THE ANAEROBIC FILTER FOR THE TREATMENT OF EFFLUENT FROM A POTATO CHIP MANUFACTURER

by

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This report is respectfully submitted in fulfilment of Course 336-490 D requirements. This completes the requirements for a B.Sc. (Ag Eng), Macdonald College, McGill University.

Sincerely

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INTRODUCTION

The objective of this project was to anaerobically treat the effluent from a potato chip plant, to reduce the COD and to produce methane. Several different anaerobic processes were considered in a previous study (Appendix A) and the most suitable was found to be the anaerobic filter. The advantages of the anaerobic filter over more conventional types of anaerobic treatment stem from the fact that the filter is capable of a long solids retention time (100 days) with a relatively short hydraulic retention time (Young and McCarty, 1967). For the anaerobic filter to be competitive with the centrifugal clarifiers currently in use, it would have to be able to perform without complex monitoring, at a moderate temperature, not require substantial chemical additions, and achieve a COD reduction of more than 90%. In the design of a laboratory scale model these constraints were adhered to as much as possible. It was decided to attempt to operate the filter at 20°C, previous authors reported COD reductions of 90-97% when the filters were operated at 25°C with wastes other than potato processing effluent (Young and McCarty, 1967; McCarty, 1968; Dewalle and Chian, 1976). Even operating at 20°C it would require energy input to raise the large volumes of waste from about 9°C to the operating temperature. This might require a substantial portion of the gas produced from the digestion of the organic matter. It has been suggested that theoretically 1 kg of COD stabilized yields .120 m^3 digester gas which is 60% methane (McCarty 1964). The additions of nutrients and buffering agents add to the operating costs therefore it was hoped that they would prove to be unnecessary. In accordance with the above conditions a laboratory scale anaerobic filter was designed, constructed, and operated for 60 days. The first 30 days being considered start-up, the second 30 days the filter was operated with actual screened but untreated effluent from a local potato chip manufacturer.

LITERATURE REVIEW

In the initial study by McCarty (1968), the anaerobic filter was tested on a small scale utilizing methanol, acetate, and propionate as waste feed. The results showed that at 25°C 70-80% of the waste was stabilized by conversion to methane.

A second paper presented by Young and McCarty (1967) again utilized a synthetic waste and a laboratory scale treatment unit. The authors conclude that the anaerobic filter could prove to be a system by which dilute wastes may be treated with low initial cost and low maintenance.

Plummer et al. (1969) investigated the treatment of carbohydrate waste by an anaerobic filter in the laboratory. They found reductions of BOD of 94%, 72%, 43%, and 41% corresponding to loading rates of 101, 237, 438, and 638 pounds of COD per 1000 cubic feet of filter volume per day. They suggest that the effluent should be clarified prior to discharge in a watercourse.

Lovan and Foree (1972) attempted to treat brewery press liquor waste by anaerobic filter in the laboratory. They found that the process was suitable for this high strength waste (BOD 3100 - 14,000 mg/l). The volume of their filter was 33.4 liters and they recorded an average gas production of 20 liters per day, at about 65% methane.

El-Shafie and Bloodgood (1973) conducted a laboratory study utilizing six filters in series digesting a synthetic waste (Metrecal). They measured gas production and COD reduction as well as pH in each of the six filters. Their study indicates that the microbial activity decreases exponentially with detention time.

Taylor and Burm (1973) report on experiences during operation of a full scale anaerobic filter, treating wheat starch wastes. The filters were rock filled tanks, 30 feet in diameter and 20 feet high. The methane produced was not utilized it was piped to a flare and burned, the estimated volume of gas produced was 30,000 cubic feet per day. The filter required large additions of $NaHCO_3$ to maintain pH and alkalinity control. They found the treatment efficiency to be about 60% based on organic matter removal. The cost of the system was approximately $110,000.

Arora et al. (1975) conducted a study using the anaerobic filter for treatment of vegetable tanning effluent. They maintained a three day hydraulic retention time and varied the organic loading rates from 0.192 to 3.264 kilograms per cubic meter of filter volume per day. They operated two filters, Filter I was loaded with raw waste while Filter II had phosphate added to the raw waste. The reduction of BOD ranged from about 60% for the very high loading rates to about 95% for medium loading rates, with slightly higher values obtained in Filter II.

Dewalle and Chian (1976) experimented with an anaerobic filter utilizing recirculation and plastic media, "Surpac". They observed removals of organic matter in excess of 95%. The waste water used for the experiment was leachate from a sanitary landfill with a COD of 54,000 mg/l and a pH of 5.4. The experiment showed that the anaerobic filter, with recirculation can treat acidic wastes without buffering.

For additional review of literature pertaining to potato processing waste and general anaerobic treatment see Appendix A.

ANAEROBIC FILTER

The anaerobic filter is a specialized form of the anaerobic contact process, especially suited to the treatment of large volumes of dilute wastes. It consists of a column containing crushed stone or plastic media which provides a large surface area for the physical support of a bacterial film. The waste to be treated is pumped in at the bottom

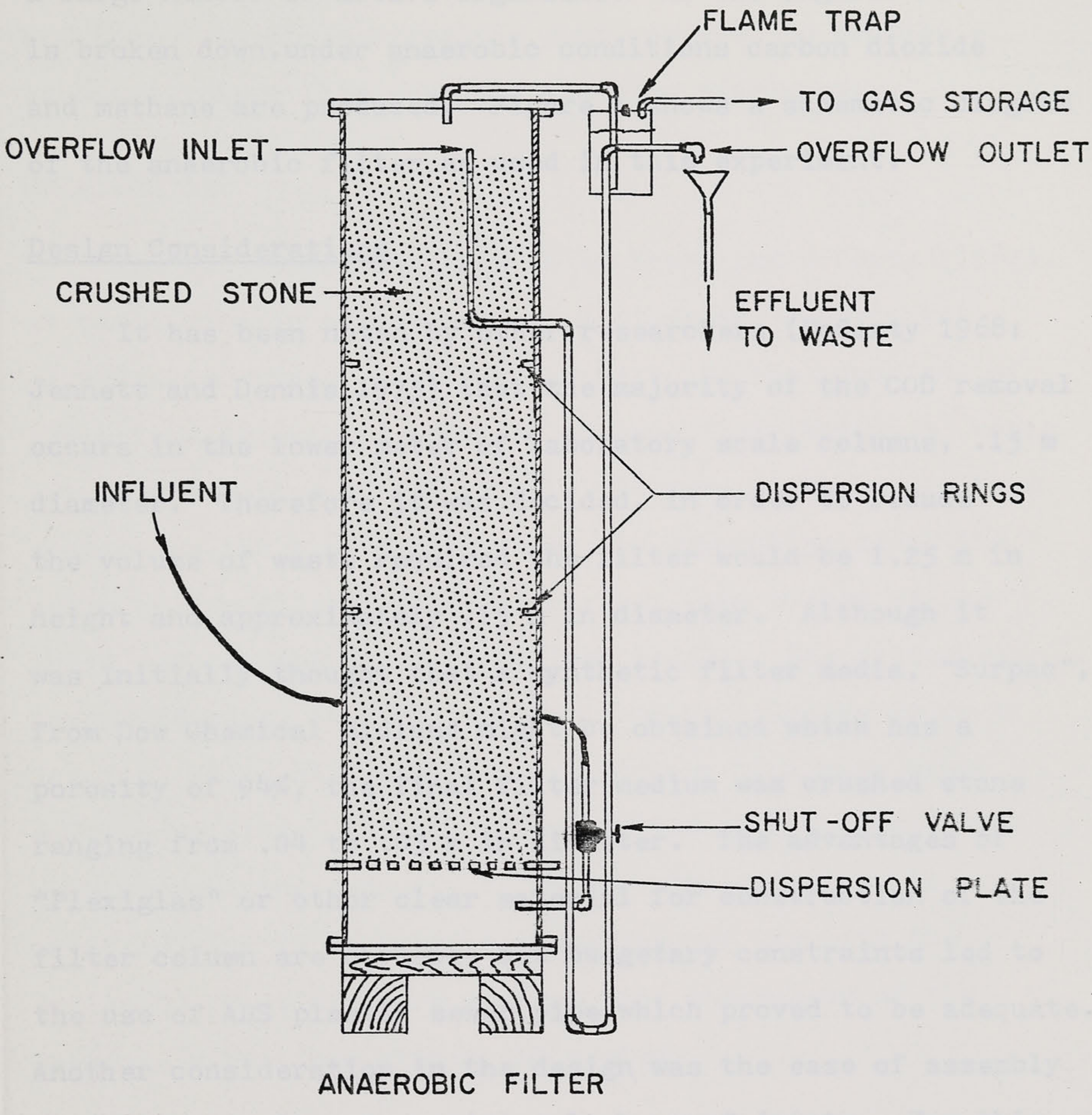

Figure 1 The Anaerobic Filter.

of the filter and travels upward coming in contact with a large number of active organisms. As the organic matter is broken down, under anaerobic conditions carbon dioxide and methane are produced. Figure 1 shows a schematic diagram of the anaerobic filter as used in this experiment.

