RECYCLING WASTES THROUGH THERMOPHILIC FERMENTATION

by

David William Shepherd

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Department of Bio-Resource Engineering

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
V6T 1W5

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ABSTRACT

Efficient treatment of waste materials from agricultural operations is a problem in most of the countries of the world. This is particularly true where livestock are being reared in large high-production confinement housing systems. There are several treatment systems available to handle the wastes from this type of operation. These systems are described with particular emphasis on thermophilic fermentation. Thermophilic treatment of wastes offers several advantages over the other types of waste treatment systems. The thermophilic system at the University of British Columbia differs from most other high-temperature systems in that no external heat source is provided.

Experiments were carried out which show that the heat necessary to maintain the temperature in the thermophilic range comes solely from microbial activity. The actions of agitation and aeration do not provide any input of heat into the fermenter. The foam which forms on the top of the liquid during a fermentation was shown to be a good insulator.

Feeding trials conducted with the liquid product from thermophilic fermentation demonstrated that this liquid can be substituted for water in the diet of pigs older than twenty-eight days of age with no harmful effects. It is possible that pigs older than fifty-six days of age will be able to utilize the nutrients in the liquid more efficiently and increase their rate of gain without increasing the amount of feed consumed.

Experiments with larger sized fermenters resulted in a commercial design for a thermophilic waste treatment system with a total capacity of six thousand gallons.

Finally, preliminary trials utilizing lignocellulose as a substrate for thermophilic bacteria indicated that these bacteria are able to utilize cellulose as a nutrient source.

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1. INTRODUCTION

The total hog population in British Columbia as of January 1, 1975 totalled 56,000 animals. This figure does not include breeding stock less than six months of age (B.C. Agricultural Statistics Factsheet). The majority of these animals were raised under partial or total confinement systems.

This method of raising swine results in heavy, localized accumulations of manure and associated wastes (Willrich and Hines 1967). The obvious and natural solution to this problem and the one which is cited most frequently is to make optimum use of the waste as fertilizer, that is to spread the waste on the land at rates stimulating maximum crop production. Such handling was economically unfavorable compared to the use of commercial fertilizers since the low content of mineral nutrients in manure did not justify the extended transport and field spreading of the organic bulk material (Turner 1975). However, with the ever increasing cost of commercial fertilizers, land spreading as a method of disposal is likely to become more widespread (Wilson 1975). There has been a great deal of research carried out in the area of high-rate land spreading. A review of the literature in this area is given in EPA publication #660125-75-101 available from the Environmental Protection Agency (Wallingford et al. 1975).

Land spreading assumes that the operator owns or has access to a large enough area of land on which to spread the manure. This is not always the case. Some operators own only the land on which the buildings are situated and others, though owning larger acreages, may not own enough land to handle the amount of wastes produced. In England and Wales approximately 24 percent of the pigs are housed on farms which have too little land to utilize the plant nutrients in the feces and urine, or to dispose of them without risk of water pollution (Richardson 1974). In certain areas of North America where both swine and corn production are combined on the same farming unit, and where the swine wastes are utilized as the major fertilizer it has been found that 335m^2 of land per animal is required for adequate waste disposal (Laak 1970; Webber 1971). This figure converts to one acre of land required for every twelve hogs.

Even when sufficient land is available there are other problems associated with land spreading. These include optimum application rates for different crops, time of application, possible pollution of surface and groundwaters and in areas with urban development, offensive odors and dust.

The hog producer, therefore, requires a treatment system which will reduce the pollution characteristics and the total bulk of the manure. An ideal treatment system would permit maximum pig performance, reduce objectionable odors, gases, and pollution hazards, prevent disease transmission, result in a usable product and be relatively automatic and economical to operate.

Some comparisons have been made between waste from human populations and swine wastes. These comparisons are based on the Biochemical Oxygen Demand (B.O.D.) of the wastes. B.O.D. is a term used to quantify the pollution characteristics of a waste;

it represents the amount of oxygen required by aerobic bacteria for the biological decomposition of the organic matter in a standard time of 5 days and a standard temperature of 20°C. The standard value for human domestic sewage is 0.08 kg B.O.D. per day per person and an average value for a 50 kg pig is 0.15 kg B.O.D. per day. A comparison of these two figures reveals that one 50 kg. pig would be equivalent to approximately two people in strength of waste produced per day. The normal market weight of a pig averages 100 kg. On this basis the waste produced from one marketable pig would be equivalent to that produced by four human beings. Consequently an operation producing 1,000 market weight hogs would also produce waste material with a pollutional strength comparable to 4,000 human beings. However, the volume to be treated would be considerably smaller since swine wastes are much more concentrated (Conrad & Mayrose 1971). Estimates indicate that construction costs alone for applying municipal waste treatment techniques to swine wastes would be approximately twenty to forty dollars per pig capacity or 20,000 dollars to 40,000 dollars for a 1,000 head operation (Laak 1970). Economically, this suggests that some other type of waste treatment system will be mandatory.

2. TYPES OF TREATMENT SYSTEMS

Treatment systems for agricultural wastes, including those from swine operations fall into two general classes, both of which utilize bacteria to decompose the manure. One process takes place in the absence of dissolved oxygen and is known as anaerobic decomposition while the other requires the presence of dissolved oxygen and is known as aerobic decomposition.

2.1 Anaerobic Decomposition

Anaerobic decomposition is a complex process involving several groups of organisms which simultaneously assimilate and decompose organic matter. This decomposition is performed in two steps. The first step involves acid-forming bacteria which convert the organic matter into volatile organic acids such as acetic, propionic and butyric among others. The second step in the process involves the conversion of these volatile organic acids into gases, mainly methane and carbon-dioxide (Fair et al. 1968) (DeWalle & Chian). Anaerobic organisms obtain their energy from the oxidation of complex organic matter but utilize compounds other than dissolved oxygen as oxidizing agents. An oxidizing agent may be broadly defined as an electron acceptor. It is not necessary to have free oxygen molecules present to support an oxidation reaction. Compounds other than free oxygen which may be used as oxidizing agents include carbon-dioxide, inorganic sulfates and nitrates and partially oxidized organic matter such as volatile fatty acids (Willrich & Smith 1970). Complete oxidation of the organic matter results in the production of methane, carbon-dioxide, hydrogen and nitrogen gases. These products may be released to the environment without any ill effects. Incomplete oxidation of the organic matter can result when the balance between the acid-forming bacteria and the methane forming bacteria is upset. This imbalance can occur because of changes in the pH, temperature or solids content of the incoming waste stream. Incomplete or partial oxidation results in the production of mercaptans, amines and volatile acids. These products have obnoxious odors and may exert an undesirable oxygen demand upon release to the environment (Loehr 1974).

Two possible systems which utilize anaerobic bacteria for the treatment of farm animal wastes are the anaerobic lagoon and the anaerobic digester.

2.1.1 Anaerobic lagoon

The purpose of an anaerobic lagoon is the destruction and stabilization of organic matter and not water purification (Loehr 1974). The rate at which this decomposition and stabilization takes place depends upon environmental factors such as the temperature of the lagoon, the strength of the incoming waste, the pH, size of the bacterial population and the amount of mixing that takes place. The mixing is a function of the gases produced in the layer of organic sediment at the bottom of the pool. As these gas bubbles rise from the bottom layer they tend to mix the contents of the lagoon making the organic material more readily available to the active organisms (Loehr 1974).

The anaerobic lagoon began as a simple holding tank for animal manures. It was an open pit, tank or reservoir deeper than five feet which received diluted animal wastes and was not mechanically mixed (Willrich and Smith 1970). The microbial activity in such a lagoon rapidly reduces the dissolved oxygen level to a point at which aerobic bacteria cannot function therefore anaerobic decomposition takes place. Recent studies by Booram et al. 1975 and Nordstedt and Baldwin 1975 have shown that the anaerobic animal waste lagoon is actually a complex system requiring careful management of the previously mentioned factors such as pH, temperature, mixing, bacterial populations, etc.

Temperature is one of the most important factors affecting the performance of an anaerobic lagoon (Willrich & Smith 1970). Maximum decomposition takes place when the temperature of the lagoon contents is higher than 17-19^{o}C (Loehr 1974). In British Columbia and in most of Canada the anaerobic lagoon is not widely used because it remains inactive through the winter and operates only when the ambient temperature rises enough to provide a suitable environment for the biological decomposition to take place. Also, even at optimum temperature of operation the possible production of obnoxious odors can prevent the anaerobic lagoon from being utilized in areas of high population density such as the Lower Fraser Valley.

It should also be noted that the discharge from an anaerobic lagoon contains significant amounts of oxygen demanding material and is unsuitable for discharge to surface waters without further treatment (Loehr 1968). Periodic removal and land disposal of accumulated solids is also necessary, making this treatment system unsuitable for an operation with limited land area.

2.1.2 Anaerobic Digester

The other treatment system utilizing anaerobic bacteria is the anaerobic digester. This form of anaerobic digestion was first developed for use by municipalities for use in treating domestic sewage (Lapp 1975, Lawrence 1971).

An anaerobic digester is a closed vessel equipped with an external mixing device as well as a heat exchanger to maintain a temperature of between 32°C and 35°C (Loehr 1974). These digesters can be single stage, twin stage or twin stage with solids recycling and are usually constructed with concrete (Lawrence 1971).

The single stage unit utilizes a single tank. Within this tank there is a zone where the biological activity takes place and another zone where the solids settle out and are removed. A two-stage unit divides the decomposition and solid-liquid separation phases into two separate tanks. This allows each tank to be designed for optimum operation. Solids recycling involves removing a portion of the active bacterial population from the solid-liquid separation tank and adding it to waste-stream flowing into the decomposition tank. This allows the population of the active bacteria in the decomposition tank to be kept at a high concentration irrespective of the influent waste-stream concentration and is especially valuable when dealing with dilute wastes. In systems without sludge recycling the dilute wastes may not support an adequate, active microbial mass. Sludge recycling permits smaller unit volumes and efficient waste stabilization. Systems utilizing sludge recycling require a sludge that will separate and settle efficiently. However, anaerobically digested swine wastes do not settle well, and therefore this type of system would be unsuitable for use with swine wastes (Schmid and Lipper 1969).

Anaerobic digesters produce methane gas as one of the by-products. Sufficient methane can be produced to heat the digester and provide some excess fuel for other uses (Lapp _et al_. 1975). However, for use in an agricultural situation there are several limitations for such a fermentation. These include the high capital cost for proper structures, mechanical equipment and gas control devices. Methane fermentations require continual care to avoid explosions, and at times a daily feeding of the waste to the digester (Canada Animal Waste Management Guide, 1974; Jewell and Morris 1974 and Lapp 1974). Because of the necessary equipment, the high initial costs, the potential operating problems, the need for competent operators, and the fact that further treatment and disposal of the sludge is necessary, controlled anaerobic digestion systems likely will not be widely applied to agricultural wastes (Loehr 1974; Jewell and Morris 1974 and Lawrence 1971).

2.2 Aerobic Decomposition

Aerobic treatment systems utilize bacteria which require the presence of free oxygen in their environment. The aerobic bacteria or "aerobes" require dissolved oxygen (d.o.) for metabolism using oxygen as an electron acceptor, as opposed to the previously mentioned anaerobes which use electron acceptors other than oxygen (Loehr 1974). With aerobic breakdown of the biodegradeable organic matter the final products of digestion are carbon-dioxide, water and new bacterial cells. This does not mean that after digestion by aerobic bacteria no residue is left except for carbon-dioxide and water, however, it does mean that aerobic treatment breaks down organic matter without producing obnoxious odors. For a given organic loading, aerobic conditions will produce a more oxidized end product or effluent than similar anaerobic conditions and will permit a more efficient conversion of the carbon source to microbial cells. This increase in the number of microbial cells can be regarded as an asset as well as a liability. The higher population of microbes allows greater microbial degradation, faster decomposition and shorter detention times. On the other hand, the greater number of synthesized microbial cells in an aerobic digester will increase the sludge disposal problem unless the cells or their constituents are utilized as a resource (refeeding or production of single-cell protein).

There are several types of aerobic treatment systems and many modifications to the aerobic process which can be used to meet specific treatment requirements. Such factors as the degree of treatment required, characteristics of the waste, nutritional and oxygen requirements of the bacteria, temperature and pH effects and economic considerations serve as the basis for these modifications (Metcalfe & Eddy 1972).

Aerobic treatment systems include oxidation ponds, lagoons, oxidation ditches, trickling filters (all of these operate at ambient temperatures) and a high temperature system termed thermophilic aerobic fermentation.

2.2.1 Oxidation Ponds

The oxidation pond or naturally aerated lagoon is the simplest type of aerobic treatment system. These ponds are relatively shallow, diked structures with a large surface area to maintain aerobic conditions. This type of system has been widely used in areas where the land is fairly flat, and inexpensive, and where the climatic conditions of sunlight, temperature and wind action are favorable (Loehr 1971). The oxidation pond is not a strictly "aerobic" system. The upper layer of the pond has ample dissolved oxygen while the lower layers may have little or no dissolved oxygen. Bacteria and algae are the two important organisms in the pond (Loehr 1974). The oxygen is introduced into the upper portion of the pond through the photosynthetic action of the algae which requires proper conditions of sunlight and temperature. The oxygen produced by the algae along with oxygen from the atmosphere is mixed with the liquid by diffusion and by the wave action at the surface. Microbial action takes place at all levels of the pond. A portion of the organic matter settles to the bottom of the pond and may be decomposed by anaerobic bacteria. Organic matter which remains in solution may be further decomposed by a complex system involving true "aerobes" and facultative "aerobes". Facultative organisms have the ability to utilize oxygen as well as other material as an electron acceptor. Oxygen can therefore be used but is not required. The decomposition of the organic matter results in the release of products such as carbon-dioxide, ammonium, nitrate and phosphate ions which are required for the growth of the algae, thus completing the cycle.

Oxidation ponds are not widely used in Canada. There are two main reasons for this, one is the fact that the environmental requirements for sunshine and warm temperatures are met only for part of the year in late spring and early summer, which means that the aerobic bacteria are inactive for the rest of the year. This can lead to anaerobic conditions developing with a resultant loss in effluent quality. The other reason is the large land area required for an oxidation pond. The Canada Animal Waste Management Guide estimates that an oxidation pond to handle the manure from a 1,000 swine operation would require a surface area of 19 acres and a volume of over 15 million gallons of water for initial operation. In addition it is doubtful that the relatively small volume of manure added would maintain a satisfactory liquid depth in the pond. In British Columbia, the high cost of land eliminates the use of an oxidation pond for the treatment of farm wastes.

2.2.2 Mechanically Aerated Lagoons

Mechanically aerated lagoons are another common type of aerobic treatment system used in the handling of animal wastes. An aerated lagoon differs from an oxidation pond in that aerobic conditions within the medium are maintained by mechanical agitation or diffused aeration. The actual lagoon is usually constructed in the form of an earthen basin with some protection on the bank from the wave action caused by the aeration unit (Loehr 1974). The mechanical aerators used usually consist of a floating platform supporting a set of motor driven blades which are partially submerged. When turned, these blades create turbulence at the surface which has the effect of "beating" oxygen into the liquid. The diffused aeration system operates by supplying compressed air to perforated pipes located at the bottom of the basin. The diffusion method is more practical in cold climates where ice can accumulate on floating aerators and reduce their efficiency

(Pos and Robinson, 1973).

