Cell Protein Recovery at a Canadian Reef Feedlot. Canviro Consultants, 1982.

A methane digester was designers, constructed and operated at Roslyn Park Farm, Waterloo, Ont., on a 4500-beef cattle feedlot utilizing predominately food processing wastes as feed. Impetus for installing a digester was an odour problem and increasing energy costs to operate the feedlot. It was felt that anaerobic digestion would he economically feasible if single cell protein could he recovered for refeeding at the feedlot. This was Canada's first effort at such a venture and set the stage for future work under the program.

The facility design was based largely on the experimental unit at the Kaplan Industries feedlot in Bartow, Florida. The cattle are kept in confined open-front, slotted-floor barns. The digestion system was integrated with the existing liquid manure handling system. A centrifuge separates out the solids which are then transported to another site for composting and the liquid digester effluent is spray irrigated on the land to utilize the fertilizer component.

Figure 4. Anaerobic digester at the Roslyn Park Farm cattle feedlot where animals are fed mainly with food processing waste.

The anaerobic digester is a reinforced concrete sealed-silo type tank having a volume of 636 m . The digester is mixed with a top mounted turbine type mixer, made of pressure treated wood baffles. The tank was placed partially in-ground and insulated with 50 mm thick styrofoam. The roof and exterior piping was insulated with polyurethane sprayed-on foam insulation. The system was intended to operate thermophillically.

Steam mixed into the incoming manure brings it up to the process operating temperature. To make up for heat losses from the digester, additional steam is injected directly into the digester. Biogas is withdrawn from the top of the digester, cooled in a water jacketed heat exchange pipe, passed through a sediment/drip trap to remove grit and moisture and finally through a gas meter. A gas blower then pumps the gas into steel pressure storage tanks at 6.g - 34.5 kPa. The biogas then flows automatically to the steam boiler on demand.

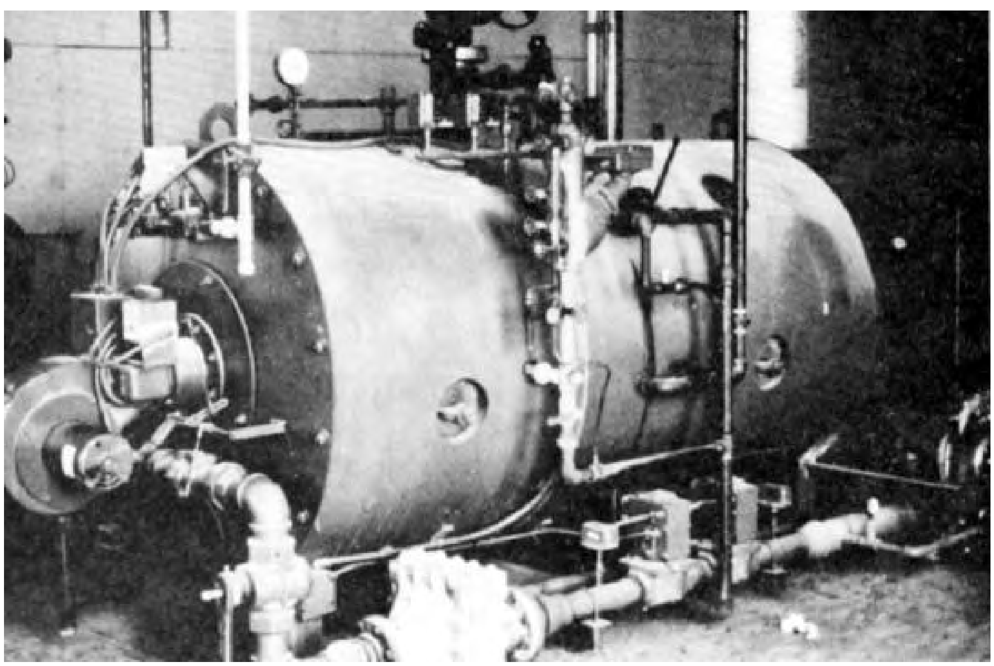


Figure 5. Methane fired boiler for steam production

CSA approved gas safety equipment was provided, together with pressure and temperature control instrumentation. A propane auxiliary fuel system was provided for system start-up and periods when insufficient biogas is produced. When the system boiler did not utilize the biogas the gas was flared off as a cheap convenient way to accomodate surplus gas within the experiment.

Digester effluent is withdrawn from the tank bottom and pumped directly to the protein recovery unit consisting of a second centrifuge (Sharples, high speed, solid bowl, 224 kW, 0.136 m /min with polymer conditioning system). The protein recovery centrifuge and polymer dewatering aid were selected to maximize recovery of the protein solids from the digester effluent. The protein is concentrated from approximately 4% dry matter (by weight) to 20% in the centrifuge cake. Recovered protein is conveyed to a farm truck for transportation to storage for refeeding as a ration protein supplement. The final, processed liquid manure is pumped to an earthen storage pond for spray irrigation.

The system was designed to handle 40 percent of the feedlot's manure with some components designed for 100 percent in anticipation that the process would prove to he economical. Little information was found in the literature on designing the protein recovery system.

As a result of other laboratory work, the contractor concluded that gas production and stability would he improved if whey was added as a carbon source. This was done for a few months until early summer when the quality of the whey deteriorated rapidly in the warm weather. Use of whey was then stopped. This was a good decision as it is unrealistic to develop a system that requires an ingredient not available to every feedlot operator who might consider utilizing a digester.

Laboratory work by the contractor on another contract showed that 10 days of retention time could be achieved at 35ºC without whey and that single cell protein (SCP) recovery was equivalent under mesophyllic conditions. The feedlot operator also decided to restrict the use of SCP to only the feedlot site, thus the need for the better pathogen reduction required to permit off site use was less important. Agriculture Canada originally supported this work because it was proposed to function at the higher (thermophillic) temperature, 65ºC.

Another variable not anticipated was the variation in the characteristics of the raw manure. During rainy periods it was diluted to less than 3 percent solids content. As with any process startup, there was considerable variation in the operation of the digester, especially when it went through a transition from thermophillic to mesophyllic temperatures and when inputs changed (like cheese whey and extra rainwater). Any conclusions on the performance must take these variables into account and are thus not too definitive. A major finding was that the digester is more stable in operation and not as easily upset as originally predicted.

Single cell protein was recovered. Since the substrate for the thermophillic operation was 75 percent centrifuged manure and 25 percent whey it was not typical of a beef feedlot. Also the animal feed was not typical since food processing wastes formed the major part of the diet.

An energy analysis of the system was made using energy credits for protein supplement, SCP replaced and the energy expended to acquire the protein supplement. Similarly, an energy analysis is given comparing the digester system with an aeration system predicted to achieve the same level of odour control.

The economic analysis was done primarily to justify expanding the system rather than to establish the economic aspects of the system operation. For example, expanding the system to treat all of the manure would increase single cell protein generation, but the total value of this is questionable, if it cannot all be used on the site. The protein supplement credits from the protein on a per animal basis are high relative to the production costs and a reasonable profit margin. No account is given of how much protein was actually recovered to offset purchased feed although some attractive extrapolations are made.

A problem in extrapolating the Roslyn Park Farm results is that this site is not representative of Canadian feedlots, because the diet is based on food processing wastes. These are high in energy but low in protein thus the recovered protein is a valuable and necessary requirement for this particular feedlot. A feedlot using typical farm-produced feeds inherently has substantial protein and the protein supplement requirements range from a smaller quantity to nil. The value of the single cell protein from this operation may not be representative for others. Nevertheless, basing a feedlot on food processing wastes is encouraged as it is an effective way in making at least some use of food wastes rather than as land fill.

In general the report provides all the data collected and makes projections to provide a perspective of how the system could function on a feedlot system. It should be realized that the data from this project were some of the first in Canada. There was a strong interest on the applicability of the technology, therefore many people used this data as their principle source of information. However, several years of routine operation are required before the data can be considered reliable. Unfortunately this was not possible.

Contract No. 9-1928

Analysis and recommendations of the Safety Aspects of Methane Gas (Biogas) Production from Agricultural Wastes. Ruchan, Lawton, Parent Ltd., 1980.

Safety codes potentially applicable to hiogas digesters were reviewed and hazards identified. It was found that there were no formal codes in North America directly applicable to these types of digesters. Following standard gas codes is not practical, but they should be used as a guide to ensure that an adequate standard of safety is maintained. Biogas is wet, corrosive, difficult to detect because it is odourless and colorless and potentially toxic due to its hydrogen sulphide content. The report lists a series of guidelines to follow in designing an anaerobic system.

The report includes a brief discussion on ways to cope with the corrosion problems of H S and CO in the biogas. Scrubbing, drying the gas to prevent acid formation and using corrosion resistant materials are also discussed.

Contract No. ER14

Evaluation and optimization of protein recovery from anaerobically digested beef feedlot wastes. Canviro Consultants, 1985.

The literature was reviewed and very little information was found on the value of anaerobic digestion as a source of nutrients. It was decided that the standard Kjeldahl analysis would he used to determine crude protein levels and the standard ammonia analysis would be used to determine the non-protein-nitrogen levels.