Design Considerations

It has been noted by other researchers (McCarty 1968; Jennett and Dennis 1975) that the majority of the COD removal occurs in the lower meter of laboratory scale columns, .15 m diameter. Therefore it was decided, in order to reduce the volume of waste required the filter would be 1.25 m in height and approximately .15 m in diameter. Although it was initially thought that a synthetic filter media, "Surpac", from Dow Chemical Midland might be obtained which has a porosity of 94%, the final filter medium was crushed stone ranging from .04 to .03 m in diameter. The advantages of "Plexiglas" or other clear material for construction of the filter column are obvious, but budgetary constraints led to the use of ABS plastic sewer pipe which proved to be adequate. Another consideration in the design was the ease of assembly and the necessity of providing leak proof joints. For this reason all materials used in the construction of the filter and gas handling system were either ABS or PVC plastic which can be joined by solvent welding. A final design consideration was the regulation of the flow, initially it was hoped that the system would operate via gravity feed

It proved to be impossible to regulate the flow accurately since the system is subject to varying pressure conditions. For this reason a peristaltic pump was used to provide a constant volume flow over the changing pressures.

Construction

The filter was designed after Young and McCarty (1967), it was 1.25 m in height and .15 m diameter, constructed of ABS sewer pipe. A dispersion plate in the lower end of the column (Figure 1) provided an even distribution of waste across the bottom of the filter. To prevent the waste from by-passing the treatment process, by travelling along the walls of the filter, dispersion rings were placed at one-third and two-thirds of the column height. The filter was assembled using "G E Silicon Seal" on all flanges prior to joining, while all permanent connections were made using solvent welding. The column was filled with crushed stone with a resulting porosity of 49.4%. The long loop in the overflow pipe is to prevent the escape of gas with the effluent, by maintaining a water seal regardless of the pressure variations within the system.

GAS HANDLING

Any complete system that utilizes anaerobic fermentation for waste stabilization must take into account the collection, storage and utilization of the gas that is produced (Figure 2). Digester gas is approximately 60% methane and 40% carbon

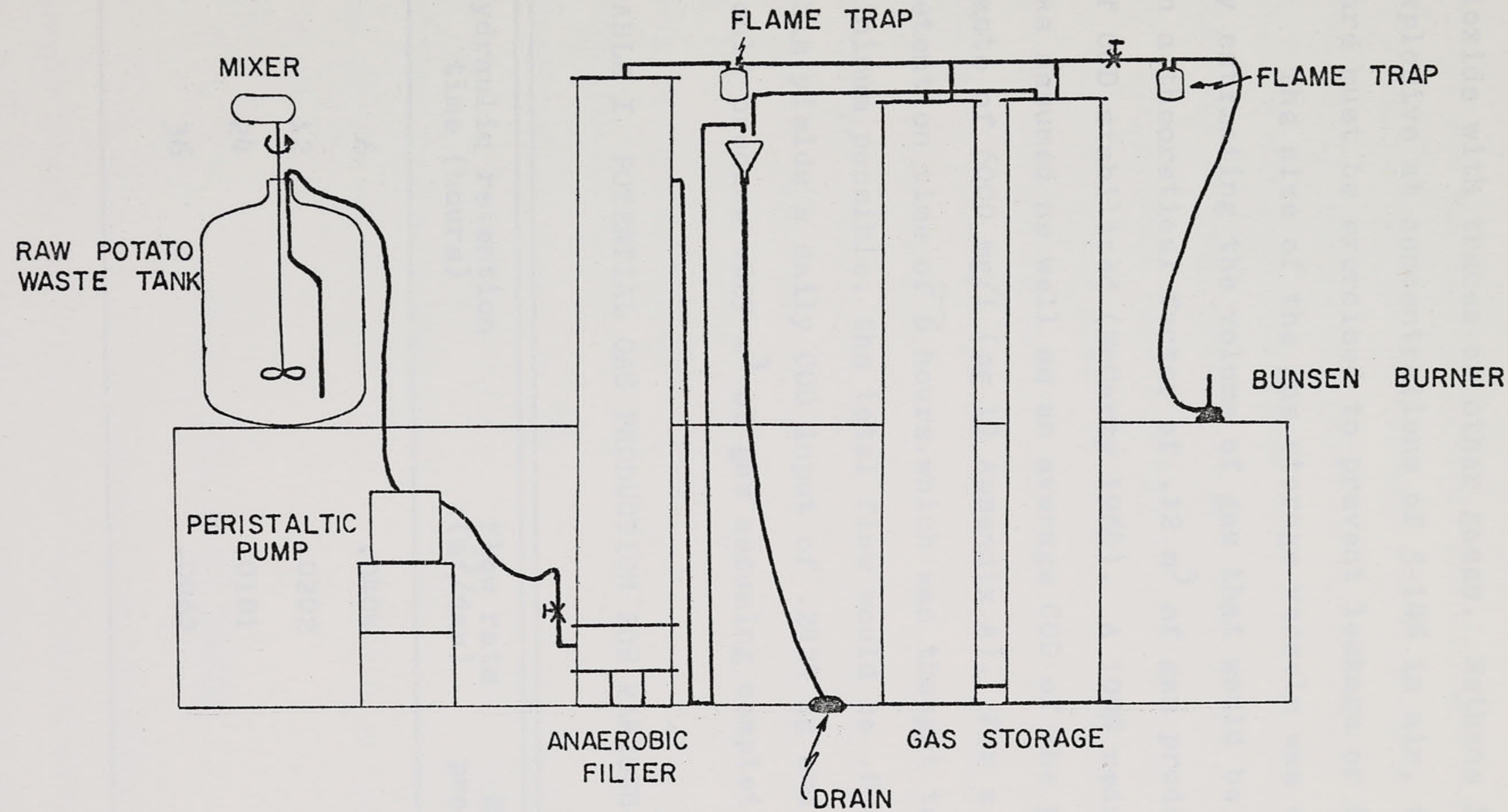

Figure 2 Schematic Diagram of the Experimental Set-up.

dioxide with traces of other gases. Methane is highly explosive at concentrations of 5-14% in air, therefore care must be exercised to prevent leakage or ignition.

The size of the gas storage vessels was determined by estimating the volume of gas that would be produced based on a theoretical factor of .12 m^3 of gas produced per kilogram of COD stabilized (McCarty 1964). A 100% reduction of COD was assumed as well as an average COD of the potato waste of 6000 mg/l (pg 19 Appendix A). For a hydraulic retention time of 6 hours, which was thought to be the minimum possible, the total flow would be .0404 m^3/day. This yields a daily COD input of .2424 kg and theoretically could produce .029 m^3 of gas assuming complete COD reduction.

TABLE I POTENTIAL GAS PRODUCTION FOR VARIOUS FLOW RATES

Hydraulic retention time (hours)	Flow rate (m^3/day)	Estimated gas production (m^3/day)
6	.0404	.0292
12	.0202	.0146
24	.0101	.0073
36	.0067	.0049

It was decided to provide gas storage capacity for 1.5 days production at the shortest hydraulic retention time. This was accomplished by constructing two columns of .15 m diameter ABS sewer pipe 1.2 m in height. The total gas storage capacity was .0424 m^3 as constructed.