Satisfactory treatment of livestock wastes has been obtained in aerated lagoons that have a volume of approximately fifty times the daily manure production. However, if the aerated lagoon is considered to be for the final or long-term storage of the sludge a much larger working volume would be required. If the lagoon is to be de-sludged once a year or more then the volume can be reduced, otherwise, a lagoon capacity sufficient to permit a detention time of two to three years is recommended (Jones et al. 1972).

Ludington et al. 1967 conducted a study into the effects of aeration on odor levels. For continuous operation an aerator that provides 1.5 times the total daily $B.O.D._5$ is the minimum size recommended to obtain waste stabilization. The aeration requirement for complete odor control is not greatly different from this figure, however, for partial odor control an oxygen supply of one-half to one-third the total daily $B.O.D._5$ is recommended. This decreased rate of aeration discourages the release of many of the volatile acids and the associated gases such as hydrogen sulfide and mercaptans.

Edwards and Robinson 1969 found that a considerable reduction in the nitrogen content of chicken manure may be effected by aeration which can be of great importance when land for disposal is at a premium.

Mechanically aerated lagoons require continuous aeration for maximum bacterial activity to take place. When oxygen is limited, the oxidative respiratory mechanisms of the bacteria cannot function with the result that anaerobic degradation of the substrate prevails. If this condition persists considerable time is required to return to normal aerobic conditions once the aerator is restarted.

Facilities having a detention time of 1.5 to 2 years may have a volatile solids reduction of as much as sixty to seventy percent (Jones et al., 1972). There is a build-up of sludge in an aerated lagoon similar to that which occurs with an anaerobic lagoon. This sludge requires periodic removal and disposal normally by land spreading.

Even though mechanically aerated lagoons are essentially odorless and reduce the pollutional characteristics and volume of the waste the fact that they require a substantial area of land and a periodic removal and disposalof the sludge makes them impractical for use in operations which are situated on small acreages or where land values are high.

2.2.3 Oxidation Ditch

Another type of aerobic treatment system for livestock wastes is the oxidation ditch. This system was originally developed in the early 1950's as an economical method for purifying municipal waste flows from small communities and industries by the Research Institute for Public Health Engineering (TNO) in the Netherlands.

The success of the oxidation ditch in meeting the low-cost treatment requirements of small communities aroused the interest of many livestock producers in North America. According to one source (Canada Animal Waste Management Guide 1974) there were approximately 400 oxidation ditches in operation in the United States. A large number of articles have been written describing the design and installation of oxidation ditches for swine operations (Smart *et al*. 1975; Sutton *et al*. 1975; Eisenmann and White 1975; Taiganides and White 1971; Robinson *et al* 1970; Windt *et al*. 1971; Foree and O'Dell 1969; Jones *et al*. 1972; Day *et al*. 1971). These are just a few of the articles which have appeared in the literature in the last few years.

The oxidation ditch is similar to the mechanically aerated lagoon in the fact that a surface aerator is used to supply the necessary oxygen. The key components of the system are a continuous open channel and a surface aeration rotor. The rotor is used to mix and propel the ditch contents along the channel as well as to simultaneously supply oxygen to the system. The influent waste stream does not require any pretreatment, untreated wastes can be added directly to the system. This facilitates the installation of the ditch directly beneath slatted floors, thus saving labor and pumping expenses. The design of the ditch is dependent upon the $B.O.D._5$ of the waste which is being treated. In an oxidation ditch, the volume of the ditch per animal is less important than the oxygenation capacity of the rotor. The rotor must supply the amount of oxygen required to meet the demand ($B.O.D._5$) of the wastes entering the ditch. Loehr (1974) indicates that if the amount of oxygen supplied is inadequate the ditch becomes oxygen limited, poor process efficiencies result, and odors as well as foaming problems occur. The amount of oxygen supplied by the rotor is controlled by the depth of the rotor in the liquid, the r.p.m. of the rotor and the design of the blades on the rotor (Loehr 1974). A comprehensive discussion on the use and operation of the oxidation ditch can be found in the U.S. E.P.A. publication "Aerobic Treatment of Livestock Wastes" by Jones et al. published in 1972. Some of the reasons that the oxidation ditch might be chosen over the other possible treatment systems are:

1. It is an odorless process, with the exception of small amounts of ammonia at times and an earthy odor given off by the contents.
2. It has the ability to handle shock loads. Once the system is operating properly, the ditch can absorb brief heavy loadings without upsetting the biological process.
3. It fits well into the farmers work schedule, requiring very little attention or maintenance.
4. The process fits readily under the labor-saving slatted floor system, eliminating extra pumping or flushing systems.
5. It is a reasonably inexpensive process, both in capital cost and operating cost.

The oxidation ditch is not without its disadvantages as well. Problems with bearings, improperly designed rotors, motors and belts caused many failures with the first units. The experience and knowledge gained from solving these problems has been used in the design of new equipment resulting in fewer breakdowns and less maintenance (Smart et al. 1975).

Most oxidation ditches are operated on a continuous flow basis where the ditch is kept full to the level of an overflow sluice gate. The overflow from the sluice gate has little or no odor and its $B.O.D._5$ is in the range of 2,000 to 3,000 ppm. which is unacceptable for direct discharge into a natural body of water. (Canada Animal Waste Management Guide). This effluent requires further treatment which usually takes the form of an aerated lagoon or spray irrigation onto a land surface.

2.3 Thermophilic Digestion of Animal Wastes

Up to this point the anaerobic and aerobic systems described in the text have been operating at ambient temperatures. Temperature is one of the most important environmental parameters affecting the growth, activity and evolution of organisms (Allen 1953).

2.3.1 Types of Micro-organisms

Farrell and Campbell defined three different types of bacteria which may be isolated from culture media maintained at temperatures above $55^{\circ}C$. They were as follows:

1. Thermotolerant:

   These organisms are considered generally to be able to grow and proliferate best at $28^{\circ}C$ to $40^{\circ}C$ and merely tolerate or survive at the higher temperatures for short periods. They do not reproduce at these higher temperatures.

2. Facultative:

   These organisms are facultative in that they may grow at more than one temperature range but prefer the higher thermophilic conditions.

3. Obligate:

   These organisms are obligated to grow in the thermophilic range. They usually proliferate best at $60^{\circ}C$ to $65^{\circ}C$ and show no growth below $42^{\circ}C$.

The thermophilic or heat loving digestion system was first developed for treating municipal wastewaters. Kambhu and Andrews (1969) conducted a series of simulation studies using thermophilic aerobic bacteria. They showed that by increasing the oxygen transfer efficiency and by thickening the sludge it was theoretically possible for thermophilic aerobic digestion of municipal wastewaters to be self-generating with respect to the heat required. Therefore, thermophilic bacteria when supplied with enough oxygen and concentrated nutrients will function exothermically releasing sufficient heat to maintain the temperature of the system above ambient conditions. Later works by Popel and Ohmnacht (1972) and Suruce *et al*. (1976) contain numerical examples showing that it is possible to operate a self-sustaining system in the thermophilic range.

2.3.2 Factors affecting the rate of Thermophilic Digestion

There are several factors which influence the rate at which the biodegradable volatile solids (BVSS) will be oxidized. BVSS represents those solids which can be broken down into CO_2 and H_2O by the bacteria.

1. Concentration of BVSS:
   An optimal concentration of BVSS in the waste since it serves as the source of available nutrients, mainly carbon and nitrogen. When these nutrients, along with others, are available in good supply they increase the growth rate which in turn increases the reaction rate.
2. Temperature:
   Temperature affects the rate of biochemical and chemical reactions. According to the classic thermodynamic discovery of Arrhenius, the

biochemical reaction rate follows an equation which can be empirically expressed as $\frac{d \ln k}{dt} = \frac{E}{RT^2}$ where k is the reaction rate constant, T is the absolute temperature, R is the gas constant and E is the energy of activation (modification Singleton *et al.* 1973).

3. Mixing:

Adequate mixing is very important in order for thermophilic digestion to take place. Mixing of the medium accomplishes two things, it removes inhibitory end products from the vicinity of microbial cell metabolism and it brings the cell into continuous contact with fresh nutrients including oxygen.

4. Oxygen Transfer Rate:

The transfer of oxygen from the air, through the medium and into the cell is an important factor in thermophilic digestion. The faster and more efficiently oxygen is transferred into the system the quicker it is available for substrate oxidation and subsequent heat energy release.

5. Composition of Solids:

In order for maximum growth to occur the nutrients e.g. Carbon, Nitrogen and Phosphorus must not only be present but also available to the cell in balanced amounts (Coulthard 1973).

6. Concentration of Nutrients:

The conversion of hydrocarbons and carbohydrates into microbial cells and heat is given by the following equations. It is noted that for every Kilogram of cell wt. synthesized, 3,000 to 7,600 kilocalories are produced.

i) for Hydrocarbons

$$2_n CH_4 + 2_n O_2 + 0.19_n NH_4 + (P, K, S \text{ etc}) \longrightarrow$$

$$n\,(CH_{1.7}O_{0.5}N_{0.19}\ \text{Ash}) + {}_nCO_2 + 1.5_n H_2O + 200{,}000 \text{ Kcal.}$$

ii) for Carbohydrates

$$1.8_n CH_2O + 0.8_n O_2 \quad 0.19NH_4^+ + (P, K, S \text{ etc}) \longrightarrow$$

$$n\,(CH_{1.7}O_{0.5}N_{0.19}\text{Ash}) + 0.8_n CO_2 + 1.3_n H_2O + 80{,}000 \text{ Kcal.}$$

Therefore, a high concentration of Carbon along with other nutrients will increase the rate of reaction and the production of heat.

7. Concentration of Micro-organisms:

The viable cell density or concentration of metabolizing micro-organisms within the medium will determine the rate of breakdown of BVSS in that the higher the population the faster the reaction rate. The surface area of the average cell is a measurement of the cells ability to contact the substrate and to remove the reaction products. The surface area of 0.8 gms of wet weight cells i.e. 10^{12} cells is approximately 50 square feet. Thus a doubling of the cell population doubles the reaction rate, provided other factors are optimal for normal cell metabolism.

8. Types of Micro-organisms:

The type of thermophilic organisms found within a thermophilic process is inter-connected with the temperature and time of exposure of the system to thermophilic conditions. Another aspect of the type of micro-organisms present is the possibility of predators, inhibitors and competitors in the population. The presence of these micro-organisms may lower the population of thermophiles and adversely affect the reaction rate.

Surucu (1975) found that the nutritional requirements of pure cultures were much more exacting than the requirements for a mixed culture. This may indicate that a true synergistic or co-operative relationship may exist between species of thermophiles i.e. the ability of two organisms to bring about changes which neither can accomplish alone.

2.3.3 Advantages of Thermophilic Digestion

Thermophilic digestion has several advantages over the treatment systems already discussed. The most obvious of course is the high reaction rate which means a short detention time. The thermophilic bacteria will enable the treatment or degradation of concentrated biodegradable organic wastes to be completed in a shorter time (Surucu 1975). Matsch and Drnevich (1977) calculated that an aerobic digester operating at 50°C could achieve the same degree of degradation at one half the retention time of a system operating at 20°C.

Higher maintenance energy requirements and higher microbial decay coefficients for thermophilic bacteria have been reported by Matsch and Andrews (1973) and Allen (1953). This means that a thermophilic digester has an advantage over a mesophilic one because the amount of sludge requiring ultimate disposal would be less.

Pathogens, viruses, fungi and parasites cannot survive in the moist, hot environment of a thermophilic digester (Bragg _et al_. 1975).

2.3.4 Thermophilic Digestion of Farm Animal Wastes

The use of thermophilic digestion for the treatment of farm animal wastes has not been widely studied. At the University of British Columbia there has been a large amount of work done in the area of thermophilic digestion of farm animal waste especially swine waste (Bragg et al. 1975; Kitts et al. 1974; Coulthard 1973; Coulthard & Hendren 1973; Coulthard and Townsley 1973). These studies have resulted in the design of a simple, efficient thermophilic digester which can be adapted to many uses both agricultural and municipal. Coulthard et al. (1974) carried out fermentations on municipal, poultry, swine, dairy and beef feedlot wastes in both batch and continuous processing. The results of these tests show that it is possible for a thermophilic digester utilizing farm animal wastes to be self-sustaining in terms of temperature. The two most important factors for the maintenance of thermophilic bacteria have been found to be an adequate supply of oxygen i.e. D.O. level preferably above 1.0 mg/l. coupled with vigorous mixing to strip the CO_2 from the cells and bring them into contact with new sources of nutrients. These results agree with those of Pöpel and Ohnmacht (1972) and Matsch and Drnevich (1977). However, the results of tests with municipal sludge at U.B.C. show a much higher temperature is achieved than that in the study by Matsch and Drnevich (1977). At U.B.C. temperatures of $60^{o}C$-$72^{o}C$ have been normal with municipal sludge (Coulthard 1975). This disagrees with Matsch and Drnevich's statement that autothermal aerobic digestion is a self-limiting unit with an upper limit of $60^{o}C$. This difference could be due to a more concentrated sludge at U.B.C., different populations of micro-organisms or a more efficient oxygen transfer in the U.B.C. unit.

Other studies carried out at U.B.C. have been concerned with the suitability of the product of fermentation as a feed supplement for animals. With the ingredients currently in use, swine diets are 85% digestible. This leaves 15% to be used as a substrate for fermentation by micro-organisms. This 15% which is not digested begins to undergo chemical changes caused by secretions into the intestine and continues to change after being excreted. Microflora markedly change the nitrogenous components in fecal material. (Harmon *et al*. 1970). The nitrogen components are the most valuable in waste. While ruminants can utilize the simpler products such as urea and uric acid, swine require that amino-acids be preformed in the diet.

Studies performed by Singleton *et al*.(1973) showed that proteins from thermophilic bacteria appeared to be similar to that of mesophilic organisms with respect to molecular weight, amino-acid composition, and primary sequences of amino-acids. Mateles (1968) carried out studies on the growth of a thermophilic micro-organism on hydrocarbons. He concluded that the protein content of thermophilic organisms and the amino-acid composition of the protein would be better nutritionally than that previously described for sources of single-cell protein.

The U.B.C. studies (Bragg *et al*. 1975) showed that thermophilic processed animal waste can be incorporated into a chick starter diet at 5% and 10% of the ration without adverse effects on the rate of growth and feed conversion ratio. Coulthard (1973) listed the protein analyses of the various components of the processed slurry. The total processed slurry had a crude protein value of 17% (dry weight basis). The fine, approaching colloidal size, solids which settle out slowly had a crude protein level of 30%, and colloidal centrifuged solids from the supernatant was in the range of 50% crude protein. These results agree with those of Holmes (1971) who found that most of the dry matter and the protein in the contents of an oxidation ditch were contained in the particles of the smallest size. Subsequent analyses of fractions arising from passing through a 20, 50, 100 and 200 mesh screen show a linear increase in amino acid concentration as particle size decreases (Harmon 1972).