The physical and chemical characteristics of the digester influent and effluent were analyzed. Particular emphasis was placed on protein recovery through fractionation into solid and liquid samples of various mean particle sizes.

The laboratory scale work concluded that the reduction of total solids in the influent increased the concentration of protein in the dry matter contained in the effluent. The anaerobic digestion process increases the centrifugal recovery of total solids and crude protein. The smaller particles contain the higher levels of true protein. Calcium is removed from the effluent by the higher centrifugal forces while potassium which is very soluble is not removed. Digestion increases the amount of phosphorous recovered in the protein from 30-35 percent to 80-90 percent.

In scaling up the laboratory tests the principles of centrifugation were reviewed and the appropriateness of the various techniques discussed including the addition of polymers to increase the separation. It is pointed out that the theory of centrifugation is not straightforward and many assumptions must be made. This makes it difficult to use the theory for scaling up bench test data.

The true protein content increased substantially in the removal of the final fractions of the effluent indicating that the smaller particles contain a higher percentage of true protein. Particle size analysis on digester influent and effluent showed that the average mean particle diameter decreased to 32.9 microns from 39.2 as a result of the digestion process. However, it is not clear whether this was due to a reduction of the particles or the recycling of the single cell protein back to the digester. Results obtained at both the bench scale and full scale levels, indicated that addition of the polymer Praestol 523K significantly increased the centrifugal recovery of total solids. Changing the anaerobic digester operating temperature or hydraulic retention time did not significantly affect the nutrient quality of the SCP recovered.

Much of this work was to develop methodology for predicting, with reasonable confidence, the amount of recoverable protein based on laboratory analysis. A major weakness of the reported work is that a number of factors that could affect the results were not controlled. The results are therefore not representative of what is encountered on a typical beef feedlot in Canada:

1) The type of animal feed was not characterized. Since it was based on food processing wastes the animal manure had its own unique characteristics. Subsequent research has shown that digester performance is strongly influenced by the type of feed given to the animals.

2) Only the centrifuged separated liquid fraction of the manure was fed to the digester.

3) The digester was being run in an experimental fashion using solids retention time control (SRT). Solids separated from the digester effluent by the protein recovery centrifuge were slurried and recycled back to the digester.

4) Influent and effluent digester samples were not taken simultaneously.

5) The loading rate and the hydraulic retention time were not specified.

6) The results were not statistically analyzed.

The influence of the above factors must be carefully weighed before using the results for any assessment and designing anaerobic digestion systems. In general this research shows that over 90 percent of the nitrogen and many essential minerals found in the digester effluent were originally contained in the manure fed to the digester. If some of this material could be recovered it could improve the economics of anaerobic digestion. This was the reason the project focused on this aspect. It now appears that anaerobic digestion must enhance the recovery of protein, otherwise the economics of the process is questionable.

The Selves farm swine facilities were used to compare some bench- scale tests with a full-scale system under various operating conditions. Combinations of different polymer types, effluent flow rates and centrifuge scroll speeds were tried. The centrifuge was a high speed solid bowl type. The polymers were added to evaluate total solids and protein recovery. Digester effluent was first pumped to a vibrating screen separator where coarse non-digestible fibrous material is removed. It was found possible to predict full scale solid howl scroll type centrifuge performance on the basis of bench scale laboratory testing. It was also recommended that both total solids and protein recovery be evaluated using the bench scale test, since it was found that an increase in total solids recovery does not necessarily mean an increase in protein recovery.

Ultra filtration and reverse osmosis were also reviewed as methods of removing protein from the digester effluent and a preliminary economic analysis comparing centrifugation to ultrafiltration was made. In spite of the higher capital costs for ultrafiltration over centrifugal separation the return on capital was better, giving a shorter pay back period.

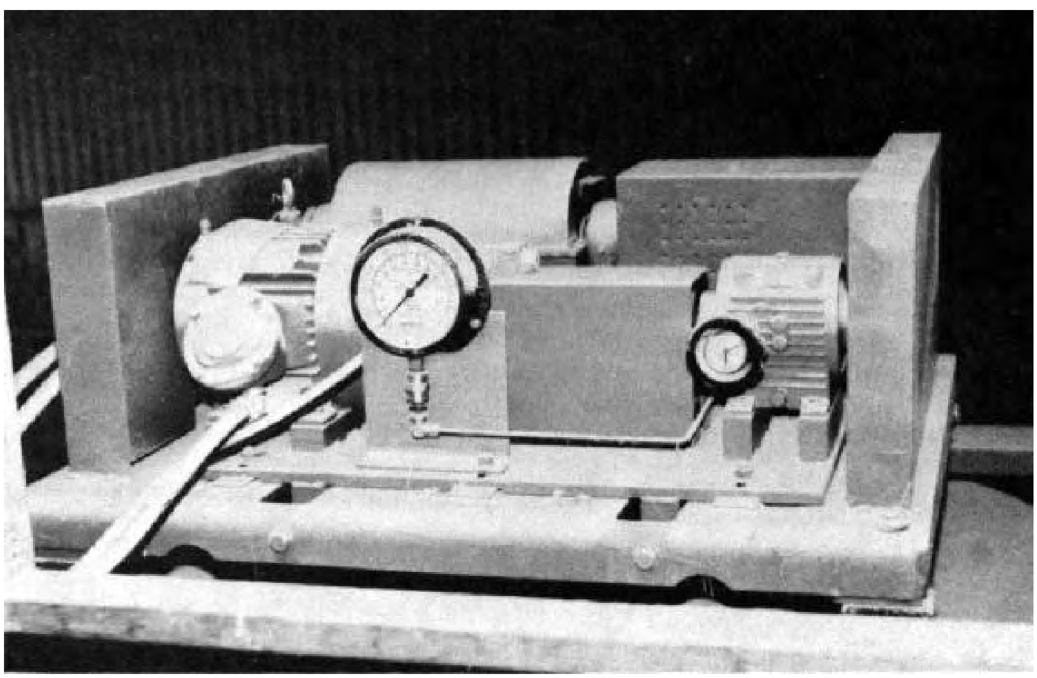


Figure 6. A farm-scale centrifuge for recovering protein from digester effluent.

Contract No. ER15

Conception of a digester for swine waste. Centre de recherche industrielle du Quebec (CRIQ), D. Morrissette, 1982.

The objective of this project was to develop a fixed film digester for a small scale swine operation of about 1400 pigs. Calculations for the design of the system are presented and costs for construction and benefits of operation are projected. It was concluded that a cast-in-place concrete is the best method for constructing the digester.

This report is quite unique in that it openly presents all the calculations and considerations needed to produce the design. Frequently this information is retained by the contractors providing only specifications of their final design and even that is sometimes lacking in detail to he of much real use to others. It should be cautioned however that the digester was not yet built when the contract report was released.

Protein recovery is discussed, but the yields and characteristics are primarily based on reports from Roslyn Park Farms contract report No. 9-1910 and ER14. The report points out that the results should he used with caution as the digestibility of the protein is not yet established. It is estimated to he 60 percent digestible. Part of the protein consists of bacteria which cannot be digested by the animal as they lack the enzymes to hydrolyse the cell membrane. Some discussion on work in Holland and Belgium, addressing mineral recovery and volume reduction is given. A design for protein recovery is not included.

As part of the project a mobile 908 L digester was set up and operated. The objectives were to study screening, preheating of the manure, adherence of bacteria to the fixed film surfaces and sedimentation rates at a farm site. The swine manure was screened and heated to 36ºC and kept in the digester for a 3-day retention period. The manure was circulated intermittently at a rate of 2 volumes per day. It was quickly found that the fixed film tubes blocked and sediment accumulated in the bottom. A finer screen (0.5 mm opening) and a more aggressive circulation rate was then used.

A conclusion of the study was that when a full-scale-fixed film digester unit is built for swine it should have a conical bottom, agitation to prevent blockage in the tubes, very fine screening of the influent and a high rate of discharge at the bottom.

To enhance the economic viability of the technology a special plastic tube was developed for the fixed film medium. A reasonable cost was considered comparable to a French product called cloisonyle available at $188 per m (1982). It was considered that passages of Cloisonyle were too small and the surface too smooth for the bacteria to adhere to. A 100 mm diameter tube with a 0.70 mm wall thickness, a 90 degree cross in the centre and a weight of 470 g/m of tube was developed. Rigid recycled PVC was selected as a cheap source of material for manufacturing the tubes. The tubes provided about 100 square metres of surface area per cubic metre of volume. An extruder was designed to produce sharp V grooves on all the surfaces during tube manufacture to enhance the roughness and thus retention of bacteria in digester using fixed film technology. Samples of the tube material were subsequently tested in other digesters (see Contract No. ER17 and ER43 at Kemptville).

Contract No. ER16

Improving Production and Reliability of Methane Digesters. University of British Columbia, Dr. K.V. Lo, 1985.

This contract had four objectives:

1) biogas production using advanced reactor concepts with liquid-solids separation pretreatment of the manure.