The columns were initially water filled, and the gas was collected above the water by displacement. The gas enters the column at the top and as the pressure increases water is forced out of the cylinders. The water outlet extends to the bottom of the gas storage containers, this maintains a water seal and prevents the escape of gas. Additional safety measures are present in the form of flame traps which prevent a flash back from the bunsen burner reaching the gas storage or subsequently to the filter. After the system was assembled as shown in Figure 2, it was pressure tested to 15 kPa (5 ft H_2O) and all leaks were sealed. The maximum pressure that would be reached in the system was 12 kPa (4 ft H_2O) due to the method of gas collection and storage.

POTATO CHIP PLANT WASTE

The waste for this project was obtained from Humpty Dumpty Aliments Ltee., Lachine, Quebec. The plant processes approximately 14 tonnes of potatoes per day, using about 200 m^3 of water for various operations. The waste water is primarily associated with the washing and peeling of whole potatoes and the rinsing of potato slices prior to frying. At the present time the potato waste is screened to remove large pieces and peelings then treated by a series of centrifugal clarifiers to remove the suspended solids. It was reported that this treatment has a COD removal efficiency of better than 80% and possible reductions up to 95%.

For the purpose of this experiment screened but untreated waste was obtained. The waste was picked up in three .189 m^3 (45 gal) drums and transported to the cold storage section of the machine shop, the temperature is several degrees warmer than outside air temperature but remained below 0^oC throughout the course of the experiment. By the use of an electric heat tape the temperature was maintained just above 0^oC in the drum from which current batches were being taken, the other drums were allowed to freeze until needed. Every three days two .018 m^3 (5 gal) batches were obtained and taken to the laboratory. One was placed in refridgerated storage and the second was emptied into the raw waste tank where necessary chemical additions were made.

The waste consisted of what appeared to be dirty water with a noticeable odor of potatoes. It was noted that if the waste was allowed to remain undisturbed, a large quantity of starch settled out. A second feature was that although the raw waste had a pH near neutrality if it was allowed to warm up to room temperature for several days fermentation began with a marked decrease in pH and a noticeable acetic acid odor. The process actually began to occur within the first 24 hours following removal from refridgerated storage.

OPERATION

Start-up

Prior to start-up a mixer was added to the system to provide constant agitation for the raw waste. This was necessary to prevent the starch from settling out of the waste.

The filter was initially filled with a nutrient solution consisting of "Carnation Instant Breakfast" and distilled water, in a ratio of one package to two liters of distilled water. The filter was then seeded with two liters of liquid swine manure from an unmixed storage tank. It had been intended that the seed sludge would be obtained from a municipal anaerobic digester, but the only one in the area had recently closed down its facility and emptied its tanks. The nutrient solution and swine slurry were circulated in a closed loop with no wasting of effluent. After three weeks of operation with no gas production it was thought that there might be a problem. The pH was measured, it was found to be 5.3, indicating that the acid forming bacteria were out of balance with the methane formers.

The optimum pH established in the literature for anaerobic bacterial growth for gas production is between 6.8 and 7.5, the pH was well below this range. Following this discovery immediate steps were taken to buffer the solution using sodium bicarbonate. It has been reported by McCarty (1964) that sodium can have inhibitory or toxic effects when in concentrations of greater than 3500 mg/l, therefore the addition of sodium bicarbonate was kept below 120 g for the volume of the filter. Actual addition was 100 g of sodium bicarbonate per .018 m^3 (5 gal) batch of potato waste. This brought the pH within the acceptable level, between 6.8 and 7.5, about 7.1. Occasionally additional sodium bicarbonate was required this was determined by daily pH measurement. After one more week of closed circuit operation it was decided to add raw potato waste and continue closed circuit operation. This recirculation was continued for two weeks with periodic wasting of effluent and raw waste additions. During this time there was no gas production, but since it was assumed that the system would work a wait and see attitude was adopted. Following two weeks of zero gas production it was decided to try to establish small scale anaerobic digester with various nutrient additions. Nitrogen and phosphorus being the ones considered to determine if nutrient additions could improve gas production. From these experiments it was determined that nutrient additions were effective in increasing gas production although there was no concrete quantitative conclusions that could be reached (Appendix B) due to the method of testing. It was therefore decided to attempt to establish a C:N:P:K ratio of 125:5:1:1, this was based on several sources which suggest an optimum C:N ratio of 25:1 and an N:P ratio of 5:1 (McCarty 1964; Singh 1975). It was thought that this would solve the problem of no gas production, therefore continuous flow operation was begun, simulating conditions in a full scale treatment facility.

Continuous Operation

The first week was considered to be part of the start-up, the waste being run through the filter but without daily COD measurement. For a first approximation the average COD from the literature (Appendix A) was used in conjunction with a formula given by Shady (1973) to determine the carbon content of the waste: Carbon = .375 COD. This gave the amount of carbon in the waste in mg/l. From this the required nutrient additions could be calculated to yield the optimum C:N:P:K ratio mentioned earlier. For an average COD value of 6000 mg/l, it was calculated that in the .018 m^3 (5 gal) batch there would be approximately .0385 kg carbon. This amount of carbon requires .00154 kg nitrogen and .00031 kg phosphorus to establish the accepted C:N:P:K ratio. Nitrogen was primarily obtained as ammonium nitrate from a 34:0:0 commercial fertilizer, phosphorus and potassium were obtained from a 5:20:20 fertilizer. Calculations showed that by using .0047 kg of 34:0:0 and .0017 kg of 5:20:20 a C:N:P:K ratio of 118:5:.9:.9 would be obtained. These amounts of the two fertilizers were added to the raw waste tank with each new batch for the first week of operation. During this first week and throughout the remaining three weeks of operation there was no significant or measurable gas production.

In the subsequent three weeks of operation the influent and effluent COD and pH were measured daily to monitor the treatment efficiency and maintain the stability of the system. The pH was measured with a pH meter which was calibrated daily using a standard buffer solution. The COD testing was done according to "Standard Methods for the Evaluation of Water and Wastewater."

When the COD of the influent was measured it was found to be higher than the average value used for computing nutrient requirements. The nutrient additions were increased to .005 kg of 34:0:0 and .002 kg of 5:20:20 per batch of waste. Based on the final average COD of 7100 mg/l, this yields a C:N:P:K ratio of 125:4.8:1.1:1.1, which closely approximates the suggested optimum. Under these conditions nitrogen could still be limiting to a minor extent.

During the second week of operation the COD reduction was found to be about 50%, this was somewhat lower than reported by other researchers, ranging from 70 to 90%.