3. USE OF LIVESTOCK WASTES AS FEED FOR SWINE

3.1 Poultry Waste

Trivelin (1961) studied the application of chick's feces from a battery brooder in the feeding of weanling pigs. A basal ration substituted with 5%, 10% and 15% of that basal ration was used with similar proportions of chick's feces. Statistical significance among treatments were not observed. Results measured in terms of average daily gain and feed conversion indicated that substitution in the ration of 5% to 10% by equal proportions of chick feces produced satisfactory results, the 5% proportion being the most advantageous.

Geri (1968) fed young pigs a diet containing poultry manure substituted for bran at levels of 7-10% for a period of four weeks. Those animals fed manure containing diets had lower daily weight gain and higher feed intake per kilogram gained. The younger pigs (17 kg.), when fed the manure substituted diets, were not as healthy as the control (many developed diarrhea). In a later trial antibiotics and vitamin B_{12} were added to the diet and larger pigs (33 kg.) were used. With these changes the daily gain and feed efficiencies were slightly better than the control. Feeding trials at the Harper Adams Agricultural College (Blair and Knight 1973) have shown that Dried Poultry Waste (DPW) can be included in swine rations at a level of 5% without influencing growth rate and feed efficiency. At levels of 10% DPW in the feed growth rate and feed efficiency were depressed. Perez-Aleman <u>et al</u> (1971) studied the effects of sterilized DPW as an additive to a conventional diet, at levels of 10%, 20% and 30%, for growing pigs from 23 kg. to 85 kg. live weight. The pigs remained healthy and no adverse affects to the carcasses were noted. It was found that for every 10% addition of manure, growth rate was reduced by 0.02 kg/day, feed conversion efficiency by 0.25 units and dressing out percentage by 0.96%. Later work by Denisov (1975) tended to support these findings.

In spite of its adverse effect on growth, manure when included in the diet decreased the backfat thickness and increased the meat:fat ratio which might improve the overall grading of the carcasses (Perez-Aleman et al. 1971; Osterc 1972; Denisov et al. 1975). Since the manure contains large amounts of fibre and ash and therefore relatively low digestible energy, Osterc (1972) concluded that the use of DPW for finishing swine was acceptable only when the ration was adjusted to balance the low energy value.

3.2 Swine Waste

The refeeding of swine waste has not progressed at the same rate as the refeeding of DPW and cattle waste to ruminants. Diggs et al. (1965) reported that average daily gain and feed efficiency of swine fed a fattening ration containing 15% dried swine waste was similar to the performance of animals fed a typical corn-soybean meal control ration. Other studies with swine manure subjected to anaerobic digestion and added at 24.5% to a fortified corn soybean meal diet, have shown this mixture to support satisfactory gain and feed efficiency in rats (Harmon et al. 1969). However, later studies by Harmon et al. 1973 failed to duplicate these results. In this second trial dried swine waste solids collected from the surface of a settling skimming tank and incorporated into typical corn-soy diets at 10% as a corn replacement or at 16.8% for replacing 3% of the soybean meal depressed weight gain and feed efficiency in rats. Orr et al. (1971) reported similar growth depressions in finishing swine as a result of using dried swine waste to replace one-third of the protein in a corn-soy diet containing 13% crude protein. Further studies by Harmon et al. (1973) with swine waste oxidation ditch liquor seemed to indicate that the fluid, when mixed with a 12% corn-soy diet at two parts of liquid per part of dry feed, caused a small, but consistent improvement in weight gain and feed efficiency when compared to the control group which had had their feed mixed with water.

Holland et al. (1975) conducted a feeding trial using unprocessed wet swine manure and dried swine manure. The manure was collected from finishing hogs and fed to gilts with an average body weight of 125 lbs. The feces were found to be of less nutritive value than the basal corn-soybean meal ration, however, the nutrients contained in the feces were in a form usable by the animal.

4. EXPERIMENTAL

4.1 Design of Experimental Equipment

4.1.1 Thermophilic Process Unit

Most of the experimental work at the University of British Columbia involving thermophilic aerobic treatment of wastes has been performed using the same process unit. The unit consists of two fermenters each with its own mixer and air sparger.

4.1.2 Fermenter Design

Figure 1, a schematic of one of the fermenters, serves to illustrate the design and layout of the tank. The two fermenters are constructed of fibreglass in order to reduce the cost and prevent the corrosion and contamination which is possible from a metal tank. Each fermenter is five feet high and four feet in diameter. The bottom is rounded on the inside to aid the mixing action. The operating capacity of each of these two tanks is 50 cu.ft. (approx. 300 gallons) with a total capacity of 62 cu.ft. (388 gallons). Fittings are provided which enable the two tanks to be joined in series so that a continuous fermentation can be carried out in addition to the normal batch operation. Each tank has an outlet and valve located at the bottom to allow draining of the contents when required. Insulation for the tanks consists

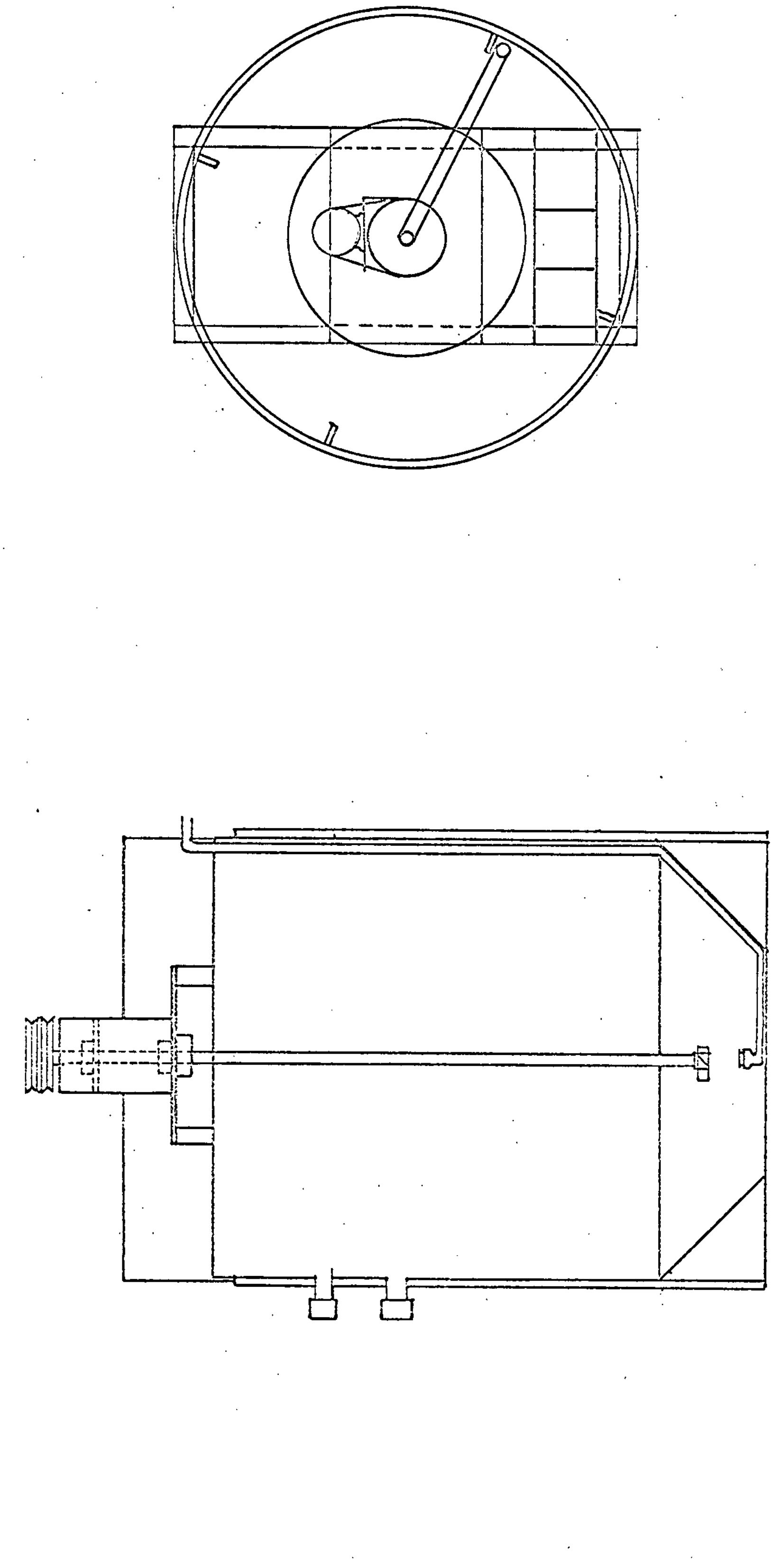

FIGURE:1 SCHEMATIC OF FERMENTER

of a one inch thick styrofoam blanket bonded to the outside and covered with a protective layer of canvas and epoxy resin. The tanks are placed directly on the ground with no concrete footings or foundations. The tops of the fermenters are not enclosed and are open to the air.

4.1.3 Mixer Design

Adequate mixing and agitation of the liquid is a vital part of the thermophilic aerobic digestion of animal wastes (Coulthard 1973). During the early tests much of the research was directed towards finding a suitable design for a mixer.

For a normal fermentation the depth of liquid in the tank is four and a half to five feet. The total length of the mixer shaft is seven feet. Designs using a bearing at either end of the shaft showed that the bearing which was submerged was subject to rapid wear, and required frequent replacement (Coulthard - personal communication). This led to a design with both bearings placed at one end of the shaft, above the level of the liquid in the fermenter. For this design the shaft was of stainless steel two inches in diameter and was hollow in order to reduce the load on the motor. Stainless steel was chosen because of its resistance to corrosion. It was discovered that this shaft had variations in its diameter along its length of plus or minus five thousandths of an inch. This was due to the extrusion process used in the manufacturing. These variations caused problems in fitting the bearings to the shaft and also caused the shafts to be out of balance. The poor fit of the bearings and the uneven weight distribution caused excessive vibration in the shaft which in turn resulted in rapid wear and unacceptably short bearing life.

The most recent design, shown in Figures 2 and 3 utilizes a solid stainless steel shaft one and a half inches in diameter. The solid shaft is manufactured by a drawing process which results in the diameter being much more uniform. Two heavy-duty flange bearings mounted eight inches apart are used to support and guide the mixer shaft. These bearings, in turn, are bolted to a supporting metal framework which also serves as a mount for the motor. Because of the increased weight of the shaft a two H.P. electric motor is used instead of the normal one and a half H.P. motor used in the earlier designs. A totally enclosed motor is used to avoid damage due to dust or a build-up of foam in the fermenter. The motor and mixer shaft are connected by a double V-belt pulley which reduces the r.p.m. by 50 percent resulting in a final shaft speed of 880 r.p.m. The mixer unit as a whole is mounted on a wooden frame which rests across the top of the fermenter. Rubber bushings are used between the mixer bases and the wooden frame in order to reduce the amount of vibration transmitted to the tank.

The solid shaft mixer was installed in February 1976 and has not required a change of bearings to-date.