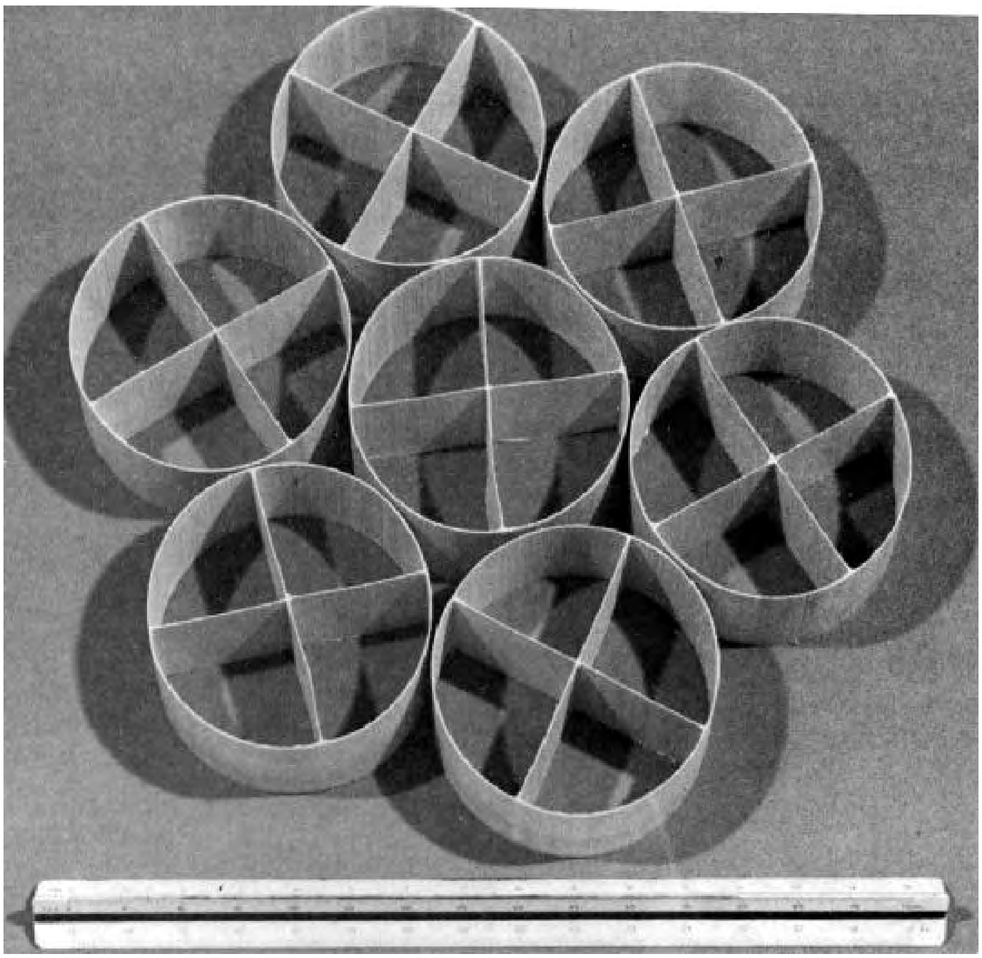


Figure 7. **Cross-section of the fixed film media developed by Centre de Recherche Industrielle du Québec showing how tubes are grouped to fill the digester volume to provide a large surface area for bacteria retention.**

2) development of design criteria for on-farm carbon dioxide and hydrogen sulfide removal

3) development of instrumentation for continuous pH and biogas concentration monitoring

4) development of a microprocessor controlled monitoring and management system for on-farm use.

Dairy cattle manure from a holding area was gathered, diluted with water and passed through a liquid-solid separator with No. 2 and 10 mesh screens to remove the solids. It was then re-diluted to a volatile solids content of 3 to 5 percent and stored at 4ºC until used. Completely mixed and fixed film reactors of about 4 L capacity were built for various temperature ranges and hydraulic retention times. Fixed film material included plexiglass, nylon cloth, extruded plastic tubes, fibreglass screening, Biopods of polyvinyl chloride and extruded plastic tubes developed in Contract No. ER15. A total of 16 digesters were built.

It was found that screening out coarse solids before digestion resulted in an increase in biogas production and reduced hydraulic retention times. As anticipated, thermophillic digestion was capable of much higher rates of methane production than mesophillic and at lower hydraulic retention times than for the completely mixed reactors.

A significant volume reduction of the digester tank appears possible by using fixed film design and manure prescreening; however this finding is only based on bench scalp reactors. For example the additional cost of installing fixed film should be compared with the cost of the larger tank needed if a fixed film is not used in a given design.

Two pilot scale fixed film digesters 76 cm in diameter and 94 cm high were set up and instrumented using an AIM-65 computer. The digesters were mixed using liquid recirculation. Gas production was monitored by two pressure transducers to control a given volume and then relating the pressure reading to volume displacement. In this way the digester was operated and its production recorded by the computer. How well the computerized system functioned is not stated in the report. Feeding for a large part of the time was done manually. Results showed that the mixing and heating consumed considerable energy and could further complicate the analysis in scaling-up to full size. Gas yields were somewhat lower than expected.

Since pH is considered a good indicator of how well a digester is functioning, a method of continuously monitoring pH using a low cost electrode was studied. It was concluded that use of expensive industrial electrodes, which are more reliable and require less maintenance, is probably the best method of monitoring pH.

One important objective was to design and test a suitable sensor for measuring the methane content of the gas continuously during biogas production, an important objective as rate of methane production is a good indicator of the performance and "health" of the digester. One sensor was installed and tested. Carbon dioxide did not seem to affect the reading, however, ammonia did, and would probably have to be scrubbed out before taking the measurement. Finally it was found that there are methanometers on the market, two were tested, gave good results and no further development work was done on the sensor. It was not demonstrated that these meters could he used on a continuous basis as the contract required. However, the literature from the meter manufacturers makes this claim.

Removal of hydrogen sulfide was studied to develop practical methods. Carbon dioxide and hydrogen sulfide were supplied from compressed gas cylinders and saturated with water to simulate biogas. Three fixed beds of scrubbing material were built through which the gas mixture was passed. The materials tested were peat moss, potting soil and soil from a greenhouse. No conclusions were made as meaningful data was not obtained. It should be noted that methane was not used in these tests.

A large amount of research was undertaken by the contractor and this contract was only part of the program of research at the university. Although, all the objectives of the contract were investigated, the results are of a preliminary nature. The data are not backed by sufficient long-term data to attain a reasonable level of confidence and reliability. More work remains to be undertaken to verify the results obtained using farm scale digester systems.

Contract No. ER17

Design, construction and monitoring of a complete anaerobic hog waste treatment system with energy recovery. MacLaren Engineers Inc., D. Maat, 1985.

The objective was to design, construct and monitor a full scale anaerobic swine waste treatment system utilizing the anaerobic fixed film technology developed by the National Research Council. The digester was originally built for a 150 sow farrowing operation. This was later expanded to include the growing and finishing of the hogs.

The digester was of glass lined steel construction (i.e. similar to a farm silo) featuring the stationary down-flow fixed film anaerobic process. The reactor was filled with 100 mm diameter PVC tubing with mechanically roughened surfaces to provide a fixed film for bacteria retention. Hog waste enters at the top and exits from the bottom cone of the digester. Biogas is cooled upon discharge to remove moisture, stored in a flexible bag and fed to a dual-fuelled propane-biogas engine generator set which produces electricity. Provision was made to sell surplus electricity to the local utility through an automatic switching system. Solids are separated out before manure enters the digester and mixed with dry feed and refed to the sows.

The reactor was seeded with effluent from beef waste and was brought to full load within R weeks. No plugging or settlement problems were encountered in the system during a year of operation. This is mainly due to the screening of the influent, resulting in only solids less than 1.5 mm diameter entering the digester.. After initial recycling of the reactor effluent to assist in buildup of bacteria on the plastic tubes, subsequent recycling has only been to maintain temperature and has a turnover rate of 2 to 4 days. Recycling was done on an intermittent basis.

The system design is simple in principle, with all moving parts readily accessible for maintenance and repair. Further design work is warranted to utilize equipment of lower cost and more common to a farm enterprise than the industrial equipment used in the prototype.

After six months operation, the digester was opened up and proper functioning per the design was observed. No plugging or buildup of hair, fats or grease was evident inside the digester. A bacterial slime was coated on two thirds of the tube lengths indicating methanogenic bacteria and that the digester was underloaded.

The reactor effluent was found to have a greatly reduced odour level, no odour being detectable beyond two meters from the lagoon storage. Similarly, when spread on the land no odour could be detected beyond 3 meters.

The report provides an economic analysis, but this is of little value as it is based on a prototype design and the revenue benefits need better confirmation. Electricity is produced for the farm and any surplus sold back to the electrical utility. Aside from a few mechanical problems with peripheral equipment, the digester system has functioned reasonably well requiring a relatively low level of operator skill.

The reactor was operated for 44 weeks, the duration of the time for monitoring in the contract. Attempts were made to characterize its performance. However, its operation was never consistent enough to draw any real conclusions. Subsequent to this contract financial support was given to extend the monitoring for an additional year.