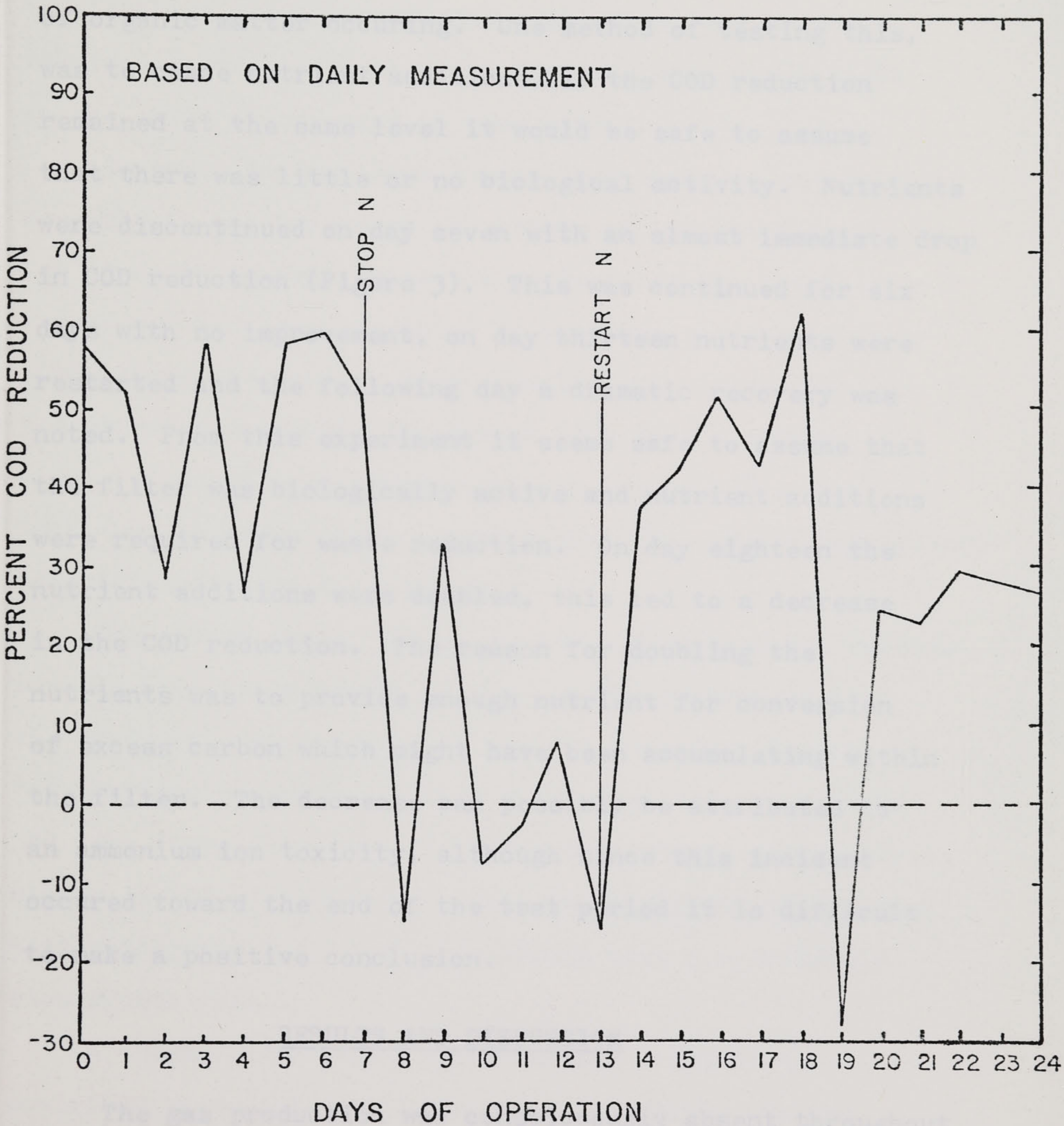

Figure 3 Graph of COD Reduction vs Days of Operation

From this the question arose as to the biological nature of the filter. Was the filter simply acting as a trap for the suspended solids or was there biological conversion of organic matter occuring. One method of testing this, was to cease nutrient additions, if the COD reduction remained at the same level it would be safe to assume that there was little or no biological activity. Nutrients were discontinued on day seven with an almost immediate drop in COD reduction (Figure 3). This was continued for six days with no improvement, on day thirteen nutrients were restarted and the following day a dramatic recovery was noted. From this experiment it seems safe to assume that the filter was biologically active and nutrient additions were required for waste reduction. On day eighteen the nutrient additions were doubled, this led to a decrease in the COD reduction. The reason for doubling the nutrients was to provide enough nutrient for conversion of excess carbon which might have been accumulating within the filter. The decrease can possibly be attributed to an ammonium ion toxicity, although since this incident occured toward the end of the test period it is difficult to make a positive conclusion.

RESULTS AND DISCUSSION

The gas production was conspicuously absent throughout the course of the experiment and the COD reduction was well below the expected 85-95% range. There are several possible explanations for these results: 1) Insufficient temperature for bacterial activity, 2) The length of the experiment was not sufficiently long enough (60 days) to establish a large bacterial population, and 3) The required species of methogenic bacteria were not present in the swine slurry used as seed mixture.

In order to develop a system that would be economically feasible it was necessary to operate at ambient temperature (20°C) which is well below the optimum for the mesophillic range. It had been suggested by previous authors (McCarty 1968, Young and McCarty 1967, Dewalle and Chian 1976) who had operated anaerobic filters at 25°C that operation might be possible at temperatures as low as 20°C. In this case it seems quite possible that the reduced temperature adversely affected the results.

The second factor which may have influenced the results was the relatively short duration of the experiment for the study of a slow growth biological process. Several of the previously mentioned studies extended for a period of 300 days, five times the length of this study, and achieved higher levels of treatment. This is likely due to the fact that methogenic bacterial populations have a notoriously slow growth rate.

A third factor which may have made a significant contribution to the poor showing of the filter was the inability to obtain bacteria from an active anaerobic digester. For this reason slurry from a unmixed swine

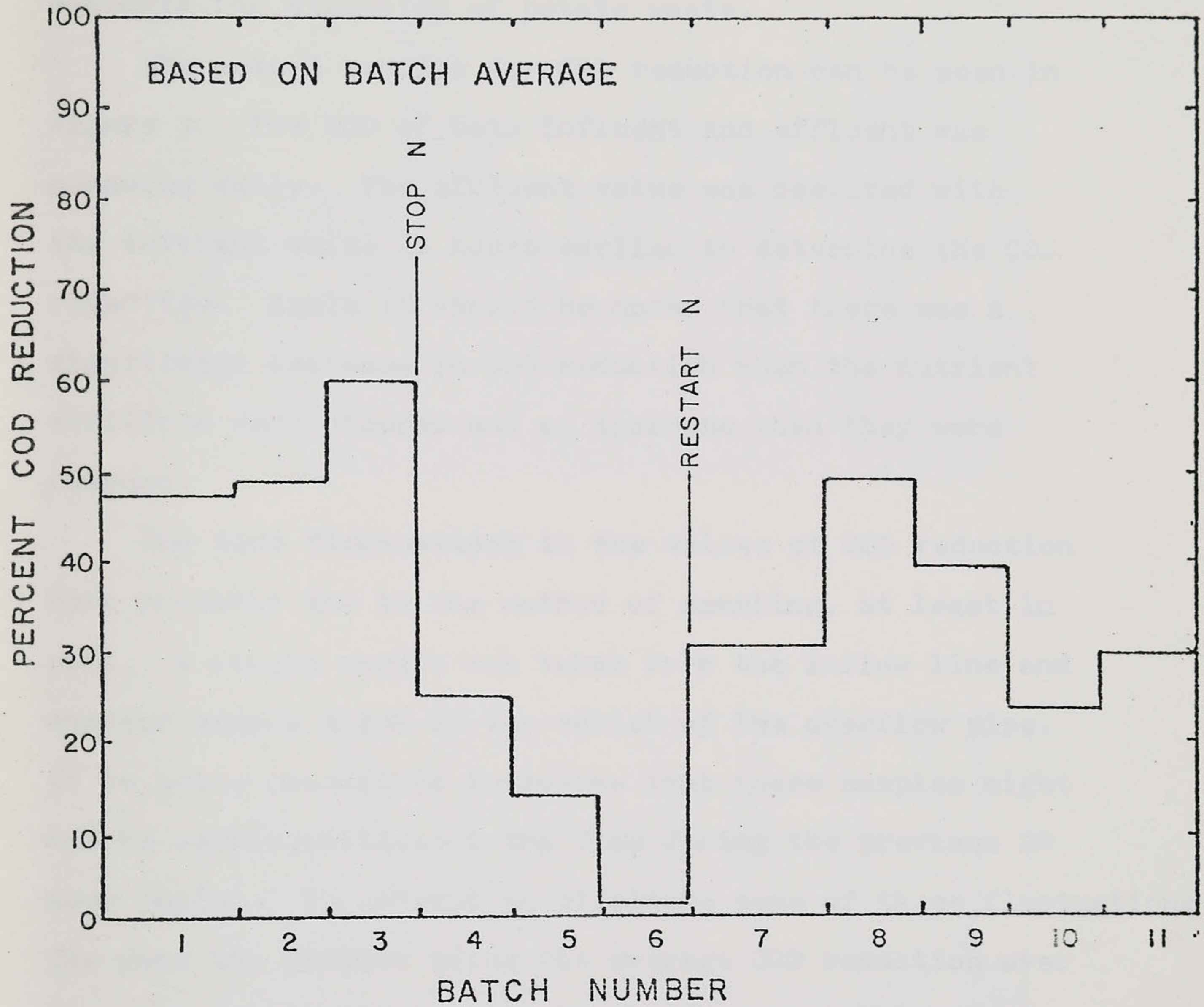

Figure 4 Graph of COD Reduction vs Waste Batch as an Average

manure tank was used to seed the filter. This mixture possibly did not have sufficient numbers of the correct bacteria for digestion of potato waste.