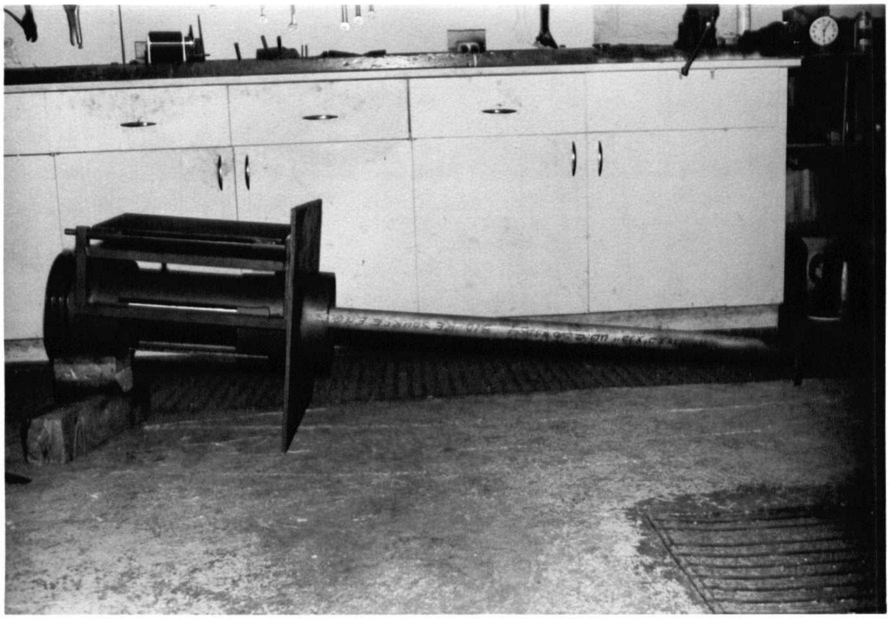

FIGURE:2 SOLID SHAFT MIXER

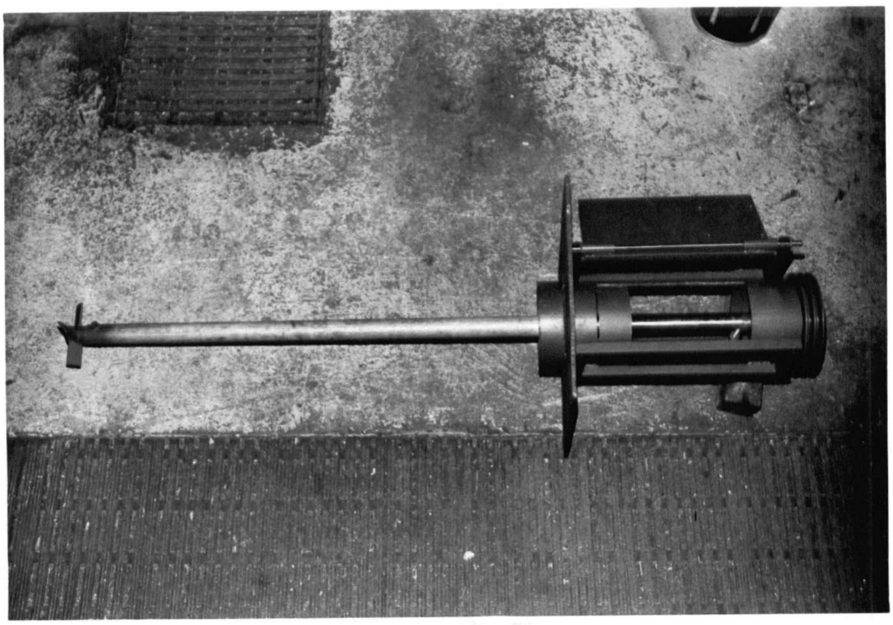

FIGURE:3 SOLID SHAFT MIXER

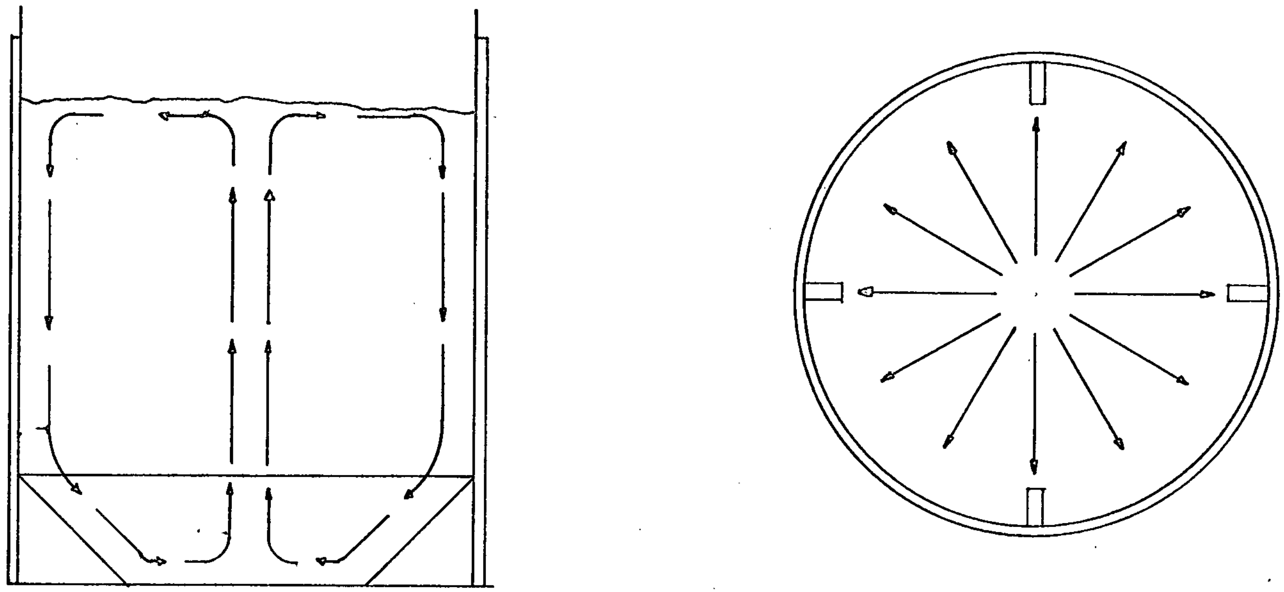

FIGURE:4 MIXING ACTION

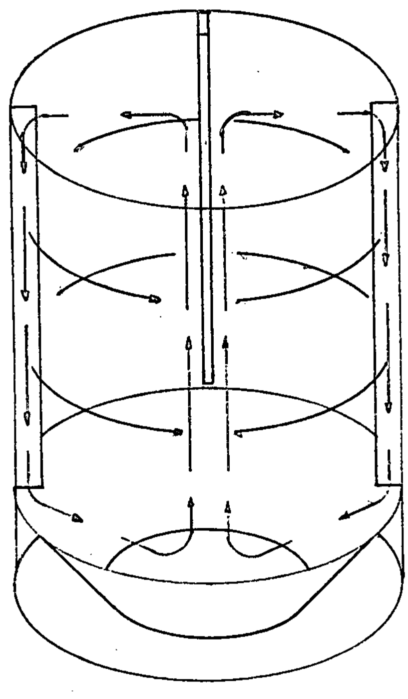

FIGURE:5 MIXING ACTION

4.1.4 Agitation

Agitation of the liquid is accomplished by a four bladed propeller attached to the end of the shaft. This propeller has a diameter of four inches from tip to tip and the blades are pitched at a 45° angle. Figures 4 and 5 illustrate the mixing action in the tank. Four wooden baffles are spaced 90° apart around the inside of the tank to insure complete mixing. The propeller has two functions one is agitation of the liquid and the other is mixing in the air supplied by the spargers. This combination of mixing and aeration gives the most efficient transfer of oxygen from the gas to the liquid (Hatch 1975).

4.1.5 Aeration

Oxygen in the form of compressed air is supplied to both fermenters by a Jacuzzi Model 331 compressor mounted on a pressure tank. Each fermenter has its own air line equipped with a valve and an airflow meter so that the amount of air being supplied can be carefully controlled and independently recorded. The flow meters used are Roger Gilmont Size #5 which measure air flow over the range of 5,000 ml/min to 75,000 ml/min. In order to maximize the oxygen transfer efficiency air spargers are used. These spargers are mounted directly beneath the propellers of the mixers. Currently, two types of spargers are in use at U.B.C. These are shown in Figures 6 and 7. The first type (Figure 6) consists of a flat plate attached over the air outlet. The purpose of this plate is to break the incoming stream of air into small bubbles over a wider area. The function of the ball beneath the plate is to block the aperture of the air line in the event of a compressor failure and prevent the air line from becoming plugged. The second type of sparger (Figure 7) is shaped like an inverted cone, the sloping sides of this cone have channels spaced evenly around their circumference. The air stream from the compressor strikes the point of the cone and spreads up the channels. This insures the breaking-up of the airstream and the formation and even distribution of small bubbles into the liquid. This second type of sparger is also equipped with a ball to prevent plugging of the air line.

4.1.6 Foam Breakers

During the early stages of a new fermentation large amounts of foam are produced. This foam, consisting of very small bubbles with thick membranes is quite firm and stable. This stability can lead to an accumulation of foam in the top of the fermenter to such a degree that it overflows the sides of the fermenter. Overflowing can result in a physical loss of the substrate, interference with electrical equipment, reduction in temperature and, because the temperature of the foam is lower than the temperature of the liquid, less effective pathogen kill.

In the later stages of the fermentation the increase in temperature tends to decrease the surface tension of the liquid.

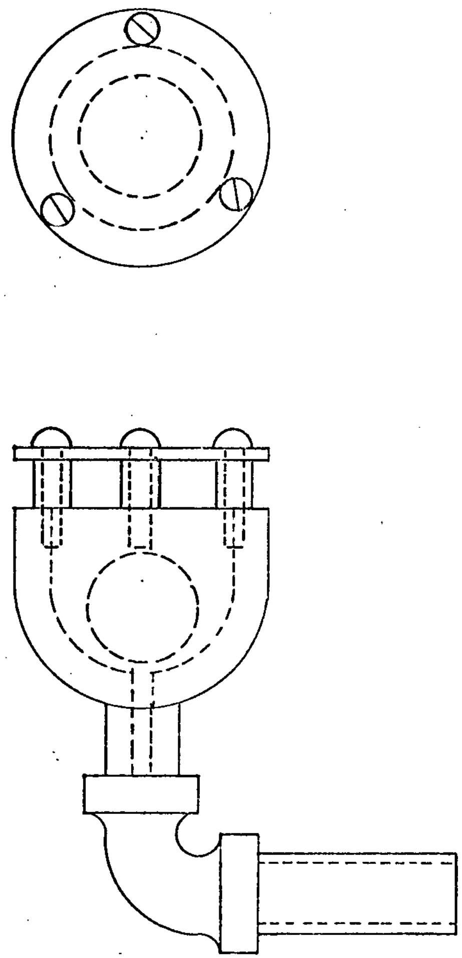

FIGURE:6 AIR SPARGER TYPE 1

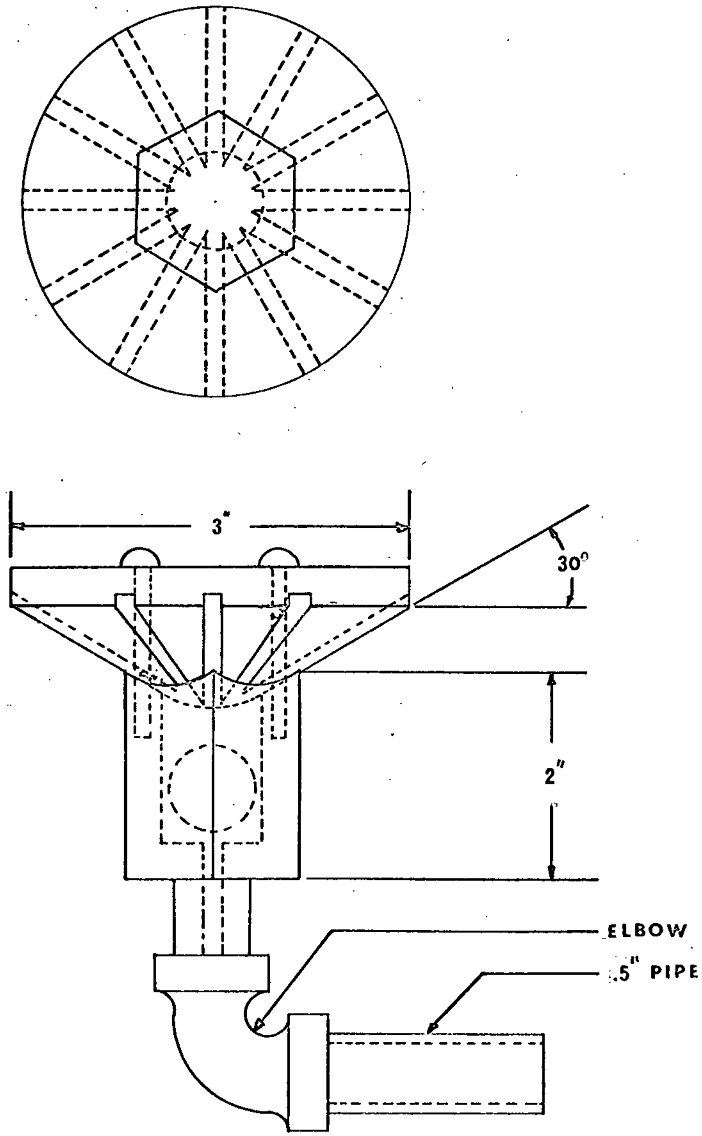

FIGURE:7 AIR SPARGER TYPE 2

A decrease in the surface tension produces a foam which has larger bubbles with thinner membranes which are more sensitive to vibration, turbulence, wind currents etc. and burst more readily. As a result this foam does not accumulate to the point of overflowing.

In the early stages, control over the level of foam in the fermenter was accomplished by a mechanical device consisting of a blade welded to a shaft which is attached to a 1/4 H.P. electric motor. Originally, the blade was bolted to the end of the shaft, however, vibration tended to loosen the bolt and when coupled with rotation of the shaft caused the bolt to unscrew itself resulting in the loss of the blade.

The foam is sheared mechanically by the blade in order to maintain a constant level. The motor is enclosed and mounted on the same wooden framework which supports the mixer.

4.2 Energy Requirements for Maintenance of Fermenter Temperature

4.2.1 Introduction

Studies involving thermophilic aerobic digestion at U.B.C. have repeatedly shown that during fermentations, substrate temperatures of $60^{o}C$-$65^{o}C$ can be maintained over a period of several days or weeks (Coulthard 1973). However, whether or not the total energy required to maintain the temperature came from microbial action was not known. In order to investigate what effects the mechanical action of agitation and aeration have on heat production and temperature maintenance, and the relative insulation value of foam compared to styrofoam a number of experiments were designed relative to the following objectives:

a. To investigate the effect of mechanical energy from agitation on the total amount of energy required to maintain a given temperature.

b. To investigate the combined effects of agitation and aeration on the total energy required to maintain a given temperature.

c. To investigate the effect of aeration on the total amount of energy required to maintain a given temperature.

d. To examine the variation between the energy input required for temperature maintenance with a styrofoam cover on the top for insulation as compared to detergent foam as insulation.

4.2.2 Materials and Methods

a. Introduction

Fermenter #2 at U.B.C.'s Thermophilic Unit was drained of all organic matter and the inside was then scrubbed with a brush and rinsed several times with hot water. All accumulations of organic matter were removed from the mixer support and foam breaker as well. The elimination of organic matter was to ensure that during the experiments there would be no possibility of significant heat production from microbial activity. Energy for increasing and maintaining the temperature, aside from that which might be supplied by aeration and agitation, would come from two 1,500 watt 220 volt water heater elements. These heater elements were mounted through the wall of the fermenter 15 inches above ground level and spaced 180 degrees apart. The fermenter was then filled with tap water and a cover made from a one inch thick styrofoam sheet which was then fitted to the top of the fermenter.

b. Temperature Regulation

For this set of experiments a temperature of $65^{\circ}C$ was chosen as a representative fermenter temperature level during normal thermophilic fermentation of hog waste. The fermenter temperature was regulated by controlling the amount of electric power reaching the heater elements. During the initial stage of the experiment when a steep rise in temperature up to $65^{\circ}C$ was desired the power was uninterrupted. Once the desired temperature of $65^{\circ}C$ was reached the power was supplied to the heaters in small pulses. The frequency and strength of these pulses was regulated by a proportional controller in order to maintain the temperature at $65^{\circ}C \pm 3^{\circ}C$. A circuit diagram for this controller is included in the appendices.

c. Power Measurement

The amount of power required for maintenance of the temperature during these experiments was measured using a kilowatt-hour (Kwhr) meter. This is the same type of meter used by the Utility Company to measure household consumption of power. Readings were taken at least once a day with the time of day, fermenter temperature and Kwhrs being recorded. These figures were then used to compute the amount of heat energy in British Thermal Units (B.T.U.) required by the heater elements under the varying conditions of aeration and agitation. To convert power consumption in Kwhrs to heat energy in B.T.U. a multiplying factor of 3413 B.T.U./Kwhr was used. The result from this calculation was then divided by the elapsed time (hrs.) to obtain B.T.U./hr. The number of Kilowatts used over a given time period (T_1-T_2) was determined by:

$$Kw = \frac{A_{T_1} - B_{T_2}}{(T_2 - T_1)}$$

where: A_{T_1} = meter reading (Kwhrs) at time T_1

B_{T_2} = meter reading (Kwhrs) at time T_2

d. Experimental Conditions

i. No Agitation - No Aeration

Under conditions of no agitation and no aeration it is possible that a temperature gradient could form between the heaters and the temperature probe. To prevent such a gradient from forming the mixer was switched on for a short period of time to draw the warmer water up from the bottom of the tank. This action was repeated at intervals throughout the day.

The temperature in the fermenter first reached $65^{o}C \pm 3^{o}C$ on November 18. For the next seventy-two hours, the temperature was maintained at this level with no agitation or aeration provided, except as noted above. The figures obtained during this time were used as a basis for comparison with the experiments which followed.

ii. Agitation

To investigate the effect of mechanical energy from agitation on the energy requirement for maintenance of temperature, agitation was begun on November 21 and continued for a period of one-hundred and one hours. Throughout this time period the temperature remained at $65^{o}C \pm 3^{o}C$.

iii. Agitation and Aeration

The combined effect of agitation plus aeration on the energy required for temperature maintenance was determined by continuing the agitation and supplying compressed air at normal levels of 11.5 to 14 litres/minute. Readings were taken over a period of forty-nine hours while the temperature remained at 65°C ± 3°C.

iv. Aeration

To study the effect of aeration by itself on the energy requirement the mixer was switched off and aeration was continued at the previous levels. Readings were obtained over a period of ninety hours.

v. Detergent Foam vs. Styrofoam as Insulation

At the conclusion of the aeration only phase described above, the water which had been lost due to evaporation was replaced by tap water. This caused the temperature in the fermenter to drop to 45°C. Once the temperature was again steady at 65°C ± 3°C the styrofoam cover was removed, aeration and agitation begun and a surfactant* added to produce a foam similar to that which forms during a normal waste fermentation. Since aeration and agitation were both required for the foam to form it was not possible to investigate their independent effects only their combined effects.

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* Commercial detergent manufactured by the Mandate Roman Company of Vancouver, B.C.