Contract No. ER19

Evaluation of an anaerobic digester. Urgel Delisle et Associés, 1984.

This contract was issued to monitor the performance of a digester during its first year of operation. The digester had already been built for a 350 cow dairy operation, at Pike River in. Quebec for producing electricity for the farm operation. Cattle at the digester site were housed both in free stalls and over slats. During the summer, they are out on pasture and manure collection is greatly reduced. The digester is 11 m wide, 20 m long and 4 m deep, having a usable capacity of 600 m . The manure follows a U shaped pattern making it partly a plug-flow type and partly a mixed digester, as biogas is recirculated for mixing. A flexible bag was used for gas storage and provided capacity for the electrical generation system. No electricity was sold off the farm. Waste engine heat is used to heat the manure and the building housing the digester. The digester was constructed with capacity for 600 head resulting in an increased retention time. The viewpoint of the farmer operator was considered a priority in the project since he is to be the ultimate operator. Hence simplicity, minimum time for managing the operation and its control were considered paramount criteria.

It is concluded that there is really no consensus on what should be monitored to indicate the health of the bacteria in the digester. Methods include monitoring the rate of biogas production, the ratio of carbon to nitrogen or the pH. From the farmer operator's viewpoint tinformation must be understandable, or it is of little use. The information should be of the type that will help him control and obtain maximum gas production from the digester.

The project was initiated with an extensive literature review addressing the parameters that control and demonstrate the functioning of the digester. These parameters were then monitored. Emphasis was placed on controlling the digester externally with a minimum of instrumentation and laboratory tests as compared to being concerned with investigating the basic digestion process.

The report presents a good discussion of the factors that control anaerobic digestion and stands out as an excellent literature review. Although not part of this contract, information about start up of the digester is presented. Initially filled with water, it was heated by propane to 30ºC in two weeks. Manure was added in daily increasing increments of 2 m /d until the desired loading rate was attained. One month after startup enough biogas was produced to replace the propane. The engine generator was not operated consistently throughout the experiment because of technical problems with the engine. Because of the excess capacity, the digester had good stability. The report discusses the problems with some of the pumps not functioning and the variations this caused. Much of this information is useful for accounting for what happened but of little value otherwise.

The problem of pumping manure was discussed. A diaphragm pump had to be abandoned because of its reciprocating motion, fibers tended to separate out and accumulate in the pump until the pump could no longer move or its effective capacity has been reduced to nil. A second 22-kW pump already on the farm required too much power for the generating system and also had to be discarded. An 11-kW pump with better starting characteristics was then selected.

In a one-year period the farm consumed 255,000 kWh of electrical power and the generator set produced 115,000 kWh representing 45% of the farm demand. However, due to the size of farm, its peak electrical demand, reduction due to farm generated electricity and the pricing structure of the electrical utility a cost saving of only 25% was realized. These effects are important to consider when making any economic analysis. A point to note is that the enormous capacity of a public utility can run all the farm equipment at once, while with an engine generator set, careful load planning is necessary and can again add to the investment cost. The price structure used by utilities certainly does not encourage on site electrical generation.

A discussion is presented on the experiences with an inflatable Hypalon reinforced biogas storage hag. The hag was installed in an excavation matched to its shape, but was not protected from the environment. Considerable problems were experienced with holes in the bag probably resulting from the frequent flexing. The bag fractured along a line of condensation on the bag caused by the biogas. The bag was subsequently installed in a metal container and then replaced with a heavier bag, reducing failure frequency considerably. However, long-term durability still needs to be determined.

Figure 8. Flexible storage bag for methane gas

The report summarizes some of the problems that were encountered over a year of operation. Although none were extremely serious, it is obvious that solving them all took time. It was found that the gas engine required considerable maintenance and much of the engine peripheral equipment required changing. Sometimes the solutions are not initially obvious and considerable time or specialized expertise were required to find the cause.

It was estimated that to maintain the digester required 15 to 30 minutes per day, with 1 to 2 hours regular maintenance plus another unscheduled 4 or 5 hours per week for the engine, plus an additional 2 to 3 hours per month of outside help, such as an electrician, plumber or mechanic was necessary.

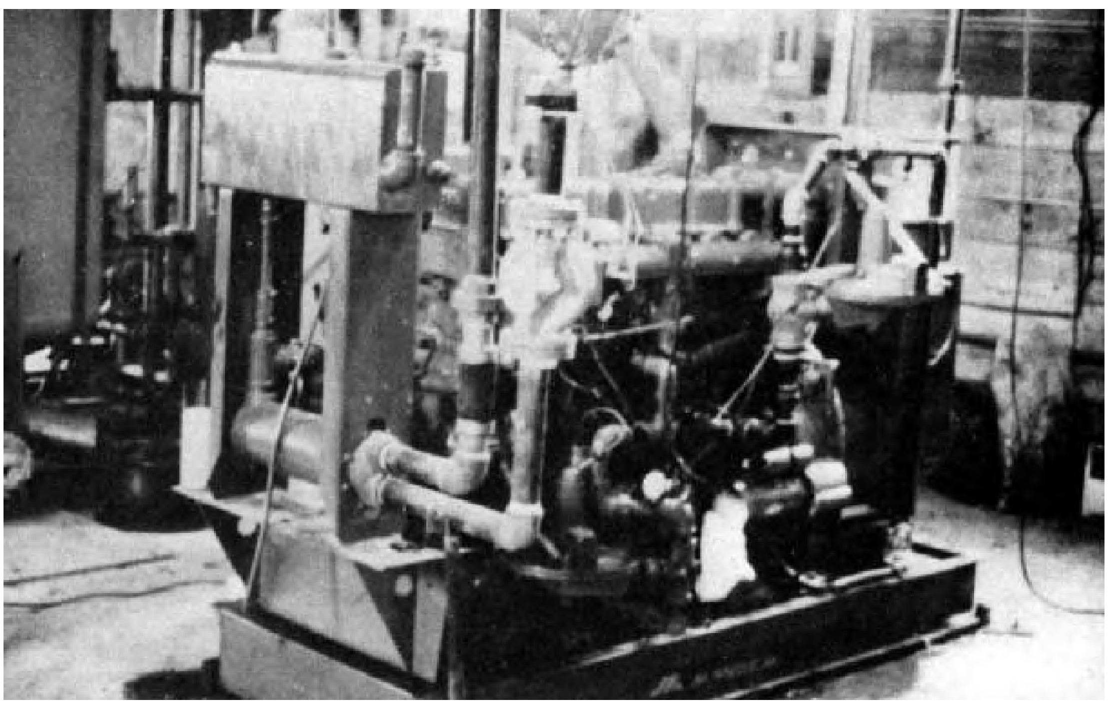


Figure 9. **Engine generator set with heat recovery from the engine for digester heating**

It was observed that the farmer operator was not really at ease with the operation of the digester. The situation required a daily analysis such as, how much manure to add, changing the heating rate or achieving a better digestion and utilization of energy. The speed at which some of these decisions must be taken needed improvement because sometimes there were delays of several days. There was a definite reduction in interest on the part of the farmer-operator as time passed. Some of this could be attributed to poorer system performance and greater operational difficulty than the farmer had anticipated.

In examining the costs and benefits from the digester, it does not appear to break even at current costs of electricity. The capital cost of the system was further subsidized by the labour supplied by the farm during construction. No value was put on the reduction in odour achieved, thus no comments on this were made in the report.

The conclusions were as follows:

1) The oversizing of the digester giving it a 25 day retention time greatly enhances its stability enabling it to cope with several adverse conditions.
2) Reduced gas production from lower operating temperatures is offset by the longer retention time. The volatile solids were reduced 36 percent and the BOD 72 percent.
3) The age of the manure is important, with older manure being characterized by a low volatile solids to total solids (VS/TS) ratio.
4) The manure in the digester is characterized by the pH, alkalinity, ammonia and sometimes the volatile acids.
5) Average biogas production was 576 m per day, consisting of 58 percent methane.

6) If the biogas is not scrubbed, a regular maintenance program of all gas conduits is necessary.

7) Under optimal conditions, the system could provide 83 percent of the farm electrical needs.

8) Supplying electricity for this type of farm operation is very difficult because of the peak demand loads.

Contract No. ER31

Study of high solids content anaerobic fermentation of crop residues. University of British Columbia, Dr. V. Lo. 1986.

The objective of this work was to study a mixture of crop residues and dairy manure for digestion. In conventional systems it is necessary to add water to the crop residues to decrease the total-solids content, thereby requiring a much larger capacity system.

It was anticipated that a system using this mixture will permit higher organic loadings and the digested product could be used directly as a constituent in animal feed without the additional step of centrifugation.

The report begins with a literature review of the work done on high solids digestion. A substantial amount of work in this area has been done particularily at the laboratory scale. The intended uniqueness of this work relative to work reported in the literature is not given.

Initial tests were done with wheat straw and dairy cattle manure in 1 L fermentors. The straw was finely ground and mixed with raw manure. Various combinations of manure screenings, ground straw and diluted manure were evaluated for biogas production in two larger laboratory scale units of two 6 L capacity. Various biogas production rates found are presented in the report accompanied by explanations on the possible reasons for the variations.