The actual results for COD reduction can be seen in Figure 3. The COD of both influent and effluent was measured daily. The effluent value was compared with the influent value 24 hours earlier to determine the COD reduction. Again it should be noted that there was a significant decrease in COD reduction when the nutrient additions were stopped and an increase when they were resumed.

The wide fluctuations in the values of COD reduction were probably due to the method of sampling, at least in part. A single sample was taken from the inflow line and another sample taken at the outlet of the overflow pipe. It is quite reasonable to assume that these samples might not be representative of the flow during the previous 24 hour period. To attempt to eliminate some of these fluctuations the data was graphed using the average COD reduction over the time period for a given batch of waste. This was done based on the assumption that a given batch of waste was homogeneous although there might be variation between batches. These results can be seen in Figure 4. The period when nutrient additions were stopped shows clearly batches four, five, and six.

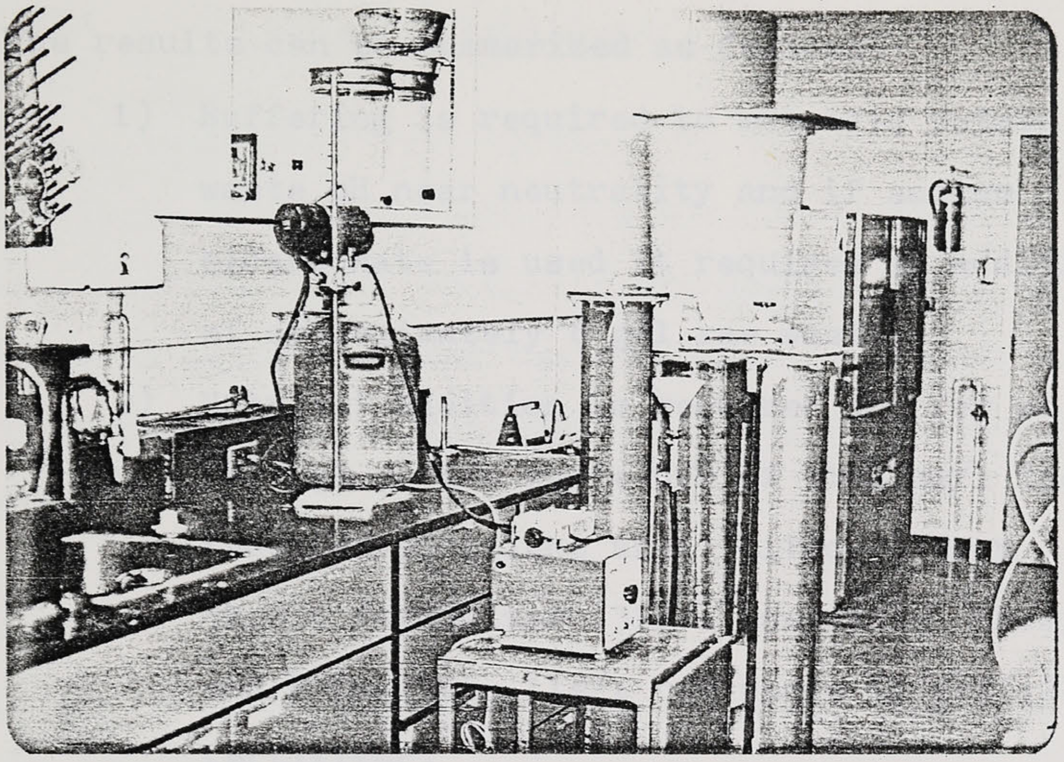

Figure 5 Experimental Set-up.

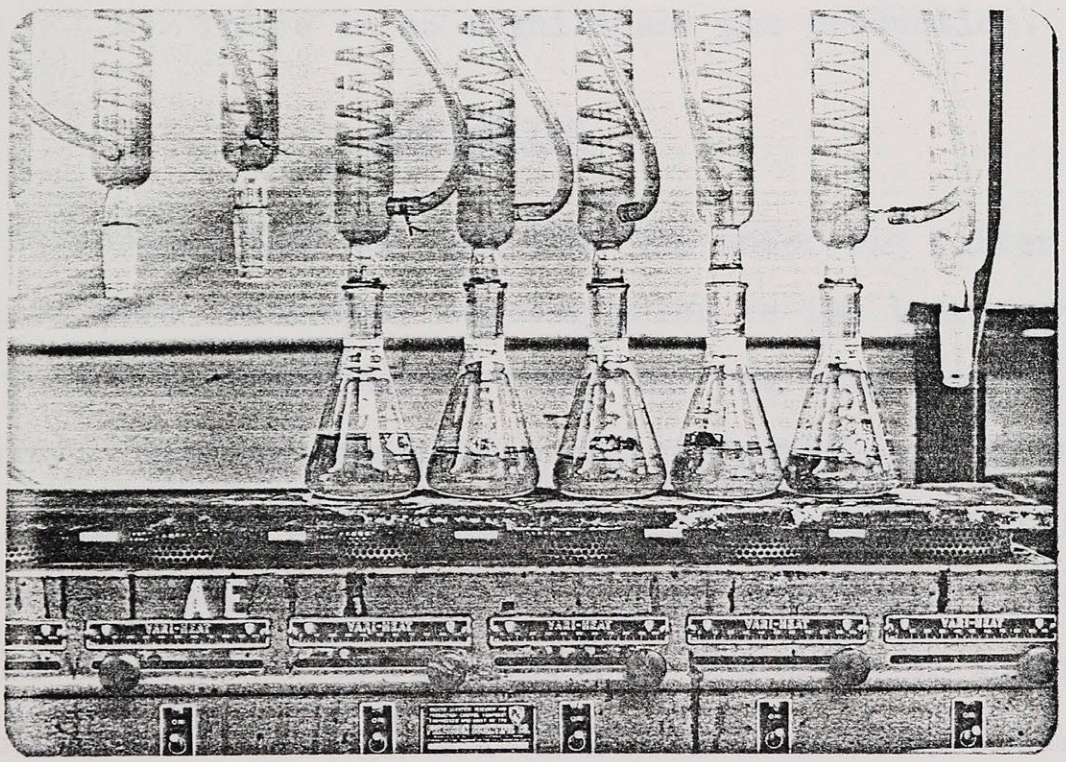

Figure 6 Electric Heater and Condensers for COD Testing.

The results can be summarized as follows:

1) Buffering is required to maintain potato waste pH near neutrality and if sodium bicarbonate is used it requires an addition of approximately 6 g/l raw waste.
2) Nutrient addition is required and for an average potato waste COD of 7100 mg/l the required additions are: Nitrogen from 34:0:0 fertilizer .31g/l raw waste, Phosphorus and Potassium .11g/l raw waste of 5:20:20 fertilizer.
3) The COD reduction at 20^{o}C averages about 50% for an organic loading rate of 7.1 kg COD per cubic meter filter volume per day.
4) There is no significant gas production.

CONCLUSION

It appears that at this time the anaerobic filter requires more laboratory testing prior to its introduction as a full scale treatment process for the potato processing industry. Although the filter has the potential for COD reductions of 95% and substantial energy production this particular study was unable to achieve this level of results. Further experimentation is needed in the areas of acclimatizing the bacteria to reduced operating temperature, optimization of organic loading rate and hydraulic retention time, and production of a seed sludge suited to this high starch waste.

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APPENDIX A

ANAEROBIC TREATMENT OF POTATO CHIP PLANT WASTES

by

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Abstract

A review of literature pertaining to wastes from the potato chip industry as well as the literature on anaerobic treatment processes suitable for food processing wastes is presented. The paper establishes the average potato chip plant waste characteristics, in terms of volume of flow and quality. Possible alternative processes are investigated, the final conclusion being that only the anaerobic filter is potentially suitable. A preliminary process design for an anaerobic waste treatment facility for a potato chip plant and gas handling system is included.