4.2.3 Results and Discussion

The readings from these experiments are given in Table I and presented graphically in Figures 8 and 9. The Daily Maximum and Minimum Temperatures for the ambient air during the experiment are given in Table II. These figures were obtained from the Faculty of Agricultural Sciences Plant Science Department Weather Station which is located in the same general area as the Thermophilic Unit.

a. No Agitation & No Aeration

For the first 72 hours while the temperature was maintained at $65^{o}C \pm 3^{o}C$ with no agitation or aeration the heaters expended a total of 273,040 B.T.U.s. On an hourly basis this is 3792 B.T.U.s/hr. This figure was used as a basis for comparison with the results of the experiments involving agitation, agitation and aeration, and aeration.

b. Agitation

Agitation unaccompanied by aeration was supplied for a period of 101 hours. The total energy requirement for this same period was 416,386 B.T.U.s or 4,133 B.T.U.s/hr. This is an increase of 9% over the energy requirement with no agitation and

Table 1.

Date	Temp °C	Treatment	Kw-hrs	Time hrs	Kw	Avg.B.T.U./hr
Nov. 17	55	No Aeration & No Agitation				
Nov. 18	66	" "	42	24.27	1.73	
Nov. 19	--	--	--	--	--	--
Nov. 20	--	--	--	--	--	--
Nov. 21	65	Agitation after reading	80	72.08	1.11	3792
Nov. 22	65	Agitation	32	22.38	1.43	
Nov. 23	65	Agitation	26	24.62	1.06	
Nov. 24	65	Agitation	27	24.33	1.11	4133
	65	"	6	4.59	1.31	
Nov. 25	65.5	Aeration after reading	31	24.83	1.25	
Nov. 26	66	Aeration & Agitation	23	19.58	1.17	
Nov. 27	65	Aeration & Agitation	27	22.92	1.18	4075
	--	Agitation off after reading	9	6.92	1.30	
Nov. 28	--	Aeration	--	--	--	
Nov. 29	60	Aeration	86	45.83	1.88	6839
Nov. 30	63	Aeration	53	24.59	2.16	
Dec. 1	62	Aeration off after reading	42	19.91	2.11	
	66.5	No Aeration-No Agitation	8	5.00	1.6	
Dec. 2	66	No Aeration-No Agitation	20	17.17	1.16	
	45	H_2O Added	2	1.91	1.05	
	53	No Aeration-No Agitation	9	4.84	1.86	
Dec. 3	65	" "	37	17.5	2.11	
	66	" "	6	4.25	1.4	
	66	" "	4	2.66	1.5	
Dec. 4	66	Styrofoam removed				
		Foam added	24	20.25	1.18	
		Agitation & Aeration				
Dec. 5	68	Agitation & Aeration	21.5	24.42	.880	
Dec. 6	66	Agitation & Aeration	12.5	21.25	.588	2516
Dec. 7	66	" "	12	26.83	.447	
Dec. 8	64	" "	15	20.91	.717	
Dec. 9	66	" "	25	23.25	1.07	

Table II.

Date		Daily Maximum	Daily Minimum	Conditions
Nov.	17	10	8	Clear
	18	8	6	Overcast
	19	9	6	Partly cloudy
	20	9	5	Cloudy
	21	8	6	Cloudy
	22	8	6	Cloudy
	23	8	6	Overcast
	24	8	7	Clear
	25	9	6	Clear
	26	7	2	Clear
	27	5	-2	Partly cloudy
	28	5	0	Partly cloudy
	29	5	0	Partly cloudy
	30	5	1	Overcast (fog)
Dec.	1	2	1	Overcast
	2	3	1	Overcast
	3	5	3	Overcast
	4	3	3	Overcast
	5	4	3	Overcast
	6	6	4	Overcast
	7	9	8	Overcast
	8	9	6	Overcast
	9	7	6	Overcast

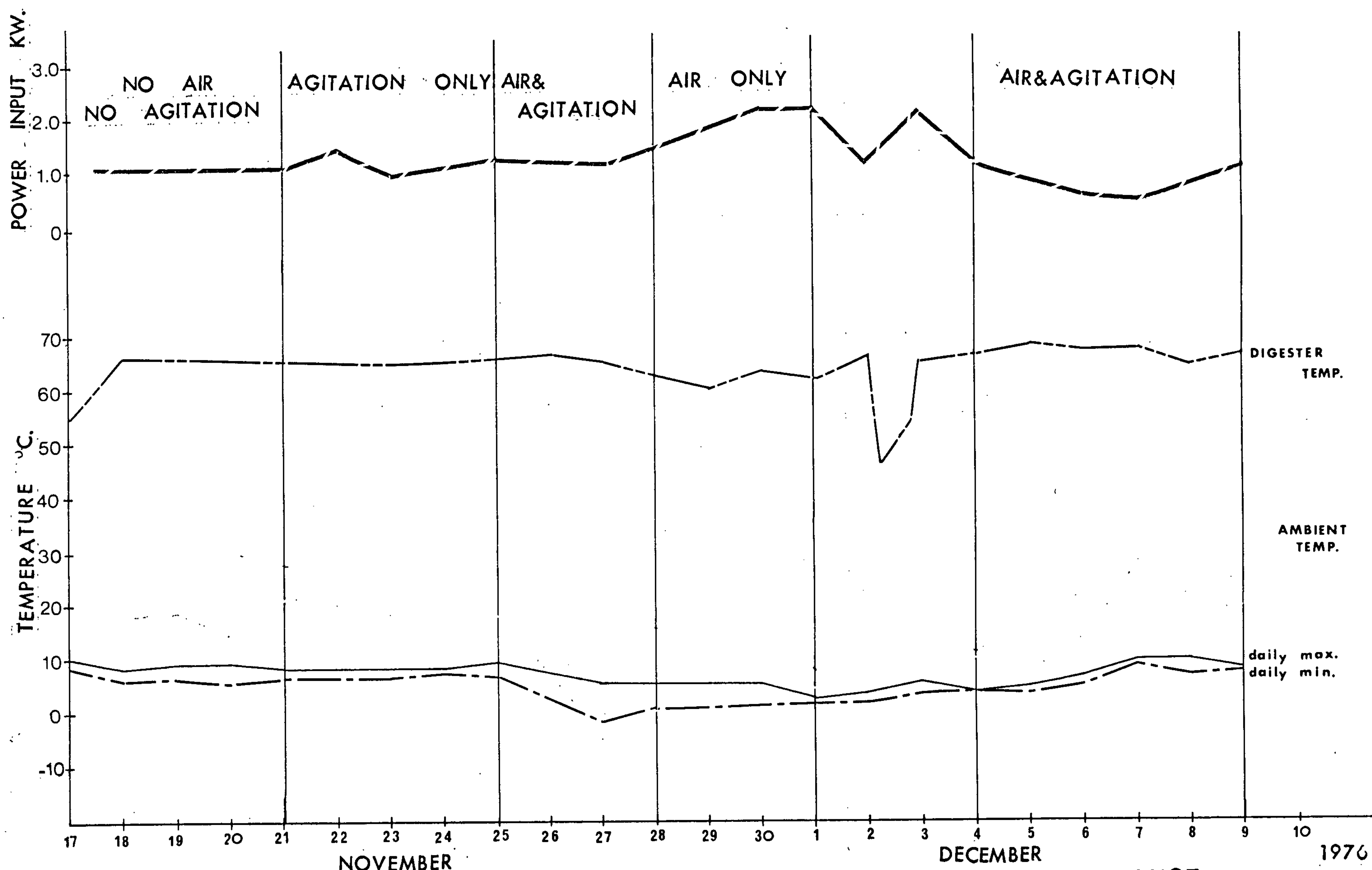
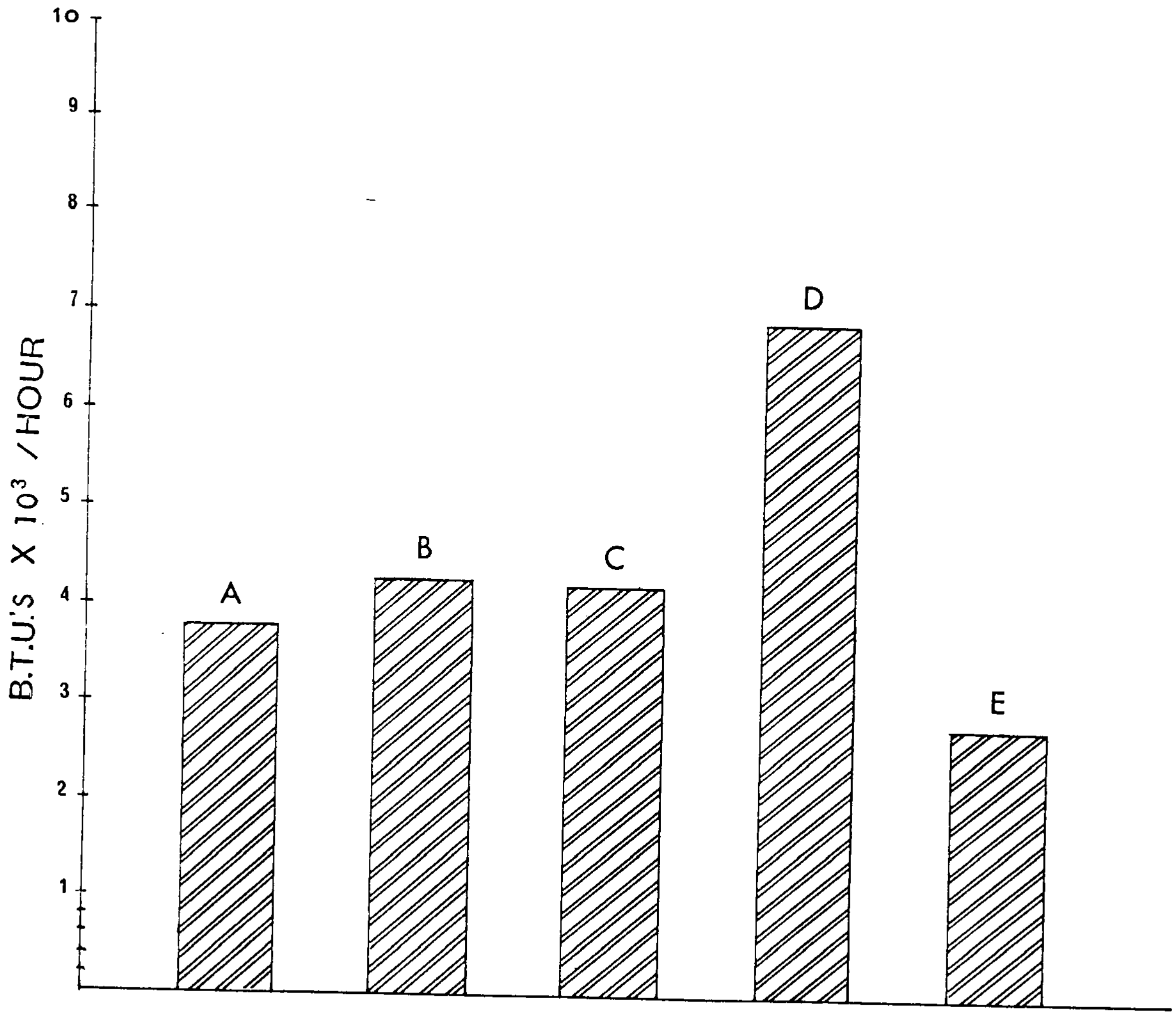


FIGURE:8 POWER REQUIREMENTS FOR TEMPERATURE MAINTENANCE



LEGEND

A STYROFOAM INSULATION
NO AERATION . NO AGITATION

B STYROFOAM INSULATION
NO AERATION . AGITATION

C STYROFOAM INSULATION
AERATION AGITATION

D STYROFOAM . INSULATION
AERATION . NO AGITATION

E DETERGENT FOAM INSULATION
AERATION AGITATION

FIGURE:9 HEAT REQUIREMENTS FOR TEMPERATURE MAINTENANCE .

no aeration. When the sources of error in this experiment such as the use of water instead of hog waste and the possible effect of ambient temperature are considered the 9% increase in the energy requirement may not be significant. However, it should be noted that it was an increase and not a decrease which indicates that the energy input from the mechanical action of agitation is negligible.

c. Aeration and Agitation

The combined effect of aeration and agitation raised the energy requirement from the basic level of 3792 B.T.U.^{s}/hr. to 4075 B.T.U.^{s}/hr. This represents an increase of 7.5%. As was the case with agitation the amount of the increase may not be significant however the fact that it was an increase and not a decrease is important.

d. Aeration

The action of aeration increased the energy requirement to 6839 B.T.U.^{s}/hr. which represents an increase of 80% over the requirement with no agitation or aeration. This increase was partly due to the fact that a gap existed between the styrofoam and the mixer shaft. The incoming airflow caused the water to bubble through this gap and across the top surface of the styrofoam which greatly increased the heat losses due to evaporation and contact with ambient outside temperatures. However, other researchers (Matsch and Drnevich 1977) have stated that the greatest heat loss in an aeration system is with the aerating gas. Aeration by itself would have the effect of increasing the amount of energy required for maintenance of the fermenter temperature.

e. Foam vs. Styrofoam

The use of a detergent foam as insulation for the top of the fermenter reduced the energy requirement to 2516 B.T.U.^{s}/hr. This is a reduction of 51% from the basic condition of no agitation or aeration with styrofoam insulation. As previously noted it was necessary to provide both agitation and aeration in order for the foam to form. When compared to the energy requirement for styrofoam with aeration and agitation there is a 64% reduction. These reductions indicate that an artificial detergent foam covering (which better) approximates the physical state of the natural digestion foam than styrofoam) does in fact provide better insulation for the top of the fermenter than does styrofoam.

4.3 Feeding Trial

4.3.1 Introduction

It has been demonstrated that compared to untreated manure, aerobically treated swine waste from an oxidation ditch has an enhanced protein value (Holmes 1971, Harmon 1975). Further work by Harmon & Day resulted in a system for refeeding the liquid from an oxidation ditch as a replacement for H_2O, with an increase in rate of gain and feed conversion efficiency (Harmon & Day 1974, Harmon & Day 1975).

The product from thermophilic fermentation of swine waste also has an enhanced protein value over that of raw manure (Shepherd 1973, Bragg et al. 1975). To-date feeding trials with this product have been confined to using the dried product in animal and poultry rations (Kitts et al. 1974, Bragg et al. 1975, Kwok 1975). The purpose of this study was to assess the acceptability and potential performance of Thermophilic Process Mixed Liquor (TPML) when fed as a liquid to young pigs.

4.3.2 Materials and Methods

A total of forty-one piglets from four litters were used for this study. They were divided into four pens A, B, C, and D. The four pens were further divided into two groups. Group I formed by pens A + C had a total of 20 animals, Group II formed by pens B + D had a total of 21 animals. At the beginning of the trial the animals were 28 days old and their average weight was 11 Kg. The trial lasted for a period of 28 days with the pigs being weighed every two weeks. Both Groups were fed dry feed ad libitum. U.B.C.'s B2B ration was used throughout the trial. This ration is formulated by a commercial feed company to contain approximately 16% Crude Protein. Group I served as the control group, they were allowed free access to the self-waterers located at the rear of the pens. Group II, the experimental group, was supplied with TPML as a complete replacement for water. The self-waterers in Group II pens were plugged and troughs were installed at the rear of the pens.