A 300 L polyethylene tank insulated and heated with a hot water jacket, centrally installed, was used as the pilot-scale digester. A 3:1 manure solids-to-straw ratio by weight was used. The resulting level of methane produced in the biogas was very low. It was felt that because the main substrate was the solids residue separated from raw manure slurry it contained too much undigested grain and other cellulosic material ingested by the cattle. Constraints in the project limited the work to the higher solids content residue mixed with chopped wheat straw.

The pilot scale study was not able to reproduce the laboratory-scale results. It was concluded that the liquid fraction contains the bulk of the readily biodegradable and reactive material available for anaerobic digestion. In addition the pilot-scale work was plagued with minor technical problems.

It was concluded that the experimental results support the, literature findings that high solids anaerobic fermentation of agricultural residues is feasible. There are serious concerns that mixing will be an important factor in scaling up the process. In general this work did not indicate that it would he impractical to develop a total manure handling system.

Contract No. ER33

Study on the scrubbing of biogas. Centre de recherche industrielle du Québec, P. Toupin, 1986.

The objective was to develop a suitable method for removing hydrogen sulphide from biogas. A new scrubbing material made of asbestos and iron oxide was developed. It has a large surface area of 75 m /g and is capable of removing 3.7 x 10^{-}g of hydrogen sulphide per g of material per hour.

A discussion on the common scrubbing technology used in the oil refinery business is given. A pilot system to scrub biogas from a 1 m mobile digester was built and installed. Several different materials with an iron oxide base were produced and evaluated. The reaction of sulphur with iron oxide is exothermic and the material can reach 45ºC. The regeneration however is ten times more exothermic and must he done under controlled conditions of temperature and humidity to avoid the risk of combusting the sulphur. It was found the most important aspects are:

1) quantity of iron oxide contained in the scrubbing material
2) crystalline structure of the iron oxide
3) size of particles or porosity
4) pH of the gas
5) humidity of scrubbing material
6) temperature of operation
7) other factors such as CO content of the biogas, gas humidity, temperature and purity.

A brief discussion is given for each of these factors.

Wood, peat moss and asbestos were considered for supporting the scrubbing material. The function of the support material is to maintain humidity, provide an alkaline environment and a medium for the microorganisms involved.

A scrubbing system comprised of two 7-L units was built and operated in the mobile laboratory and a smaller unit for evaluating the scrubbing materials was built for laboratory operation. Results of the various materials tested are presented, with iron oxide mixed with asbestos giving the best results. Although it was concluded the material worked well, it remains to be verified how well it will work under long term cycling. It was decided to scale up the system for a 50 m swine waste digester.

In an annexed report, it was noted that the production of heat was a problem and the air added to regenerate the iron oxide had to be very carefully controlled to keep the temperature below the required limits. The report recommends that the new scrubbing material formulation needs to he optimized, the cost of its production determined and its durability tested in light of its potential.

An extensive account of the tests undertaken and the results are presented in the appendices of the report.

Contract No. ER34

Study, demonstration and experimentation of a fixed film digester for swine wastes. Centre de recherche industrielle du Québec, 1986.

The digester designed in a previous contract (ER15) was constructed. The system was started up and monitored. The contractor is to prepare a heat balance of the digester and study the economics of a fixed film versus a conventional system. Also the study includes determining the applicability of an induction motor for producing electricity and an analysis of the different methods of using biogas. The final report is to include a set of prints describing the system. There was a large overrun on the construction cost indicating that expertise to accurately estimate costs is still not readily available. Manpower costs was the major cost underestimate.

Reports are not yet available.

Contract No. ER35

Comparative evaluation of five biogas storages. Urgel Delisle et Associés, M. M. Cournoyer, 1986.

This project was undertaken to seek a reduction in the cost of capital equipment and maintenance for a biogas system. At the Gasser farm, Pike River, Quebec, five inflatable bag materials were evaluated for storing biogas. The evaluation was carried out over a period of one year and the results include many visual observations. The materials tested were CPE (chlorinated polyethylene), XR5 (ethylene interpolymer alloy), PVC Vintex (polyvinyl chloride), PVC Sarnafil (polyvinyl chloride), and Hypalon (chlorosulfonated polyethylene). Each bag was filled with 275 L of water to anchor them in their sand bedding.

Because of the low energy content of biogas and the high pressure to liquify it, it is best to utilize the biogas daily and use the bags as temporary storage to handle peak gas demands (e.g. for heating or electrical generation). The bags were chosen as the most practical and low cost method of temporary storage, requiring no gas compression. The problems found in using the bags were over-inflation, movement in the wind and other climatic effects. Bag materials must have the following characteristics:

1) Resistant to temperatures from -20ºC to 35ºC
2) resistant to weather effects (wind, snow, ice, solar radiation)
3) be air and water tight
4) resistant to mild sulphuric acid
5) easy to maintain and repair
6) readily available.

A volume of 30 m was selected with an operating pressure of 1.72 kPa but capable of withstanding a peak pressure of 3.42 kPa.

The investigators point out the danger of doing a test at increased pressure, as it may cause the bag to leak and to stretch to the extent that it doesn't return to its original shape.

For hypalon and CPE, patching material for tire tubes worked quite well. The report describes procedures used for patching the bags, pointing out that there is very little knowledge available on bag repair. It was found that most of the repairs can easily be done by the farm operator at a low cost. However, at 7.84 kPa most of the glues tended to fail.

The best method of anchoring the bags was to put some water in them, making a depression in the soil to retain the water. Sand bags were then attached at each corner of the bag at the mechanical joints.

It was found that storing biogas in an inflatable bag at a low pressure is a practical method. It is preferable over a storage system that requires gas compression. A windbreak to protect the bag is strongly recommended.

Contract No. ER39

The evaluation of single and two stage anaerobic digestion of poultry manure. Canviro Consultants Ltd., 1986.

The objective was to develop the technology for the anaerobic digestion of poultry manure. No literature appears to have been reviewed for this study as no justification or discussion is given for the types of digesters that were selected. Nor is any justification provided for taking the manure in a solid form containing 20 percent solids and diluting it 5 to 7 percent rather than developing technology for solid manure handling. This necessitates a switch by the farming operation to a liquid manure handling system. The trend in poultry operations is to solid manure systems making it unlikely that a liquid system will he adopted by farmers.

Poultry manure is well known for its high protein content and extensive research has been done on using it directly as a feed. The researchers established that anaerobic digestion was worth pursuing for increased protein value, as protein recovery was one of the objectives of this work. Several laboratory scale digesters of 25 L and 50 L were operated in various combinations to examine:

1) completely mixed single stage
2) completely mixed first stage for acid formation
3) fixed film second stage for methane production
4) fixed film single stage.

A comprehensive exposé of the performance of the digesters and their measurable characteristics is given. The fixed film material was examined with an electron microscope. However for what reason or what was concluded from these tests is not reported. All the manure was screened, even when transferred between the digesters for the two-stage process. It was found that half of the fixed film media tubes where plugged after six weeks of operation.

Protein recovery work was abandoned in favour of operating and evaluating a single stage fixed film digester. This was based on previous work on poultry manure under a contract with the National Research Council. The results of the previous work are included in the report. Polymers were not found cost effective in enhancing protein recovery because of the high concentration of grit in the manure. The grit and heavy solids lower the protein content of the resulting centrifuge cake. It was concluded that protein recovery from poultry manure cannot be recommended for farm scale operation.

A design giving sizes and anticipated performance figures and an economic summary is presented for the following reactors:

1) a single stage completely mixed
2) a two stage completely mixed followed by a fixed film type
3) 45,000, 100,000 and 250,000 hen layer operations, single stage fixed film.

It was found that only the 250,000 hen operation using a completely mixed or two stage design had any possibility of being economically viable. The single stage fixed film design would always operate at a loss. It should be noted that these designs were originally conceived for protein recovery requiring the manure to be diluted and screened. Also the fixed film tended to plug and was unworkable.

Contract No. ER41

Control equipment for anaerobic digestion. Urgel nelisle et Associés, 1987.

The objective was to build and test controls to monitor the performance of a digester, analyze the data, take corrective action if necessary and inform the operator of what happened. The contract was extended to establish the reliability of the equipment developed. The final report is expected in March 1987.

Contract No. ER42

Evaluation of capital cost reduction for anaerobic digestion systems through advanced process concepts. Roslyn Park Farm Ltd., 1986.

The objective was to optimize the operation of a full scale anaerobic digestion system under conditions where the solids retention time is less than the hydraulic retention time. The solids would be removed from the effluent and put back into the digester thereby increasing the microbial retention time. It was anticipated that the productivity would be improved, resulting in reduced capital and operating costs.

The project got off to a poor start because the Roslyn Park Farm digester used for the project was not operated consistently for the first 3 to 4 months. The project was stopped. No results or report were produced.

Contract No. FR43

Optimization of recovering and refeeding of protein from anaerobically digested swine waste to swine. Canviro Consultants, 1986.