Résumé

L'étude présente un survol de la documentation sur les déchets de l'industrie des croustille de pomme de terre et sur différents traitments anaérobiques de déchets offrant un certain intérêt pour l'industrie alimentaire. Le rapport donne la qualité et le volume moyen des déchets produits par une usine de croustilles. Plusieurs possibilités sont explorées mais seulement la méthode de filtrage anaérobique offre un certain poteutiel. Finalement le prototype d'un système de traitment anaérobique de déchets de pomme de terre et de manutention de gas produit est aussi présenté.

Introduction

The objective of this project has evolved over the past year and a half and in its final form it is: To develop a process for treating potato chip plant wastes utilizing anaerobic fermentation. The food processing industry was chosen for this project as a second choice, it was originally hoped that an anaerobic waste handling system could be developed for the beef farmers in Québec, this proved not to be economically or technically feasible at the present time. The reasons for this include the lack of required technical training to operate an anaerobic digester, the highly explosive nature of the gaseous product, and the difficulties involved with storage and utilization of the gas. The farmer simply can not utilize the quantities of gas that a digester is capable of producing. Methane requires extremely large amounts of energy to compress it, for this reason tank storage is not practical, while conversion to electic power is inefficient. Digester gas, 65% methane, is best suited for use as a source of heat by direct combustion, this reduces the required scrubbing, necessary when the gas is used as fuel for internal combustion engines. For the above reasons the farmer was left to the future and another source of waste was sought. The food industry became the natural choice since they produce high strength wastes and consume large quantities of energy primarily used in heating processes. These wastes have been discharged into watercourses in a relatively untreated state until recently. Water pollution control legislation which is becoming more common has forced many of the food processing plants to install waste treatment facilities.

The original objective of this project was to complete a detailed design of an anaerobic waste treatment system for a food processing plant. As the perinent literature was reviewed it became increasingly clear that the information regarding anaerobic digestion of food processing wastes was limited. Although the anaerobic process has been used for many years to digest municipal sewage, it has seen extremely limited industrial application. The reasons for this have been: slow rates of organic matter breakdown, digester failure due to toxic components of the waste, low rate of bacterial growth, and required elevated temperature (35° C) for optimum operation. Basically the process has not been seen as economically feasible when direct discharge to watercourses was permisible, recently with the introduction of water quality control legislation there has been renewed interest in the anaerobic process for waste treatment. Due to the lack of detailed information in the literature the objective of this project was modified to the development of a process design for anaerobic treatment of a specific food processing plant waste. In accordance with this revised objective it was decided to investigate the wastes from various food processing industries. Several cannery wastes and wastes from the potato processing industry were considered. The final choice was a potato chip manufacturing plant, one reason for this choice was the size of the potato industry in Canada, farmers in 1970 produced 2.5 million tonnes of potatoes (12). Another was the suitability of the wastes for anaerobic treatment, the wastes produced contain high BOD and are not known to contain substances inhibitory to the anaerobic organisms. As for the specific choice of a potato chip plant, this was based on the fact that Québec has eight potato chip plants, and in Canada a total of $74.3 million was spent on potato chips in 1970 (12), making it the largest potato processing industry in terms of product sold.

Once the type of plant was chosen it was necessary to determine the quantity and quality of the wastes produced, this was found to be well documented in the literature. Then came the task of finding an anerobic process which would be suitable to the large volumes of high strength wastes. The anaerobic process was initially chosen for this project because of the idea of "free" energy. It quickly became obvious that there is no such thing as "free" energy and the recovery of methane from wastes might prove to be extremely costly. Anaerobic digestion of wastes has additional advantages as a method of waste stabilization aside from the production of methane, it also produces relatively small amounts of biomass during the destruction of organic material. This eliminates the necessity for sludge wasting, a large problem in aerobic treatment systems. The efficiencies of anaerobic and aerobic systems are similar although the anaerobic process requires a longer detention period due to smaller numbers of active organisms. The requirements of the process to be chosen were that it had to be efficient, relatively trouble free, capable of handling large volumes of waste water, and economical. If an anaerobic process could be developed that would meet these requirements and produce energy the reduction of pollution might be made more acceptable to the industry.

LITERATURE REVIEW

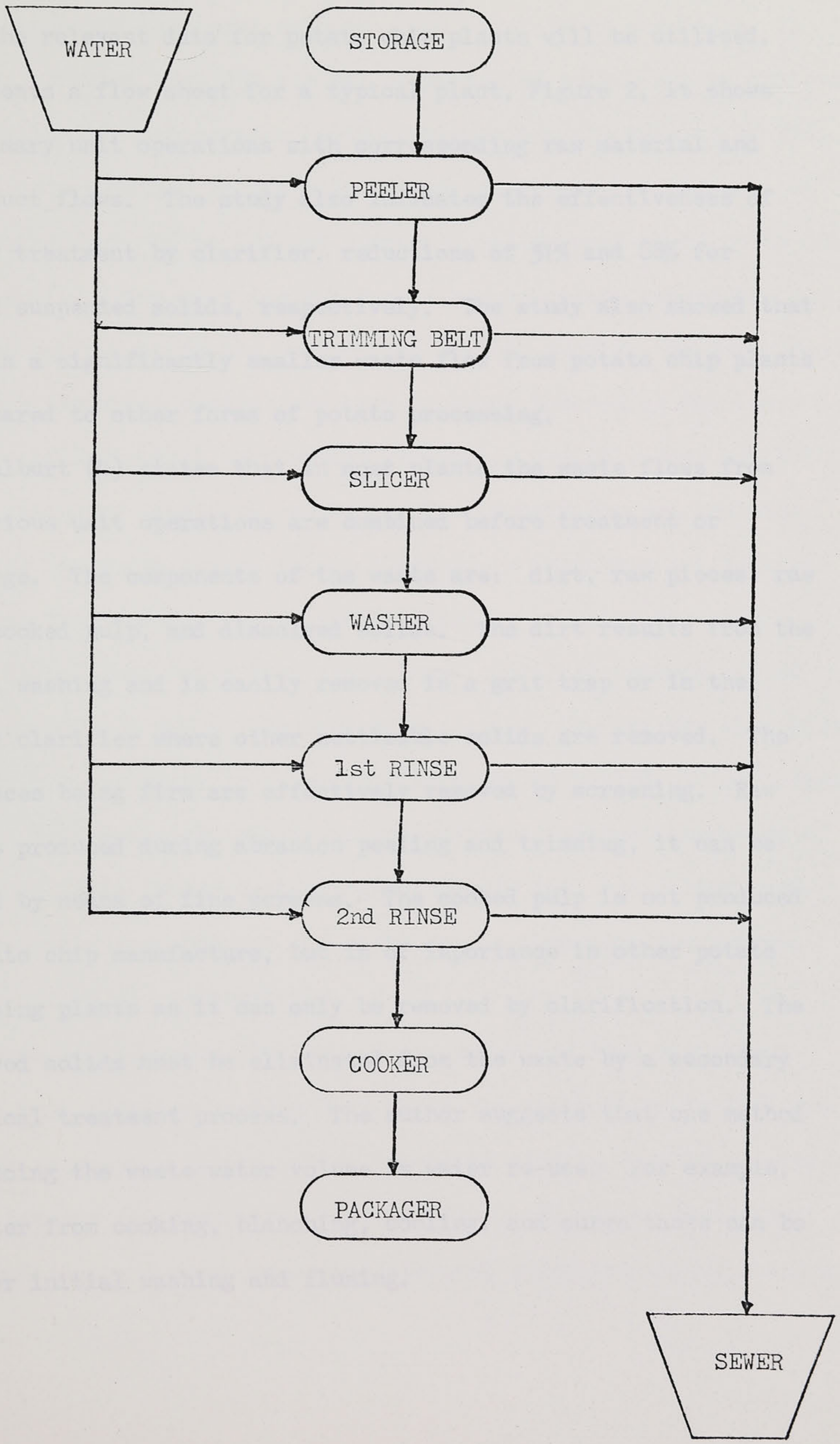
This is a review of literature pertaining to potato processing wastes and methods of treatment as well as general anaerobic processes used in the treatment of food processing wastes.