The TPML from the fermenter was cooled before being fed to the animals. Preliminary trials indicated that the animals would drink the warm TPML but not as readily as when it had been allowed to cool. No solids separation or drying was attempted. Immediately before placing the TPML in the troughs it was thoroughly mixed to ensure that any settled solids would be placed back into suspension. The troughs were filled by buckets in the morning and late afternoon, usually at the same time that the animals were fed.

4.3.3 Results & Discussion

There were no deaths or signs of illness in either Group I or Group II during or after the trial. The results shown in Table III are on a total weight gain/pen basis. Some of the ear tattoos were illegible and therefore it was not possible to record individual weight gains. An analysis of these results using the F test showed that the differences in weight gains/pen were not significantly different indicating that TPML was acceptable as the total replacement for H_2O for young pigs in this trial. These data would fall between the two groups of pigs fed oxidation ditch mixed liquor (ODML) by Harmon _et al_. Harmon and coworkers (1973) reported that pigs younger than 28 days of age when fed ODML grew less rapidly than the control animals. However, these same pigs when fed ODML at 56 days of age, grew faster than the control group.

Table III

		Weight gain (kg)
Group I (H_2O)	Pen A	130.4
	Pen C	103.6
	Avg.	117.0
Group II (TPML)	Pen B	86.6
	Pen D	114.4
	Avg.	100.5

The animals used in this feeding trial with TPML fall between the two age groups used by Harmon. Since there was no significant difference in the growth between the control and treatment groups it would indicate that this data is in agreement with Harmon (1973) falling between the two age groups. Taken with Harmon's earlier work (1973), the results suggest that as the pig gets older it is able to utilize the nutrients from the recycled feed more efficiently. This trend can be seen in the change in average daily gains for the first two weeks as opposed to the last two weeks. The average daily gain per pig is shown in Table IV.

Table IV

		Average Daily Gain (Kg)	
		0-14 days	14-28 days
Group I (H_2O)	Pen A	.335	.441
	Pen C	.446	.478
	Avg.	.390	.459
Group II (TPML)	Pen B	.271	.289
	Pen D	.320	.496
	Avg.	.296	.392

Group I the control group increased their average daily gain to .459kg/day for the final two weeks from .390 kg/day for the first two weeks. This is an increase of 17%.Group II the TPML group increased their average daily gain to .392 kg/day from .296 kg/day an increase of 32%. This fact when considered with Harmons results supports the theory that as the animal gets older its digestive system is able to utilize the nutrients from the recycled feed more efficiently. This increase in efficiency is most probably due to the establishment of a population of microflora in the gastrointestinal tract which is able to utilize the TPML more efficiently.

Trials using older animals are required to further explore the possibilities of using TPML as a total H_2O replacement for pigs. The results of this feeding trial show that Thermophilic Process Mixed Liquor (TPML) can be used as a replacement for water in the diet of pigs between the ages of 28 and 56 days with no apparent detrimental effect on their health or rate of gain.

4.4 Commercial-Size Application

4.4.1 Introduction

As was previously mentioned the Thermophilic Research Unit at U.B.C. has a total operating capacity of 600 gallons. Although this is adequate for preliminary research a larger unit would enable a wider range of experiments to be carried out. In addition, commercial size operations would require larger fermenters for many specific applications. For these reasons a "scaling-up" of the fermenter size was proposed and planned. It was convenient that a new swine operation was being planned by Kriwokon Enterprises for installation at Port Alberni on Vancouver Island. The research group at U.B.C. was approached concerning the possibility of utilizing thermophilic fermentation to handle the wastes from the new operation. For this new operation, it was decided to incorporate the "scaling-up" of the fermenters with a waste handling system which would include refeeding of the product.

4.4.2 Location & Layout of Farm

Kriwokon Enterprises is situated on approximately seven acres of land near Port Alberni, B.C. Feed crops are not grown on the farm because of the small land area, all the feed is purchased from a commercial feed company. There is, therefore, no cropland on which to spread the untreated manure nor is there a sufficient area for a lagoon with an irrigation system. In situations such as this a thermophilic treatment system with refeeding of the product has several advantages:

a. The fermenters do not require a large land area for installation. For this particular installation the entire unit including fermenters, product tank, control house, pumps and compressors can be placed on a 13 ft. x 41 ft. concrete slab.

b. The product from the fermentation can be recycled and therefore does not require an irrigation system or field spreading for final disposal

c. As a result of the high temperature fermentation the product is pasteurized.

d. The product from the fermentation has an enhanced protein value and when recycled as a feed can result in a reduction in the amount of commercial feed required without significantly affecting the rate of gain.

The purpose of this new operation is to produce and raise weiner pigs for the feeder hog market. The estimated yearly production is 6,000 weiner pigs and plans exist for future expansion to a complete farrow to finish operation. At the present time, the breeding herd consists of 316 sows and 12 boars. In addition, up to 360 weiner pigs may be present at any one time. The animals are housed in two separate buildings. Figure 10 shows the general layout of the buildings and their dimensions. Both buildings are aluminum sheathed structures erected on concrete foundations. Insulation is provided by sheets of rigid polyurethane foam on the walls and ceilings. The gestating sows are kept in the larger building along with the boars. The smaller building is divided into three sections.

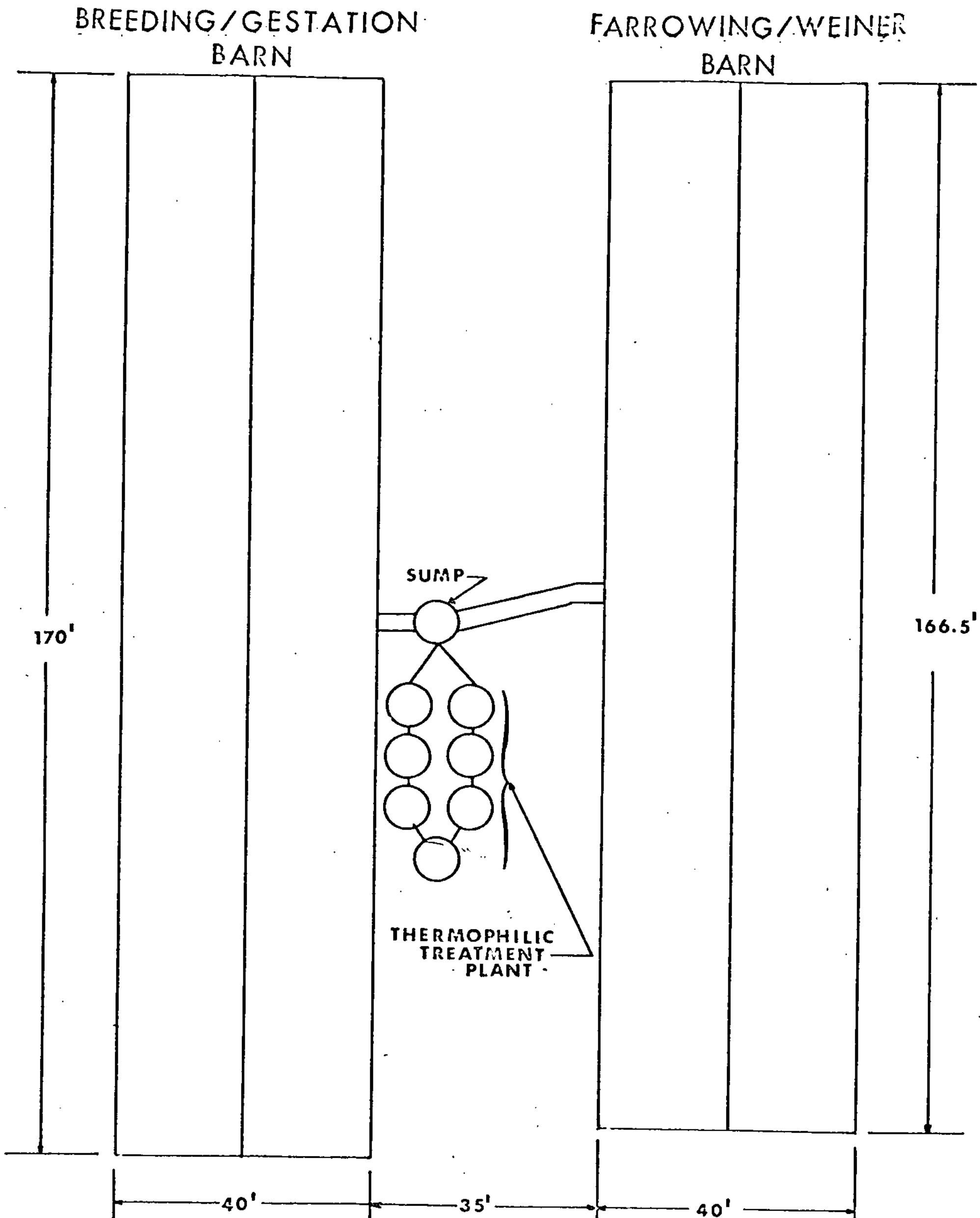


FIGURE: 10 LAYOUT OF PORT ALBERNI OPERATION

The farrowing area with sixty individual farrowing crates is located in the western half of the building. The eastern half of the building is largely occupied by the pens for the weiner pigs. These pens are divided into three sections with 6 pens to a section for a total of 18 pens. The small area remaining at the extreme eastern end of the building is used as an office, dressing room area.

4.4.3 Waste Collection System

The wastes from both buildings are collected by a system of gutters beneath the floors. These gutters are covered by metal gratings. The manure falls or is trampled through these metal gratings into the gutters. Each gutter has a flush tank which periodically flushes the wastes from the gutter into a sump. The use of flush tanks and gutters for the collection of swine wastes has been covered in several papers (Brodie 1975, Koch 1975, Miller & Hansen 1973, Koellilar et al. 1972 and Smith et al. 1971).

In both buildings the gutters slope from either end towards the centre of the building. All of the gutters have a 3% slope (4" in 10') including the gutters which cross the centre of the buildings and empty into the sump. The gestation barn has a total of seven gutters, four across the western end and three across the eastern end. Each of these gutters has a 250 gallon flush tank. The farrowing area has four gutters each equipped with a 250 gallon flush tank. The weiner area has three large waste gutters, one located beneath each of the three sections of pens. These gutters are approximately 10 ft. wide and each one is flushed from a 1,000 gallon tank. All of these tanks are flushed twice daily. The wastes from both buildings are carried to the sump which is located between the two buildings. Figure 11 is a longitudinal section of the sump showing the baffles located at the two inlets. The purpose of these baffles is to direct the incoming wastes towards the bottom of the sump. The solid wastes settle to the bottom of the sump and the liquid remains at the top. The liquid is re-used as flush water and the solids are pumped from the sump into the thermophilic treatment unit. The top layer of the liquid is aerated before being re-used as flush water.

4.4.4 Estimated Levels of Waste Production

Because the hog operation was not yet in operation the level of waste production in each section had to be estimated in order to design the treatment system. Waste production was calculated on the basis of one gallon of waste produced per 100 lbs. liveweight per day. This figure and those used for animal weights were obtained from (Overcash, Humenik and Driggers 1975). The estimated levels of waste production in gallons/day calculated for each section are shown below. Each individual estimate was made for the maximum population in each section.

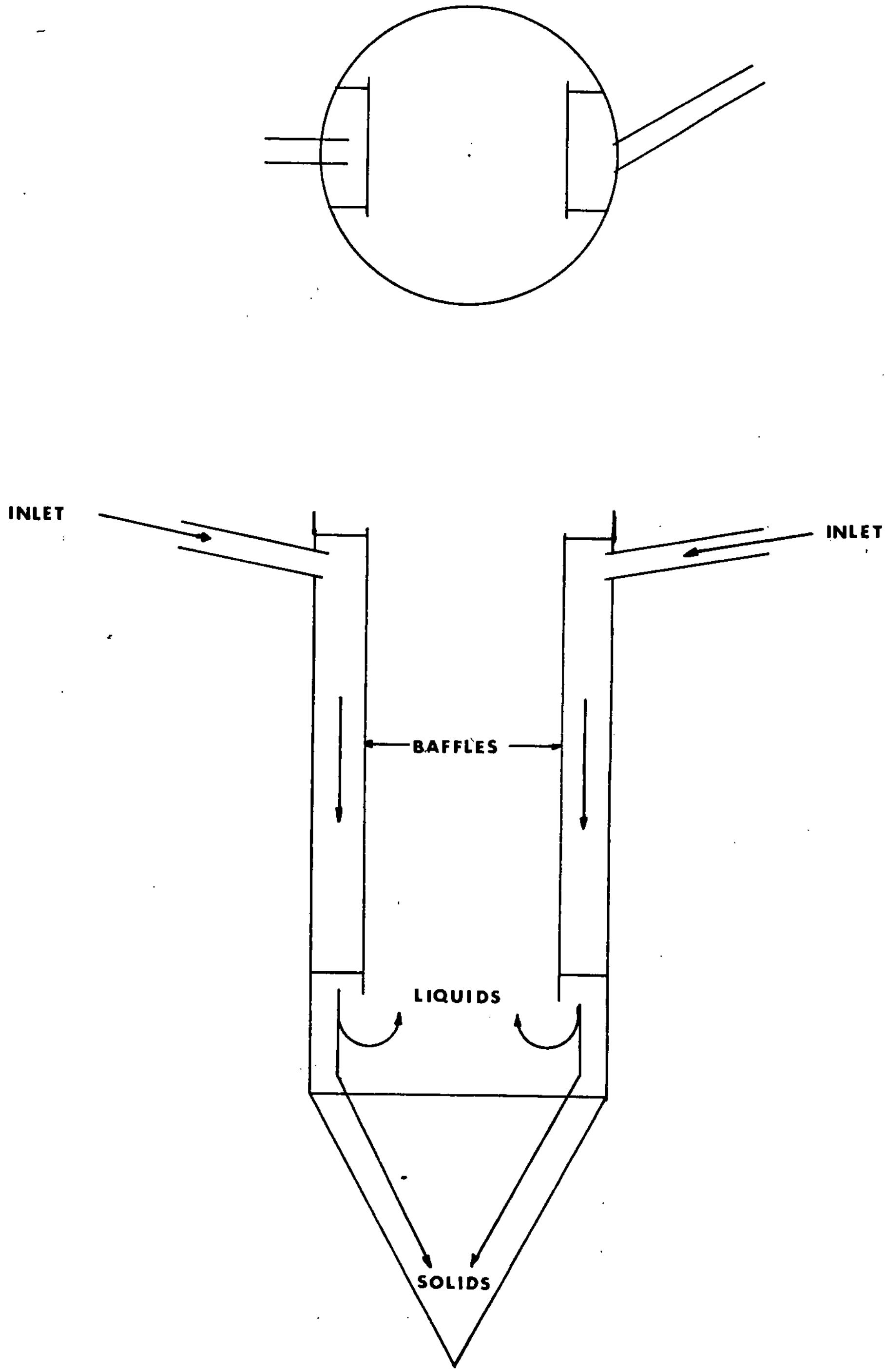


FIGURE: 11 LONGITUDINAL SECTION OF SUMP

A. Farrowing Barn

1. Farrowing Area

60 sows and litters @ 374 lbs. ea.	224 gals.

2. Weiner Area

360 weiner @ 40 lbs ea.	144 gals.

B. Gestation Barn

1. Gestating Sows

257 sows @ 275 lbs. ea.	707 gals.

2. Boars

12 boars @ 350 lbs. ea.	42 gals.
Total:	1,117 gals.