A series of bench scale centrifuge tests was used to select polymers capable of increasing the solids recovery from anaerobically digested swine waste. Polymers were selected considering relative molecular weight, charge type and level. The total solids data and sludge viscosity data were used to estimate the percent solids recovery.

Bench scale centrifuge runs were then made in conjunction with corresponding full-scale centrifuge runs. This was to provide data on polymer characteristics which affect the recovery of total solids, ash, crude protein, non-protein nitrogen, true protein, calcium and phosphorus at the bench scale and how they relate to full scale operation. Scale-lap relationships intended for predicting full scale recovery levels from bench scale tests are presented with a comparison of the results. Results for the various items tested are presented. It was finally concluded that bench scale recovery data are not a good estimate of full scale centrifuge recoveries due most likely to the inability to accurately simulate full-scale conditions at a bench scale. The recovery of true protein, phosphorus and calcium can be increased by utilizing a polymer with a low molecular weight, positive charge and a high degree of hydrolysis. Centrifuge parameters, polymer dosage, G force, scroll speed and feed rate all affect recovery rates. Based on these results, it appears that there is no point in further bench-scale centrifuge work.

A second objective was to evaluate the performance of swine fed balanced rations containing varying amounts of recovered single cell protein. The trial was conducted on starter pigs at the University of Guelph, growing and finishing pigs at the Selves farm. It was found that as the rate of substitution of SCP for regular protein feed intake increased, the rate of gain decreased. This was essentially true for both the starter and growing and finishing pigs. Close examination of the results showed that this reduction may be due to a palatability problem since feed intake also tended to decrease. A subsequent feeding trial with a flavour enhancement was recommended. Considerable data on the feed analysis and test results are presented.

The third objective was to optimize the use of the single cell protein using feeding trials. The optimum level of single cell protein previously found was verified in a feeding trial and whether feed consumption could be increased by using sweeteners or flavouring was assessed in an additional trial.

A Lotus spreadsheet program was developed to formulate nutritionally balanced rations using the major nutrients available in each ingredient. However no optimization is used, it is strictly a trial and error technique to ensure that the ration is nutritionally adequate.

All the rations were balanced for a true protein content of 14 percent, with the analysis of the single cell protein from digester effluent showing a true protein of q.4 percent. Its value as a protein supplement is then questionable. The animal must he encouraged to increase feed intake to obtain the desired amount of protein. The bulk density and palatability of the feed therefore play deciding roles.

In general the more SCP fed the lower the feed intake and the lower the rate of gain. Attempts at adding a sweetner or flavouring to the diet were not shown to have any merit.

There may some merit in refeeding digester effluent if the minerals in the diet can be recycled, especially the more expensive ones. However, the true cost of the entire system must he included in the analysis and then it is of doubtful value.

An economic assessment was made of the entire system. The feeding trials were run through an economic model and a comparison of the results made. Refeeding SCP was not economic.

This report has been very key in assessing the refeeding of digester effluent. It was found that it cannot be recommended for consideration on Canadian swine farms. Also there was little evidence given that there are aspects worth further research investments.

Contract No. ER47

Design and construction of a mobile plant anaerobic digestion facility. Canviro Consultants, 1985.

Even though considerable experience exists on anaerobic digestion, additional pilot scale technology development was considered necessary before specific optimum designs could be selected. Consequently a mobile laboratory facility with three computer-controlled digesters was built.

The digesters are a completely mixed, a fixed film and a hybrid design, each about 1 m^3 in size. The facility includes equipment for demonstrating protein production and recovery. An onboard computer processes the data gathered. Complete technical specifications for the components are given in the report.

The facility provides the capability of obtaining on-site treatability data useful for obtaining data needed for full scale digester designs. However, since its construction, it appears that comparative analysis among the different digester designs is less important than optimization of a particular selected design. This mobile system will be used for this purpose at various food processing sites under an agreement between Agriculture Canada and Environment Canada.

Contract No. ER51

Optimization of a fixed film digester. Quebec Industrial Research Centre, D. Morrissette, 1985.

The contractor has been working for the past five years to develop the anaerobic digestion system (fixed film) originated by Mr. Van den Berg of the National Research Council. The objective of this project was to operate an intermediate size fixed film digester of 616 litres on swine manure at the site of a full scale unit. This is an extension of work initiated in contract No. ER15.

The manure is screened and heated to 35ºC before it enters the digester. The contents of the digester are mixed 7 or R times per day. It is equipped with the fixed film tubes developed by CRIQ in a previous contract. The tubes are 2 meters long. The entire system was automated and required only a few visits per week.

It was found that due to a poor distribution system in the digester, the fixed film material was only partially functional. The high chemical oxygen demand resulted in a fairly acidic digester content that may have inhibited the bacteria. Other disturbances were the variations in volatile solids and the occasional use of antibiotics for feeding the animals providing the manure. The antibiotics reduced the volatile acids in the manure and the chemical oxygen demand reduction was reduced as was the biogas production. The potential problem of antibiotic effects on digester performance needs additional investigation.

Upon opening the digester, it was found that it could very easily and quickly be restored to its productivity level in a matter of days. The fixed film tubes were covered with a biofilm on the outside, but only an accumulation of minerals on the inside. This accumulation indicates that it would probably be 10 to 15 years before they would restrict flow in the tubes. Only one tube was blocked.

Performance data for the digester is extensively presented in the report. In general, it was found a reduction in chemical oxygen demand of 75 percent was possible with a retention time of 10 days. The system was quite stable except when antibiotics reduced the performance. This digester was an intermediate stage and the development of a full-scale system is still required to draw any conclusions and make recommendations.

Contract No. ER52

Research and development of anaerobic digestion technology for agricultural and agrifood applications using a mobile pilot plant trailer. Canviro Consultants Ltd., 1986.

The mobile facility built in a contract (No. ER47) required validation. The facility was installed at J.M. Schneiders in Kitchener, Ontario. The digesters were allowed to become biologically active followed by two months processing all plant effluents and finally with only the rendering plant effluent. The waste streams were characterized and their performance with four anaerobic treatment technologies was monitored and recorded. A completely mixed, fixed film, upflow anaerobic sludge blanket and a hybrid of the latter two were the technologies examined.

The capital, operating and maintenance costs of a treatment system were calculated. In making an economic comparison to the cost of discharging the waste directly into the municipal sewage system it was found the latter is the least cost alternative.

The project was successful in providing a shakedown of the equipment. A project of this type should he cost-shared to ensure that the cooperator is really interested. Future site projects will start cost-sharing with the plant operators eventually picking up all the costs of such on site feasibility tests.

Contract No. ER53

Biogas production facilities on farms - a 1985 look at the recent experience. Ralph G. Winfield & Associates, R. Winfield, 1986.

This project was jointly supported by Agriculture Canada and the Ontario Ministries of Agriculture and Food and Energy. The objective was to obtain an impartial evaluation of the anaerobic digesters that had been built in Canada. An assessment of a number of digesters in the USA was included for comparison.

The different digester types assessed are described and briefly discussed. A report on each field visit is given along with comments of the performance of each system, some of the problems encountered, the existing operational status of the units and perceived benefits.

The report concludes that anaerobic digestion definitely reduces odours, but at present this does not provide enough financial incentive for adopting the technology. If anaerobic digestion is to have a place, the benefits of energy production and digester effluent refeeding will have to justify it. Most operators had hoped to recover their capital through biogas production for heat and electricity generation and refeeding of digester effluent. However, the returns have fallen short of expectations. We obviously have the technology and expertise for designing a system, but we need more modest systems aimed at odour control that can be extended if energy prices increase again and warrant energy production.

The report gives a good perspective of how the technology fits in with Canadian farm operations. The report should he studied before contemplating installing a system or conducting further research.

Many recommendations are made in support of the research program as there are still many problems to be solved before the technology can be considered suitable for Canadian agriculture in general. The main recommendation is for the development of simpler and lower cost systems. Many of the recommendations for further research are already being addressed in ongoing research projects.

ACCOMPLISHMENTS

1) We are able to build and operate anaerobic digesters on Canadian farms despite our harsh winters.
2) The NRC fixed film technology has been scaled up and applied on Canadian farms.
3) Several engineering firms have expanded their business (nationally and internationally) and developed expertise on the design, construction and operation of digesters. These firms can be considered to be in an international competitive position and technology transfer to industry has already taken place.
4) Experience has been obtained with the technical and practical problems encountered with on farm anaerobic digestion.
5) It has been established that, in general, an anaerobic digester cannot be economically justified on Canadian farms and it will take a substantial increase in energy costs before anaerobic digestion becomes economically attractive.
6) It has been clearly established that operation of an anaerobic digestion system requires extensive dedication from the operator and/or additional technical support; the technology is still far from providing turn-key operations suitable for Canadian farms. In effect from the agricultural viewpoint the technology developed is advanced and when and if the economics involved improve, final development of suitable systems should he feasible.
7) A digester packing material that considerably reduces the cost of fixed film units has been developed.

DISCUSSION

The anaerobic digestion program can be considered successful. One of the original objectives was to achieve energy self sufficiency on the farm. Energy can be extracted from manure without any loss of its fertilizer quality.