Porges (1) analysed BOD, suspended solids, and settleable solids from a small potato chip plant. The peeler was of the abrasion type, using 234 gallons of water per 1000 pounds of potatoes with a BOD of 580 ppm and suspended solids of 1120 ppm. Washing and soaking accounted for 320 gallons of water per 1000 pounds of potatoes with a BOD of 2020 ppm and suspended solids of 4068 ppm.

In this second study Porges (2) conducts a survey of several potato chip plants, where the general process flow is seen in Figure 1. He concludes that the primary sources of wastes are from the peeler, trimming belt, slicer, and wash and rinse operations. The BOD, waste flow, and suspended solids were studied from four potato chip plants. The average water usage was 1990 gallons per 1000 pounds of potatoes, the BOD and suspended solids also per 1000 pounds ranged from 14.5 to 30.8 and 20.4 to 36.4 pounds. At the time of this article Porges states that 2700 million pounds of potatoes are chipped per year in the United States, and the water usuage is 20 million gallons per day. The size of the plants varied from 5000 to 30,000 pounds of raw potatoes processed per day. Removal of peelings and solid wastes can reduce BOD by 50%, it was also noted that a counter flow system would also prove effective in reducing the volume of waste.

Cooley et al. (3) examines several potato processing plants

FIGURE 1: Potato Chip Processing Plant (from Porges (2)).



including potato flake, potato flour, potato chips, and potato starch, and reports on their waste flow characteristics. For this study the relevant data for potato chip plants will be utilized. He presents a flow sheet for a typical plant, Figure 2, it shows the primary unit operations with corresponding raw material and by-product flows. The study also indicates the effectiveness of primary treatment by clarifier, reductions of 51% and 88% for BOD and suspended solids, respectively. The study also showed that there is a significantly smaller waste flow from potato chip plants as compared to other forms of potato processing.

Talburt (4) states that in most plants the waste flows from the various unit operations are combined before treatment or discharge. The components of the waste are: dirt, raw pieces, raw pulp, cooked pulp, and dissolved solids. The dirt results from the initial washing and is easily removed in a grit trap or in the primary clarifier where other settleable solids are removed. The raw pieces being firm are effectively removed by screening. Raw pulp is produced during abrasion peeling and trimming, it can be removed by means of fine screens. The cooked pulp is not produced in potato chip manufacture, but is of importance in other potato processing plants as it can only be removed by clarification. The dissolved solids must be eliminated from the waste by a secondary biological treatment process. The author suggests that one method of reducing the waste water volume is water re-use. For example, the water from cooking, blanching, cooling, and surge tanks can be used for initial washing and fluming.

Sproul et al. (5) state that the majority of BOD is created in the peeling process, contributing an average BOD and suspended solids of 1450 mg/l and 1740 mg/l, respectively. This article also investigates current industry treatment methods. The first being screening, it has been reported that 35% removal of suspended solids can be achieved by vibrating 10 mesh screens, with corresponding BOD removal of 27%. Primary sedimentation is the most common treatment with removals of BOD ranging from 50% to 70% and suspended solids removal of up to 80%.

Lash (6) notes that the BOD from a single potato processing plant is often equivalent to the wastes from 250,000 people. He describes a primary treatment system developed by Eimco Processing Machinery Division of Envirotech Corporation, which has recently been coupled with a secondary treatment facility. The primary process includes screening to remove coarse solids followed by primary clarification to remove fine solids, the filtered underflow is dried for cattle feed. It has been found that the primary clarifier removes 50% of the inlet BOD and 95% of the suspended solids. The article also gives data for the secondary treatment utilizing an activated sludge process followed by a secondary clarifier and tertiary treatment by means of a granular media filter containing anthracite coal and filter sand. Total reductions of BOD and suspended solids from complete process are 99% and 99.5%, respectively.

Grames and Kueneman (7) look at the solutions that have been found to the pollution problem that faced the Snake River in 1961 due to potato processing wastes. They report on studies done to determine optimum methods for screening, sedimentation, and sludge dewatering. They found that a 6 mesh screen was the most effective size combining solids removal and moisture reduction, without associated plugging. Laboratory studies showed that under static conditions settling was able to remove 90% of the suspended solids, the authors found that with proper design a continuous flow clarifier could also attain this level of removal. The optimum method for sludge dewatering was found to be vacuum filtration, the dried sludge was fed to cattle as a supplementary energy source, proving to be nutritionally equivalent to barley. The system under operational conditions removed 62.2% of the COD and 93.5% of the suspended solids.

Atkins and Sproul (8) studied the feasibility of biological treatment for a potato processing plant using a caustic peeling process. It was indicated that previous studies had shown that 95% of the BOD could be removed by activated sludge treatment, and high rate trickling filtration removed 88% of the BOD. The present study characterized the waste from a typical potato processing plant in Maine and also investigated the possibility of using a completely mixed activated sludge system to treat the wastes. It was concluded that even at the high pH, about 11, a BOD reduction of 95% could be expected.

There is a noticeable lack of literature on the feasibility of anaerobic treatment of potato processing wastes, Hindin and Dunstan (9) stand out with the lone paper dealing with this subject. They investigated the feasibility of treating potato processing waste water with domestic sewage in a conventional municipal digester. They found that mixtures of up to 50% potato chip wastes can be treated successfully when mixed with sewage after gradual acclimation. They found that the digester became 'stressed' at loadings of 75% potato wastes due to nutritional deficiencies, although there was no evidence inhibitory substances.

Anaerobic digestion for food processing plant wastes was investigated by van den Berg (10). He also looks at recent world changes that have lead to increased interest in the anaerobic process. The study determined the rate of methane production from fermentation of bean blanching, pear peeling and potato peeling wastes. It was found that due to lack of settling potato wastes were difficult to treat, as the solids and hydraulic retention times were approximately equivalent. The level for optimum methane production was indicated by a COD:N:P ratio of about 300:5:1. This study indicated that 0.4 cubic meters of methane was produced for each kilogram of volatile solids destroyed, for potato wastes this was approximately equivalent to 1 m^3 methane per m^3 digester volume per day.

The article on trickling filters at McCain's (11) notes that there is a considerable annual variation in the potato waste water due to increased trimming required for stored potatoes. This article gives a description of the treatment process which is utilized at this plant. The waste handling involves a 10 mesh vibrating screen followed by a 175,000 gallon clarifier with a two hour liquid retention time. The clarified liquid is then passed through two trickling filters containing plastic medium where 80% of the residual BOD is removed (46-50% removed in primary treatment). This is followed by a second clarifier and subsequent discharge to the river.

Stephenson and Guo (12) review the waste characteristics from the potato processing industry as well as current waste treatment methods. They attempt to separate the unit operations and quantify the wastes from each. They report that the peeling operation contributes 50-91% of the plant effluent BOD. A summary of efficiency of removal in primary clarification is also given and several biological secondary treatments are also covered. These include: activated sludge, trickling filters, aerated lagoons, and rotating biological contactors.

A classic paper by McCarty (13) gives an excellent overview of the anaerobic process. It is presented in four parts the first dealing with the microbiological and biochemical aspects of anaerobic fermentation. This covers the two steps involved in methane production, namely the acid forming phase and the methane forming step. The second part deals with optimum environmental conditions for methane production, and methods to maintain the digester at these optimum levels. The third part looks at inhibitory substances, which reduce or stop microbial activity, and the levels at which these become toxic. The final part is concerned with actual process design for use in treatment of industrial wastes.

There has been much research done recently on the anaerobic process, particularly for the treatment of animal wastes to produce methane. Several of the major source papers are discussed below as a means of general overview of the field. The basic design parameters are similar for animal wastes and food processing wastes, although there are significant differences. Animal waste is similar to municipal sewage which has been treated anaerobically for many years, while food processing wastes tend to have a much greater volume for equivalent waste load.