The total estimated production of waste per day from both barns is 1,117 gallons. The thermophilic treatment plant was designed using this figure.

4.4.5 Waste Treatment System

A flow chart for the treatment system is shown in Figure 12. For the Port Alberni operation six fermenters are used, arranged in two banks of three each. Each fermenter has a capacity of 1,000 gallons making the total capacity 6,000 gallons. The fermenters are all made from fibreglass with a one-inch thick layer of urethane for insulation. Detention time is five to six days which will ensure an acceptable level of pathogen kill. The complete

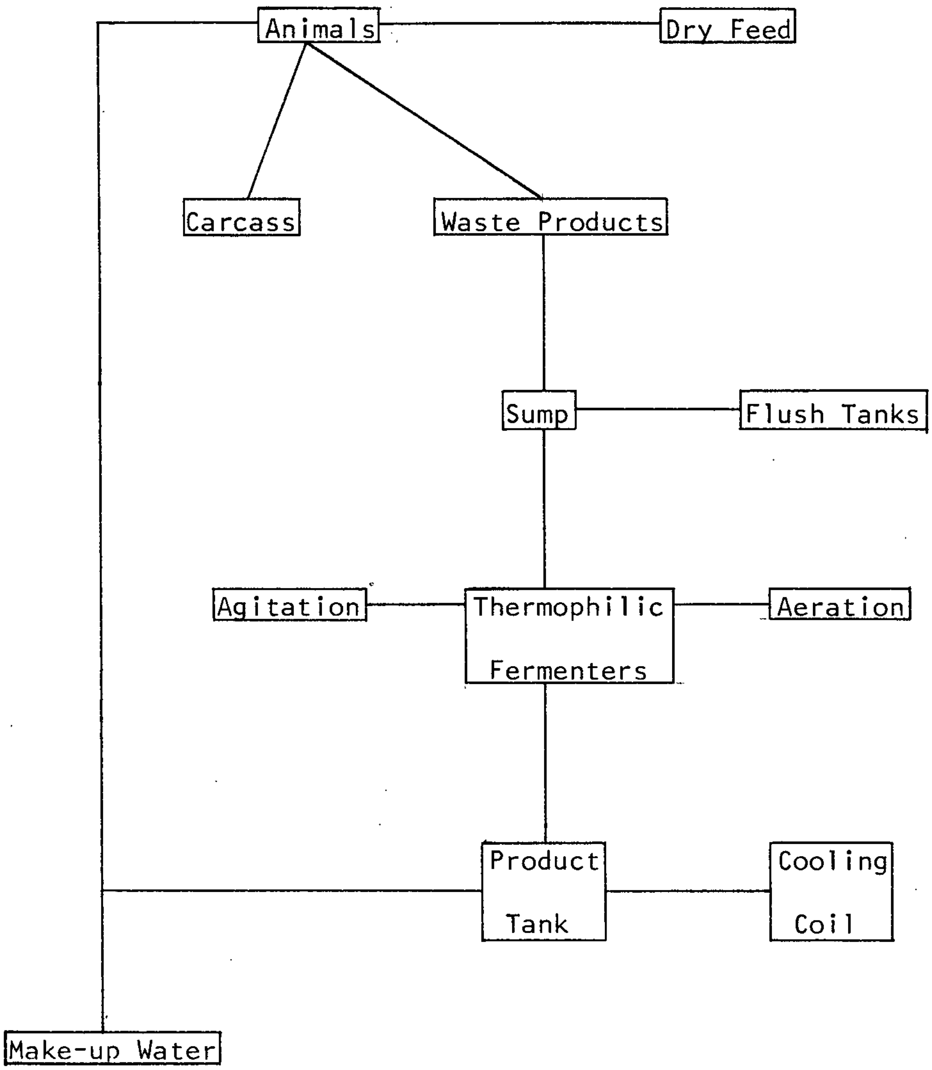
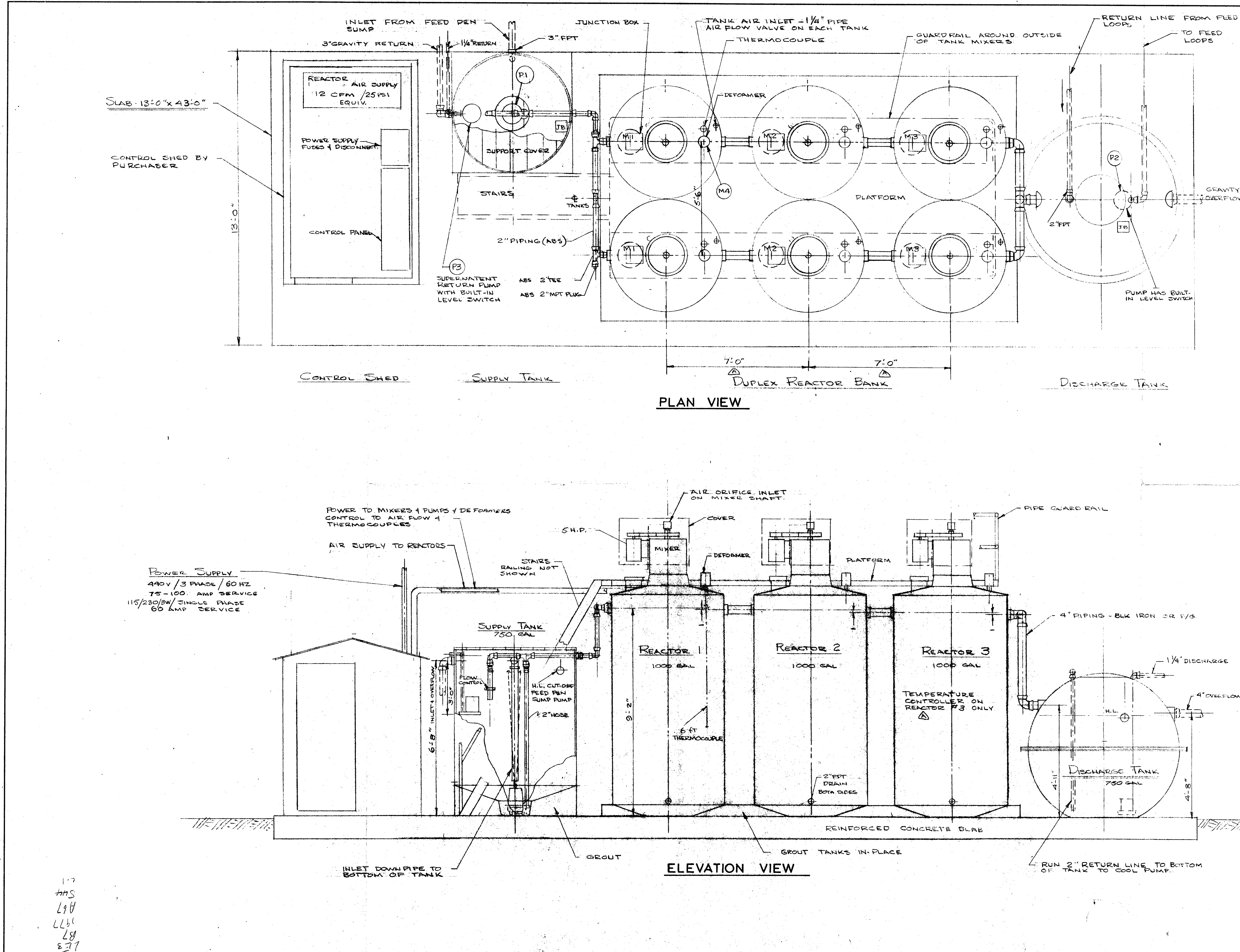


FIGURE:12 FLOW CHART FOR COMMERCIAL TREATMENT UNIT treatment plant is shown in Figure 13. Some minor differences may exist between the drawing and the actual installation. The supply tank has been replaced by the sump which is increased in size and placed underground. Also aeration of the fermenters is accomplished by spargers placed in the bottom of the fermenters; these are not shown in the diagram. Figure 14 is a photograph of one of these large fermenters showing its relative size. The mixers for these new fermenters are driven by 5 H.P. motors and are of the same general design as those described earlier in this paper. The shafts and propellers are balanced to prevent excessive vibration and premature bearing failure. As can be seen in Figures 13 and 14, the tops of these large fermenters are not open to the atmosphere as they are with the smaller tanks at U.B.C. Baffles are used to aid in the mixing and are placed in the same position as they are in the smaller U.B.C. tanks.

Compressed air for each fermenter is supplied by a single compressor located in the control house. Each fermenter is equipped with an airflow valve for controlling the amount of air flowing through the sparger. Thermocouples are mounted in each fermenter in order to monitor the temperature of the contents during fermentation.

All the main control boxes for the pumps, mixers and compressor are located in the control shed. Northern Purification Systems Ltd., the company which manufactured the fermenters, also supplied all of the necessary piping, pumps, electrical junction boxes, compressor airlines etc. as a package installation.

FIGURE 13 IS IN BACK POCKET



item	reqrd	rev.	DESCRIPTION	REFERENCE
23	1	A	P3 RECYCLE PUMP 1/3HP/115V	OSF33A
22	1		CONTROL SHED	
20			REACTOR STAIRS & RAILINGS	
19	1		AIR COMPRESSOR - 12 CFM / 25psi	
18	1		MAIN POWER FUSES & DISCONNECT	BY PURCHASER
17	1		CONTROL PANEL	
16	2		SUPPLY & DISCHARGE TANK J. BOX	
15	6		REACTOR JUNCTION BOX	
14	6		REACTOR THERMOCOUPLE	
13				
12	6		AIR FLOW VALVE	
11	6		DEFOAMER (M4)	
10	2	A	LEVEL SWITCH	
9	1		P2 DISCHARGE PUMP 1/3 HP / 115V	SP-33A/LS
8	1		P1 SUPPLY PUMP 1/2 HP / 115V	SKD-50
7	1		FEED PEN SUMP PUMP	
6	6		REACTOR MIXER - 5 H.P. / 440V	M1/M2/M3
5	-		2" CONNECTION PIPING (ABS)	
4	-		4" CONNECTION PIPING	BLK IRON
3	1		DISCHARGE TANK - 750 GAL F/G	SEPTANK
2	6		REACTOR - 1000 GAL F/G INSL.	
1	1		SUPPLY TANK 750 GAL / F/G.	

BIONOTHERM SYSTEM

SCALE: 1/2" = 1'-0" | APPROVED BY | DRAWN BY HK.
DATE: JUNE 8/76 | REV. A JUNE 28/76

NPS Sewage Treatment System

Northern Purification Services Ltd., 139 Riverside Drive, North Vancouver.

DRAWING NUMBER BT.01.01/d1A

UBC Shepherd Fall '77 MSc.

FIGURE:14 1000 GALLON FERMENTER

A standby electrical generator is also provided in case of power failure.

Once the plant is in operation and steady state conditions have been reached an estimated total of 1,117 gallons of waste per day will be pumped into the first fermenter of each bank. This will cause an equal amount of slurry to flow from the first fermenter to the second, from the second to the third and from the third fermenter to the product tank. Baffles are used to prevent the fresh waste from flowing straight through into the product tank. The flow from one fermenter to the next is aided by gravity since the outlet from each fermenter is one inch higher than the inlet to the adjacent fermenter. The liquid which flows into the product tank will be recycled to the animals as a replacement for water. Table V shows the Daily Water Requirements for swine.

Table V. Daily Water Requirement per Animal*

Body Weight (lb)	Imperial Gallons
30	.50
60-80	.70
75-125	1.70
200-380	1.2-3.0
Pregnant Sows	3.0-3.7
Lactating Sows	4.0-5.0

* Manitoba Department of Agriculture - Hog Manual.

From these figures the total daily requirement for the operation at Port Alberni was calculated as follows.

A. Farrowing Barn

1. Farrowing Area

60 sows @ 4.5 gallons ea.	270 gal.

2. Weiners

360 animals 40-50 lbs. ea.@.60 gal.	216 gals.

B. Gestation Barn

1. Pregnant Sows

257 animals @ 3.5 gallons ea.	900 gals.

2. Boars

12 animals @ 4.5 gallons ea.	54 gals.
Total:	1,440 gals.

The total water requirement of 1,440 gallons is more than the daily production of 1,117 gallons of TPML therefore an additional 323 gallons of water will be required per day to meet this requirement.

The TPML will be leaving the fermenter at a temperature of 60-65°C. Therefore, before being recycled this product will have to be cooled. The additional water required will help in this respect and a cooling coil can be installed in the product tank itself if necessary. From the product tank the liquid is pumped to troughs located in the pens. Any excess or spillage falls into the gutters and is returned to the sump. At the time of writing, this treatment system was still under construction and development and had not reached its full potential. Figure 15 is a graph of one of the preliminary fermentations that was carried out in the large fermenters. For this fermentation the fermenter was only two-thirds full and there were repeated problems with the air supply and mixers due to an inadequate electrical circuit. However, even under these adverse conditions a maximum temperature of 75°C was obtained. This indicates that the capacity of the fermenter may be increased from 300 gallons to 1,000 gallons with no adverse effects. Subsequent fermentations have been successfully carried out using these large fermenters, however, no further data is available at this time.

4.5 Thermophilic Aerobic Fermentation of Lignocellulose

4.5.1 Introduction

The idea of using materials such as wood as a feed source for domestic animals is not new (Beckman, 1915; Haber landt 1915; and Honcamp, 1931). The literature in this area is extensive

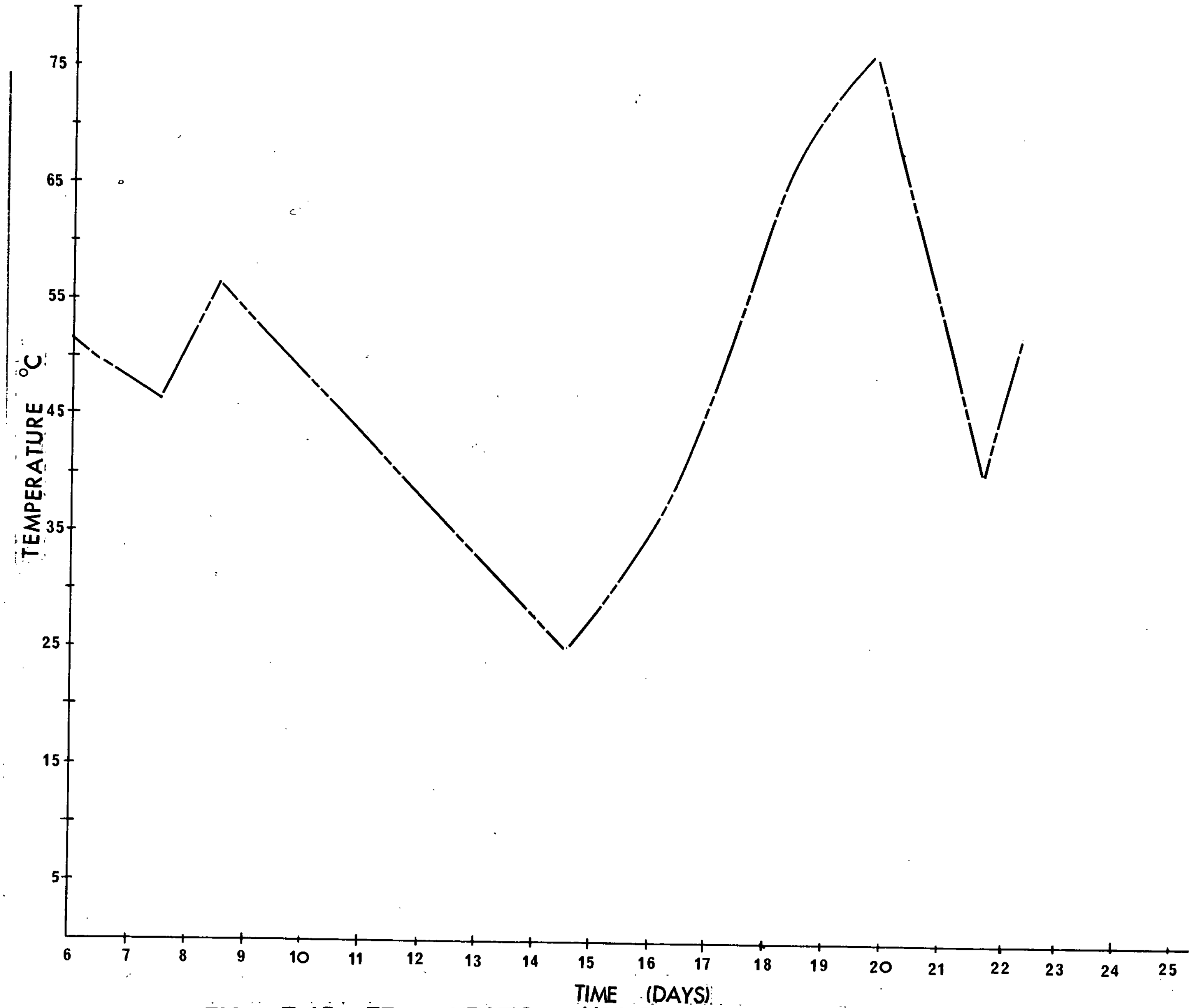


FIGURE: 15 FERMENTATION USING 1000GAL. FERMENTER and has been covered in several review articles (Kitts and Shelford 1968; Kitts *et al.*, 1969; Kitts and Krishnamurti 1976).