As with many renewable sources of energy, coincident timing of energy production and utilization is extremely important to its economic viability. Because of our climate and the requirements of anaerobic digestion, the process needs supplemental heat in the winter. The biogas can be burned directly or waste heat from the production of electricity with an engine generator set can be used. It was found that there is still enough energy left for space heating of a residence or workshop in the middle of the winter. The overall energy balance is very favourable, especially if cogeneration is employed. Though technically successful, the system cannot he justified economically.

All the systems developed were designed as add-ons; none were really designed as an integral part of the manure handling system. Too much emphasis was placed on keeping the digester functional rather than optimizing the manure handling system. While the program has developed designs that work a commercially viable unit that is safe, simple, reliable, and a low cost design has not been developed. Most of the designs were directed to protein recovery, if this objective is abandoned, simpler designs could be developed.

Emphasis was placed on making the technology work rather than developing the technology for the benefit of the farm operation. The inherent danger is that the functioning of the system takes precedence over addressing the root of the problem or that the original objective is to do something for the farm operation is overlooked. Several examples can be given.

A solution to the sedimentation problem, is to pre-screen the manure. This solves that particular problem but it creates another for the farmer. He has a liquid manure handling system, but suddenly he now also needs a solid manure handling system, an increase in equipment complexity for his operation. Another example, foaming may be a problem, putting in a foam breaker is a solution. Certainly the systems function, but the appropriateness of the technology is still in question.

There is no doubt that installing one or even two submersible recirculating pumps is one solution to the problems of scum formation and settling. However, in spite of claims that the pumps are almost maintenance free and have excellent reliability, they will break down and have to be serviced. Installing them inside the digester is therefore not a good practice because it will require shutting down the digester, opening it up and working in a hazardous environment of methane gas. This may be no problem for an engineering firm with the proper expertise and equipment but farmers would have to attempt this themselves.

Rather than screening or centrifuging all the manure one would question if many of the obstructive particles wouldn't be removed through a settling process. It would certainly be a less energy intensive method. The other alternative would be to design systems that can take all the material. There is enough evidence that screening out the solids reduces biogas production and if refeeding of digester effluent is to be practiced removing the solids also removes undigested feed which can be a significant loss.

To hasten start-up, digesters have been seeded with effluent from existing digesters. Was this really necessary? No matter what culture is used initially, the microbes best adapted to the influent and operating conditions will eventually take over. A digester on a farm is not a strictly controlled microbial facility. The one digester in the program that was started without a culture seemed to come on stream as fast as others that were seeded.

Animal nutritionists have been reluctant to get involved in the refeeding of digester effluent. Refeeding is not an engineering question and without strong support from nutritionists, success is unlikely. Information from several animal nutritionists on refeeding shows unfavourable results. In addition, it is felt that the quality of the protein obtained is mediocre and is not worth pursuing. Nutritionists point out that, in the first pass through the digestive tract, the animals will use the most-readily available protein. The less accessible protein pass on through and may then only be recycled through the animal when protein is recovered from the digester effluent. In exceptional cases where a high energy feed lacking in protein is used, it may have merit. This is not the case for most livestock operations in Canada. There may be merit in recycling some of the nutrients if they can be economically recovered.

The protein recovered from the digesters is frequently called single cell protein (SCP). This can be a misnomer because it implies that the protein is the microbes that have done the digestion. However, the digester effluent also contains undigested feed which has a protein value. Very little effort was expended on analysing the proportions of these fractions, but the protein level of the manure entering the digester closely matched that of the digester effluent. Furthermore, using the Kjeldahl nitrogen test, to determine crude protein makes no distinction regarding the protein source. Incorrectly assuming that all the protein is single cell protein may explain the poor refeeding results obtained.

Manure is still looked upon by many farmers as a liability rather than an asset. Any further complication or cost is not appreciated. The farmer's time is limited and extremely expensive at times, consequently any system must make a contribution to the operation or it will not be acceptable. Any system must be able to take all the manure as farmers don't have the time to divide their manure streams. Complicating factors include cattle on pasture in the summer, feedlots are sometimes empty part of the year, and the volume of manure increases as animals grow. Digester systems must be able to cope with these fluctuating conditions.

Anaerobic digestion is frequently presented as a solution to the disposal of animal manure, particularly when an intensive livestock operation has been built with little or no planning for manure utilization. Even after anaerobic digestion, virtually the same volume of waste still has to be dealt with. Anaerobic digestion can help by reducing the oxygen demand of the manure thereby making it less objectionable due to odour reduction. However, it is not an alternative for the disposal of manure when the land base for spreading is too small or nonexistent. The effluent from the process is still only suitable for land application, not for discharge into water courses.

Digester effluent and screenings are promoted as excellent soil conditioners with excellent fertilizer value. There is no evidence to dispute this, nor is there evidence to prove that digester effluent and screenings are better than raw manure. If anything, removing some of the protein will lower the nitrogen value of the manure as fertilizer. Anaerobic digestion unquestionably reduces the odour problem of manure and this may well help justify its application in many instances. However, a farmer who manages his manure properly such as injecting or "plowing it in" doesn't have an odour problem. Anaerobic digestion certainly can help but it isn't the only or least cost solution.

Canada enjoys relatively low electrical power rates. In United States, electrical rates are higher and through legislation the utilities must buy back power at the rate that it costs them to bring additional power into production. This is usually higher than the rate at which power is sold. In Canada the utilities really don't need the additional power from the small producer and he is therefore not encouraged. Another fact often overlooked is that the energy charges include a distribution cost. When the utilities buy back power the distribution cost is deducted thereby lowering the price to the small producer even further.

Although a farm can come close to being electrically self-sufficient through digester technology, it may not have the capacity to meet peak loads. Most power requirements tend to peak twice a day.

Even if loads can he staggered it may be necessary to install current limiting devices for the startup of large motors to minimize peak demands adding to the farmer's cost. Due to the utility rate structure a farmer producing electricity may have to pay higher rates for the reduced amount he buys, further reducing the economic gains.

The economic analyses supplementing some designs are unrealistic. Firstly, the most favourable performance figures are used leaving no margin for unforseen problems. Secondly, a more realistic business investment approach is required. Amortizing capital expenditures over 20 year periods is unrealistic. No lender would put up money for such a long period with only the system as collateral. Salvage value of these systems is very small.

The program results are beginning to generate some equipment durability information. Far from being reliable, virtually all the systems in operation in Canada still require engineering expertise to he associated with them to keep them operational. The level of expertise required for the diagnosis and repair of the systems is much above the capability of the average farmer. Without this extra support, it is questionable that the systems will remain in operation. Most of them have been built with public funds and their true benefits are therefore marginal.

A high rate digester can result in a reduced capital cost because of its smaller size, assuming the cost of the peripherals is not increased. However, it may he of questionable merit. The bulk of the manure has to be stored for some period anyway before it can be disposed of, consequently it might just as well he completely digested before it goes to storage.

Fixed film technology has not proven to be a breakthrough in the application of anaerobic digestion in primary agricultural production. The screening of the animal waste to prevent plugging has increased the complexity of the required technology and reduced the biogas production. There have been no major problems with swine manure but neither is there evidence that there is a great benefit.

The simple low cost type plug flow digester design was not sufficiently researched to establish its applicability. Although they are more popular in United States, one cannot say they have been sufficiently successful to encourage their application in Canada. There is no reason to believe that further research in Canada would produce a different conclusion.

The scaling up of laboratory results frequently produced disappointing results. However, if a little more thought was given there might have been less disappointment and perhaps the usefulness or validity of the work should have been closer scrutinized. For example, if the material is very finely ground to a powder and in scaling tap it is only chopped one should not be surprised that the results are different. Was grinding it into a powder realistic for a possible practical solution to manure handling? It is easy to get through mixing of a laboratory scale digester of a few litres but one should consider the volume of material produced and needed to be processed on the farm. The mobility of the microbes is limited and in many cases even fixed.

The value of reporting laboratory scale results in the literature is also questionable when we know the large deviations that result from scaling up. It serves few people other than fellow researchers also working only at a laboratory scale level. Laboratory scale work certainly is fundamental to this type of development but without scaled up results its results can he misleading.

It is easy to be critical of a program especially if the results have not been favourable. No doubt this criticism reflects on the participants. However, there have been many hard working dedicated people in this program who have tried hard to make a success of the technology and their contribution should not easily be forgotten or overlooked. The percentage of success in research unfortunately is always small.

CONCLUSION

Anaerobic digestion technology is not practical for most of Canadian agriculture. It is not economically viable and does not contribute sufficiently to the production objectives of agriculture. High capital costs are inherent in all the systems developed. The systems are complex, requiring a high level of expertise to keep them in operation. The hardware is unreliable in the sense that the farm operator must be prepared to devote much time in diagnosing and repairing components.

The benefits of refeeding separated digester effluent have fallen short of expectations and are of doubtful value. The cost of energy and the profitability of intensive livestock housing has to increase considerably before further consideration should be given to anaerobic digestion on the farm.