The prime obstacle in using wood or wood by-products is the chemical complexity of the relationship between lignin and cellulose (Huffman *et al.*, 1971). Free cellulose can be utilized by ruminant animals as a feed source because of the microbial population present in the rumen, another possibility would be microbial fermentation of the cellulose into a product which could be used by monogastric animals (Elgee 1975). Thermophilic organisms, both anaerobic species and aerobic species, are capable of decomposing cellulose (Gaughran 1947; Kellerman and McBeth 1912; and Murray 1944), but before this can take place the lignin must be removed (Poincelot and Day 1973).

Clarke (1938) described the relationship between cellulose and lignin as being similar to a reinforced concrete wall where the cellulose fibres are the reinforcing rods and the lignin and other constituents represent the concrete. Lignin occurs in plants chiefly as lignocellulose (Crampton and Maynard 1935). The chemistry and biochemistry of lignin and its breakdown is an extensive subject and will not be covered here. For a complete discussion of this subject the reader is referred to the following sources: Sarkanen and Ludwig 1971; Freudenberg and Neish 1968; Pearl 1967; Brown 1966; Schubert 1965 and Brauns and Brauns 1960.

To-date most methods for the removal of lignin have involved strong chemicals such as an alkali solution under conditions of high temperatures and pressures (Swan and Lewis 1975), physical reduction in size (Dehority and Johnson 1961) or use of gamma radiation (Hufmann et al. 1971).

The use of thermophilic bacteria for the removal of lignin and subsequent utilization of the free cellulose is another possibility (Surucu 1975). The first step to investigate this possibility would be to determine whether or not the thermophilic bacteria could utilize a lignocellulosic substrate such as wood as an energy source for growth and development.

4.5.2 Materials and Methods

A population of thermophilic bacteria was established utilizing hog waste as the substrate in one of the fermenters at U.B.C.'s Thermophilic Unit. Once temperatures in the thermophilic range had been reached and maintained for a period of ten days additional hog waste solids were added to the fermenter. This was to ensure that a supply of nutrients would be available during the introduction of the lignocellulose. Alder saplings from a brushy area adjacent to the Swine Unit at U.B.C. were used as a source of lignocellulose. The alder saplings were shredded by a small, portable shredder-composter.* This machine processed the saplings into a shredded material the individual particles of which were smaller than one-half by one-half by four millimeters. Two days later three kilograms of shredded alder were added to the fermenter and over the next one-hundred and eighteen days a total of 100

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* Amerind McKissic "Mighty Mac" shredder-composter.

kilograms of the shredded material were added. No further additions of hog waste solids were made. All of the alder used was not shredded at the same time, it was prepared as required throughout the experiment.

4.5.3 Results and Discussion

To determine if the population of thermophiles in the fermenter was able to utilize the alder a daily record of the fermenter temperature was kept (Figure 16). These results indicate that the thermophilic bacteria in the fermenter were able to use the alder as a nutrient source. Whether or not the thermophilic bacteria were able to degrade the lignin and free the cellulose for further fermentation can not be decided from these results. The purpose of this experiment was to determine if the thermophilic bacteria which develop during fermentation of hog wastes are able to use a lignocellulosic material as a nutrient source. It appears that this is quite possible. Further research is needed to determine which constituents of the wood are being utilized by these bacteria. Samples taken near the end of the fermentation were analyzed for crude-protein by Kjeldahl analysis. The results are shown in Table VI on a dry matter basis averaged over nine samples the crude protein level was 24.81%. However, some doubt exists as to whether or not Kjeldahl analyses of samples containing wood particles gives a meaningful value of the crude protein level in

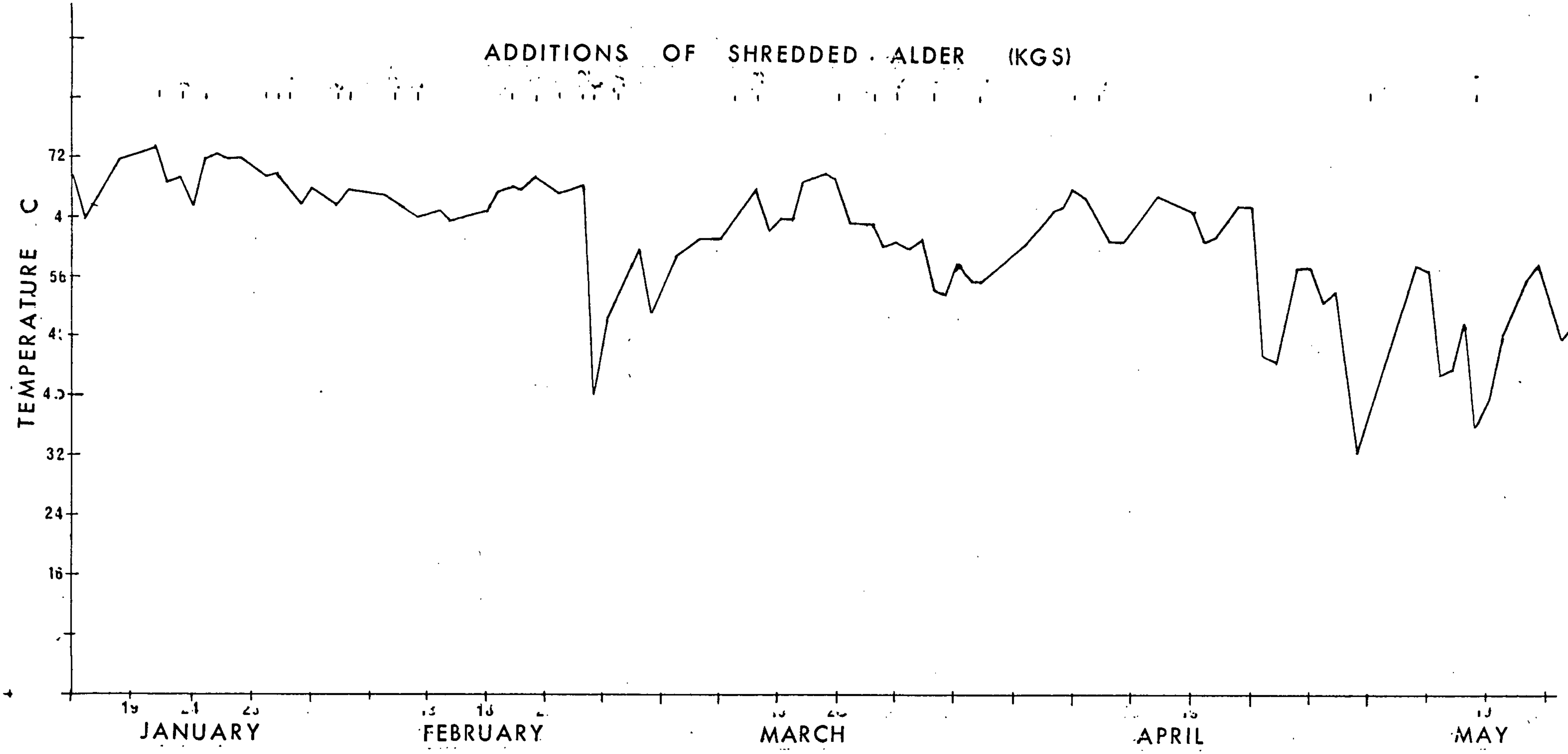

FIGURE 16 LIGNOCELLULOSE FERMENTATION

Table VI.

Sample	% Protein D.M.	% Crude Fibre	% D.M.
1-A-1	25.30		
1-A-2	24.35		
1-A-3	25.06		
1-A-4	26.10		
1-A-5	24.80		
1-A-1	24.15		
1-A-2	24.23		
1-A-3	-----		
1-A-4	-----		
1-A-5	23.65		
1-A-6	25.66		
Average	24.81		
Alder Shreds	1.56%	76.4%	56.6%

the sample (Coulthard personal communication). Therefore, the value of the final product of the fermentation as a livestock feed is not known. Research in these areas is currently being carried out at U.B.C. involving alder sawdust as a nutrient source for thermophilic fermentation and subsequent incorporation of the product into livestock rations. This research has not been completed as yet. Therefore, the results are not available for further discussion.

5.0 SUMMARY AND CONCLUSIONS

The major findings of the preceding set of experiments can be summarized as follows:

i. The heat required for maintenance of the temperature in the thermophilic range comes solely from microbial action. Agitation and aeration have no significant effect on the amount of heat required to maintain the temperature of the slurry.

ii. The product from Thermophilic fermentation of swine waste can be fed in a liquid form to animals older than 28 days of age with no detrimental effects.

iii. The capacity of the fermenters can be increased to 1,000 gallons with no detrimental effect on the activity of the thermophilic bacteria.

iv. Shredded alder can be used by thermophilic bacteria as a nutrient source.

6.0 SUGGESTIONS FOR FUTURE RESEARCH

Based on the results from these experiments, and observations made during the course of the study, the following areas for future research are suggested:

i. Feeding trials with older animals to investigate the possibility that they are better able to utilize the available nutrients.

ii. Further experiments in the area of lignocellulose fermentation to determine if thermophilic bacteria can decompose lignin.

iii. Experimentation to determine the yield and quality of single cell protein from wood.

iv. Investigations into using other organic waste materials e.g. cannery and packing plant wastes as a substrate for thermophilic bacteria.

v. The possible use of the heat produced during a fermentation for heating purposes.

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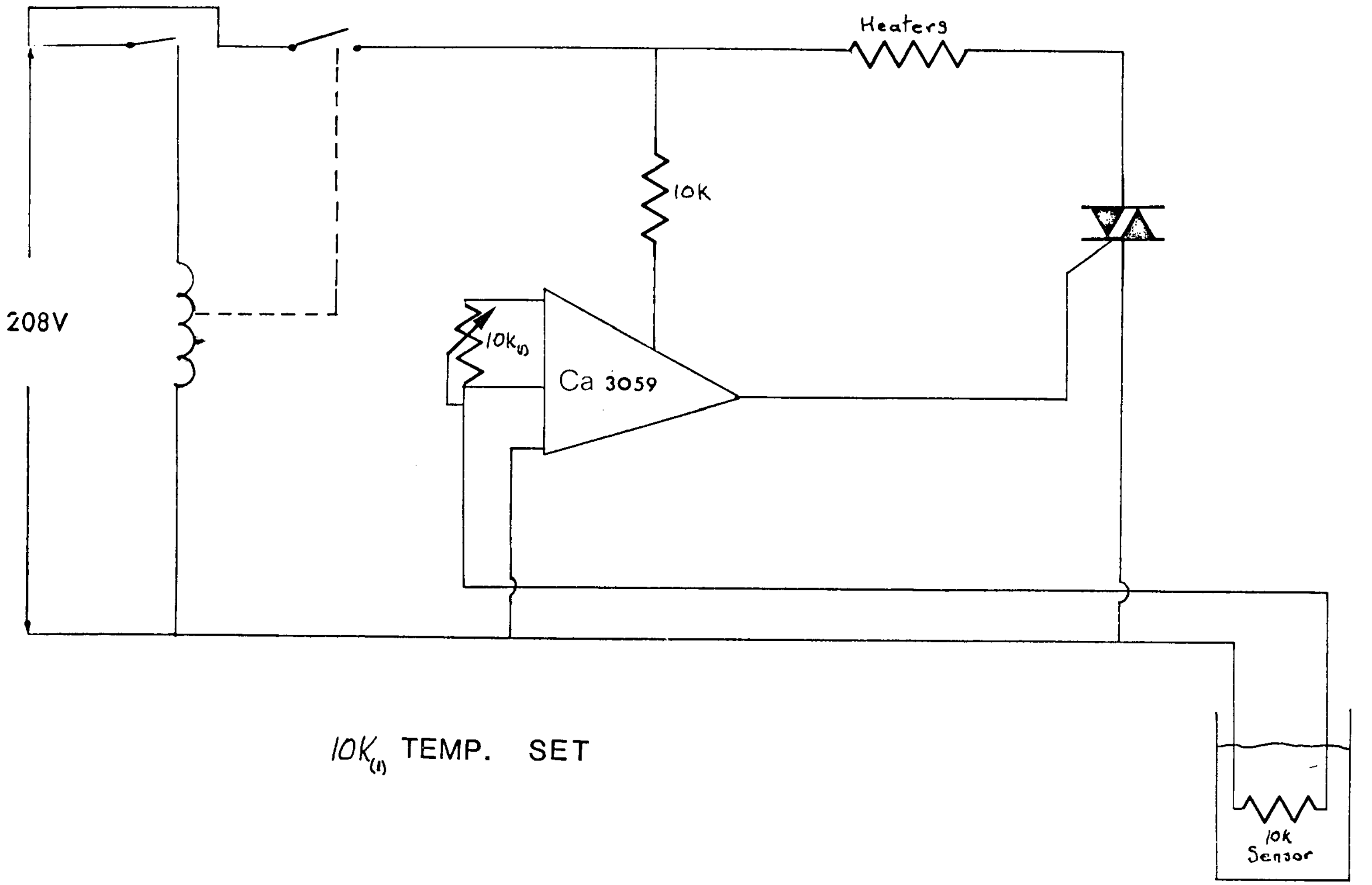
APPENDIX



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