COMMENTS ON THE PROGRAM

Good progress can be made by operating a research program through contracts, however, it is often difficult to get a proper balance in the reporting of results. Contractors will inherently emphasize positive results as a reflection of their expertise and success. Problems encountered and yet unresolved are of interest particularity when technology is being commercially applied. The hiogas program suffered from lack of suitable research facilities forcing research to he done at farm sites. This can be a valuable experience, however, good control of all the variables is not always possible. An important aspect is maintaining the interest and commitment of the farmer.

Another drawback is that contractors will tend to be secretive about their findings, especially if it means losing a competitive edge. Since anaerobic digestion is not an economically attractive option for farm applications, it is not yet warranted to publish "how-to" information as is normally the outcome of a successful research program. For this program most of the expertise already lies with the industry with participating contractors.

The above should not he interpreted that no useful information is available; very much to the contrary, we have amassed a huge amount of performance data. This data is useful for continuing development of the technology, but certainly not for development of an optimum design. There are many design changes that can he made; particularity if protein recovery is not worth pursuing. A high level of confidence should he apparent if one is to generate how-to information. Some reports contain anticipated results or methods of operation and these need to he verified.

We should not easily he influenced by the number of digesters built. At one time in the program, about a dozen full scale units were in operation in Canada and the impression was left that this was the up and coming technology currently being adopted by the industry leaders. It must he realized that these are experimental units heavily supported by public funds. As government funding has dropped off so has the number of units in operation as well as the interest of collaborators.

LIAISON WITH OTHER ORGANIZATIONS

Agriculture Canada cooperated closely with Environment Canada in the implementation of the first beef waste digestion facility. Environment Canada's objective was to address a pollution problem and Agriculture Canada was interested in the refeeding and possible energy production aspects. This initial cooperation led to additional work with the Canada Centre for Inland Waters at Burlington Ontario. During the program, the Engineering and Statistical Research Centre built several pilot scale reactors, one of which was operated at Burlington on cheese whey to study the treatability aspects. Dr. Eric Hall provided technical guidance in the design, monitoring and interpretation of results. The other pilot units were operated at various locations to provide preliminary design data. Environment Canada continues to work closely with Agriculture Canada and now manage the mobile anaerobic test facility. This has been an excellent arrangement with both Departments addressing the particular problems within their mission while being able to develop technology in its own proper technical perspective.

The National Research Council's research team under Mr. Bert van den Berg has been essential to the progress of the program. They did much of the basic research and developed the fixed film concept. Their guidance was heavily relied upon in applying the fixed film technology on the farm. In addition they performed many laboratory analyses and provided advice on sample analysis. Much of this was done on an informal basis as the need arose. Often it was tied in with work being done under contract. An excellent working relationship was developed.

The Ontario Ministries of Agriculture and Food and Energy were also very instrumental to the program. They heavily supported initial demonstration of the technology. As can readily be appreciated where development stops and demonstration starts is not easily defined. The hack and forth exchange of information and ideas contributed greatly to a well directed program for Canada.

Acknowledgement

The information in this report stems predominately from the work carried out by the contractors, the author's interpretation and discussion of their results. The report was reviewed by P.W. Voisey, J.E. Turnbull, G.E. Timbers, M. Stumborg, P.A. Phillips, T. Pidgeon, R. MacDonald, E. Hall, M. Feldman, D. Culver, R. Chagnon, M. Colwell, E. Brubaker and others. Their constructive criticism is gratefully acknowledged contributing to a better report. As with any report reviewed by a large number of people, comments abound and the author was faced with the quandry of trying to accommodate the comments and having to make compromises. This report was no exception.

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Contract final reports are available to the public. The loaning or sale of hard copy and distribution of microfiche copies is handled by the National Research Council/Canada Institute for Scientific and Technical Information (CISTI). Hard copies can be obtained on loan and microfiche copies are sold at cost.

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In addition to the contract final reports, many scientific and technical publications have resulted from Agriculture Canada's anaerobic digestion program. No attempt was made to document this, consequently a list is not available. However, through searches of the scientific literature most of the publications can be retrieved. Many extension type bulletins and articles were also produced by the extension branches of the provincial governments' as part of their mandate to keep the agricultural community informed on new technology.

LIST OF CONTRACTS

Name of Contract*	Contractor and Principal investigator	Duration & Contract File Number	$Amount
A study of the Feasibility of Using Methane Gas Produced from Animal Waste for Energy Purposes	University of Manitoba Prof. H.M. Lapp	Jun 74 - Mar 74 No. 3-1482	29,392
		Apr 74 - Mar 75 No. 4-0260	44,750
		Apr 75 - Mar 76 No. 5-0019	56,363
		Apr 76 - Mar 77 No. 6-0616	69,737
		Apr 77 - Mar 78 No. 7-0719	77,412
		June 78 - Mar 79 No. 8-1805	46,038
		TOTAL	323, 693
Development, Operation and Demonstration of a Large Farm Scale Anaerobic Digester for Production of Methane from Hog Manure	Mr. W. Langille	Apr 78 - Mar 79 No. 7-0751	73,446
Development, Operation and Demonstration of a Farm Scale Anaerobic Digester for Production of Methane from Hog Manure	Mr. John Fallis	Aug 78 - Mar 80 No. 7-0752	36,385
Design and Assessment of a Thermophillic Farm Scale Methane Digester	Rush Eng. Ser. Ltd. Mr. R. Rush	Feb 79 - Mar 80 No. 9-1910	46,875
Design of a Farm Scale Energy System Using Agricultural Plants & Crop Residues as Energy Sources & Animal Waste to Produce Raw Gas for Farm Operations	Geobi Inc. Dr. F.W. Renoit	May 79 - Dec 79 No. 9-1901	63,645

* Contract final reports were written in either English or French, and are available only in the original language. The language of the report is the same as the language of the title as it is listed here.

Name of Contract	Contractor and Principal investigator	Duration &Contract File Number	$ Amount
Analysis & Recommendations on the Safety Aspects of Methane Cas Production from Agricultural Wastes	Buchan, Lawton, Parent, Ltd.	Oct 79 - Oct 81 No. 9-1928	16,041
Evaluation and Optimization of Protein Recovery from Anaerobically Fermented Beef Feedlot Wastes	Canviro Consultants Ltd. Mr. R. Stickney	Jan 82 - Apr 84 No. ER14	135,000
Improving Production and Reliability of Methane Digesters	University of B.C. Dr. V. Lo	Jan 82 - Jun 84 No. ER16	206,000
Design, Construction and Monitoring of a Complex Anaerobic Hog Waste Treatment System with Energy Recovery	McLaren Engineers Planners & Sci. Inc. Mr. D. Maat	Mar 82 - Mar 85 No. ER17	238,000
Evaluation d'un digester anaerobie	Urgel Delisle et Assoc.	Mar 82. - Jul 83 No. ER19	82,000
Conception d'un digesteur de lisier	Centre de recherche industrielle du Québec M. Denis Morrissette	Mar 82 - June 84 No. ER15	116,000
Purification du biogaz	Centre de recherche industrielle du Québec M. Denis Morrissette	Sept 83 - Apr 86 No. ER33	45,000
Essai comparatif - cinq réservoirs à biogaz	Urgel Delisle et Assoc.	Oct 83 - Feb 85 No. ER35	34,000
Anaerobic Fermentation of Crop Residues	University of B.C. Dr. V. Lo	Nov 83 - June 86 No. ER31	179,000
Evaluation of capital cost reduction for the anaerobic digestion systems through advanced process concepts	Canviro Consultants Ltd. Mr. R. Stickney	Jan 84 - July 87 No. ER42	74,000
Evaluation of single and two stage anaerobic digestion of poultry manure	Canviro Consultants Ltd. Mr. R. Stickney	Jan 84 - June 86 No. ER39	101,000

Name of Contract	Contractor and Principal investigator	Duration & Contract File Number	$Amount
Appareillage Contrôle Digesteurs Methane	Urgel Delisle et Assoc.	Jan 84 - Mar 86 No. ER41	268,000
Optimization of recovering and refeeding of protein from anaerobically digested swine waste to swine	Canviro Consultants Mr. R. Sti ckney	Feb 84 - June 86 No. ER43	258,000
Research and of anaerobic Development digestion technology for agricultural and agrifood applications using a mobile pilot plant trailer	Canviro Consultants Ltd. Mr. R. Stickney	Apr 85 - June 86 No. ER52	176,000
Digesteur de lisier - construction, expérimentation	Centre de recherche industrielle du Québec M. Denis Morrissette	Oct 83 - Dec 85 No. ER34	464,000
Optimisation d'un à digesteur surface fixe	Centre de recherche industrielle du Québec M. Denis Morrissette	Feb 85 - Dec 85 No. ER51	33,000
Biogas Production Facilities on Farms	Ralph G. Winfield and Associates Mr. R. Winfield	Sept 85 - Mar 86 No. ER53	5,000
Experimentation d'un digesteur anaerobie	Centre de recherche industrielle du Québec	Apr 86 - Mar 87 No. ER54	50,000
Mobile anaerobic test facility at Portage la Prairie	Manitoba Water Services Board	Apr 86 - Mar 87 No. ER55	130,000

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