Jewell et al. (14) have produced a detailed investigation of the feasibility of generating methane as a fuel substitute from bovine wastes on farms. In addition the paper summarizes the process design parameters, the alternative system designs, and methods of gas handling and utilization. The paper also presents the economic aspects of energy generation, which have been noticeably lacking in the literature.

The Ecotope Group (15) reported on the design and first year of operation of a 50,000 gallon digester for dairy wastes. Their objective was to demonstrate the feasibility of a full scale digestion system. The system was operated with only minor problems, solutions to some of these are given in the report. Examples of two ideas which could be incorporated in future designs are the sloping of gas pipes equiped with traps to eliminate freezing problems and the avoidance of municipal sewage digestion technology due to the high costs. They concluded that a 250-300 cow dairy could compete with present natural gas prices, although conversion to electric power was not economically suitable.

Shadduck and Moore (16) present an annotated bibliography of articles dealing with anaerobic digestion of animal wastes to produce methane. The bibliography covers the years 1946 to June 1975. This provides a good starter for an information search into anaerobic digestion.

Several other authors examine alternative designs for anaerobic digesters. Morris et al. (17) investigate the relative costs of various systems including completely mixed digesters, both mesophilic and thermophilic, partially mixed, batch load, plug flow, and typical municipal digesters. The cost of energy produced was not found to be competetive for small units, although possibly feasible for larger units or with credit for pollution abatement. Lawrence (18) describes several anaerobic treatment systems including anaerobic activated sludge, anaerobic filter, and conventional digester, both high rate and standard rate and compares their relative merits. He makes a significant point in that although the anaerobic lagoon is presently the most common form of anaerobic treatment it is not hydraulically or biologically efficient, and any gas produced is lost.

Two authors present papers dealing with the anaerobic process for treating industrial effluents. Cillie et al. (19) review the basic parameters affecting optimum anaerobic digestion, as have been documented in the literature on municipal sludge digesters, as well as the advantages of the process. They found that the anaerobic process has seen limited use in industrial waste treatment generally limited to slaughter-house and wine distillery wastes. They discribe a full scale treatment plant for wine distillery effluent utilizing a modified 144,000 gallon "Dorr-Oliver Clarigester". From this study they determined that anaerobic digestion is more economical than aerobic processes for wastes containing more than 4000 mg/l COD. Kirsch and Sykes (20) discuss several anaerobic processes, optimum conditions for the anaerobic bacteria, and mechanisms of the anaerobic process. The authors conclude that high rate digesters require a minimum of three days detention time while the anaerobic contact process requires a hydraulic detention time of only 6-12 hours but requires subsequent settling and return of the active biological material. The high flow rate in the contact process makes it impossible to maintain the digester at 35° C by utilizing only the digester gas. The anaerobic filter is a contact process that doesn't require solids recycling and due to long solids retention time is effective at reduced temperatures, $20-25^{\circ}$ C, the hydraulic detention time is 12-72 hours.

The anaerobic filter is a process for treating dilute but high strength wastes, this makes it very applicable to food processing wastes. The initial study of the anaerobic filter by McCarty(21) contains a review of the basics involved in anaerobic fermentation contained in his earlier work. The anaerobic filter was tested on a small scale utilizing methanol,acetate, and propionate as waste feed. The results showed that 70-80% of the waste was stabilized by conversion to methane, this was at a temperature of 25° C. The author states that the advantage of the filter over other anaerobic contact processes is that with soluble wastes there is difficulty in settling out the biological materials and many of the active organisms are lost with the effluent. A feature of the anaerobic filter which is superior to its aerobic counterpart the trickling filter is the low production of biomass. In the anaerobic system the organic material is mainly converted to methane with very little going to the production of new cells. For this reason there is practically no build-up of sludge which must be removed or treated further. It was estimated that the solids retention time was on the order of 100 days.

Young and McCarty (22) present a second paper on the anaerobic filter, a study utilizing a synthetic waste on a laboratory scale. Advantages of the anaerobic filter are listed by the authors, they are: 1) ideally suited for treatment of soluble wastes, 2) no effluent or solids recycle is necessary as biological solids are retained in the filter, 3) high concentrations of active solids allow treatment at nominal temperatures, 4) very small quantities of sludge are produced eliminating the need for an extensive sludge disposal system. The authors believe that the anaerobic filter could prove to be a system by which dilute wastes may be treated with low initial cost and low maintenance.

Plummer et al. (23) investigated the treatment of carbohydrate waste by an anaerobic filter in the laboratory. They found reductions of BOD of 94%,72%, 43%, and 41% corresponding to loading rates of 101, 237, 438, and 638 pounds of COD per 1000 cubic feet of filter volume per day. They suggest that the effluent should be clarified prior to discharge in a watercourse.

Lovan and Foree (24) attempted to treat brewery press liquor waste by anaerobic filter in the laboratory. They found that the process was suitable for this high strength waste (BOD 3100-14,000 mg/l). The volume of their filter was 33.4 liters and they recorded an average gas production of 20 liters per day, at about 65% methane. They also note that the gas has an objectionable odor due to the presence of sulfides, probably as H_2S, this can be effectively removed by scrubbing.

El-Shafie and Bloodgood (25) conducted a laboratory study utilizing six filters in series digesting a synthetic waste (Metrecal). They measured gas production and COD reduction as well as pH in each of the six filters. Their study indicates that the microbial activity decreases exponentially with detention time.

Taylor and Burm (26) report on experiences during operation of a full scale anaerobic filter treating wheat starch wastes. The filters were rock filled tanks 30 feet in diameter and 20 feet high. The methane produced was not utilized it was piped to a flare and burned but the estimated volume was 30,000 cubic feet per day. The filter required large additions of $NaHCO_3$ to maintain pH and alkalinity control. They found the efficiency of treatment was about 60% based on organic matter removal, there was no reduction in efficiency following a one month shut down. The cost of the system was approximately $110,000.

Jennett and Dennis (27) conducted a laboratory study using a setup similar to Young's, to analyse the feasibility of anaerobic filter treatment of pharmaceutical wastes. The authors record a COD removal of 93-97% at loadings of 13-220 pounds COD per 1000 cubic feet of filter volume per day, this was at retention times ranging from 12 to 48 hours.

Arora et al. (28) conducted a study using the anaerobic filter for treatment of vegetable tanning effluent. They maintained a three day hydraulic retention time and varied the organic loading rates from 0.192 to 3.264 kilograms per cubic meter of filter volume per day. They operated two filters, filter I was loaded with raw waste while filter II had phosphate added to the raw waste. The reduction of BOD ranged from about 60% for the very high loading rates to about 95% for medium loading rates, with slightly higher values obtained in filter II.

Dewalle and Chian (29) experimented with an anaerobic filter utilizing recirculation and plastic media, "Surpac". They observed removals of organic matter in excess of 95%. The waste water used for the experiment was leachate for a sanitary landfill with a COD of 54,000 mg/l and a pH of 5.4. The experiment showed that the anaerobic filter with recirculation can treat acidic wastes without buffering.

Potato Chip Plant Wastes

The wastes from the potato chip industry have been well documented in the literature, but the quantities and strengths vary depending on a variety of practices within the plant. Factor affecting the quality of plant effluent are: season, screening, and the type of potato. It has been noted that plants operating with stored potatoes had higher levels of organic matter in their waste. This is due to the poorer quality of stored potatoes which requires increased trimming, and the presence of sprouts causes excessive peeling losses (2,3,12). In most of the plants peeler wastes are screened to remove the larger pieces from the waste stream, the effluent from these plants has reduced BOD and suspended solids. The variability of potatoes also contributes to differences in the waste loads. It has been observed that varieties with low solids content or smooth skins result in less BOD in the effluent than do varieties with rough thick skins (2). This variability can be seen in Table 1, where the literature values for potato chip plant effluent have been tabulated.

The wastes from the potato chip plant consist of dirt, raw pieces, raw pulp, and dissolved solids. The majority of the wastes are produced in the peeling operation, Stephenson (12) reports that this accounts for 50-91% of the BOD in the effluent. The variation in this figure is due to varied peeling methods and waste treatments. Although the majority of the waste is produced during the peeling operation a large portion of it can be efficiently removed simply by screening. The washing of the slices prior to frying produces

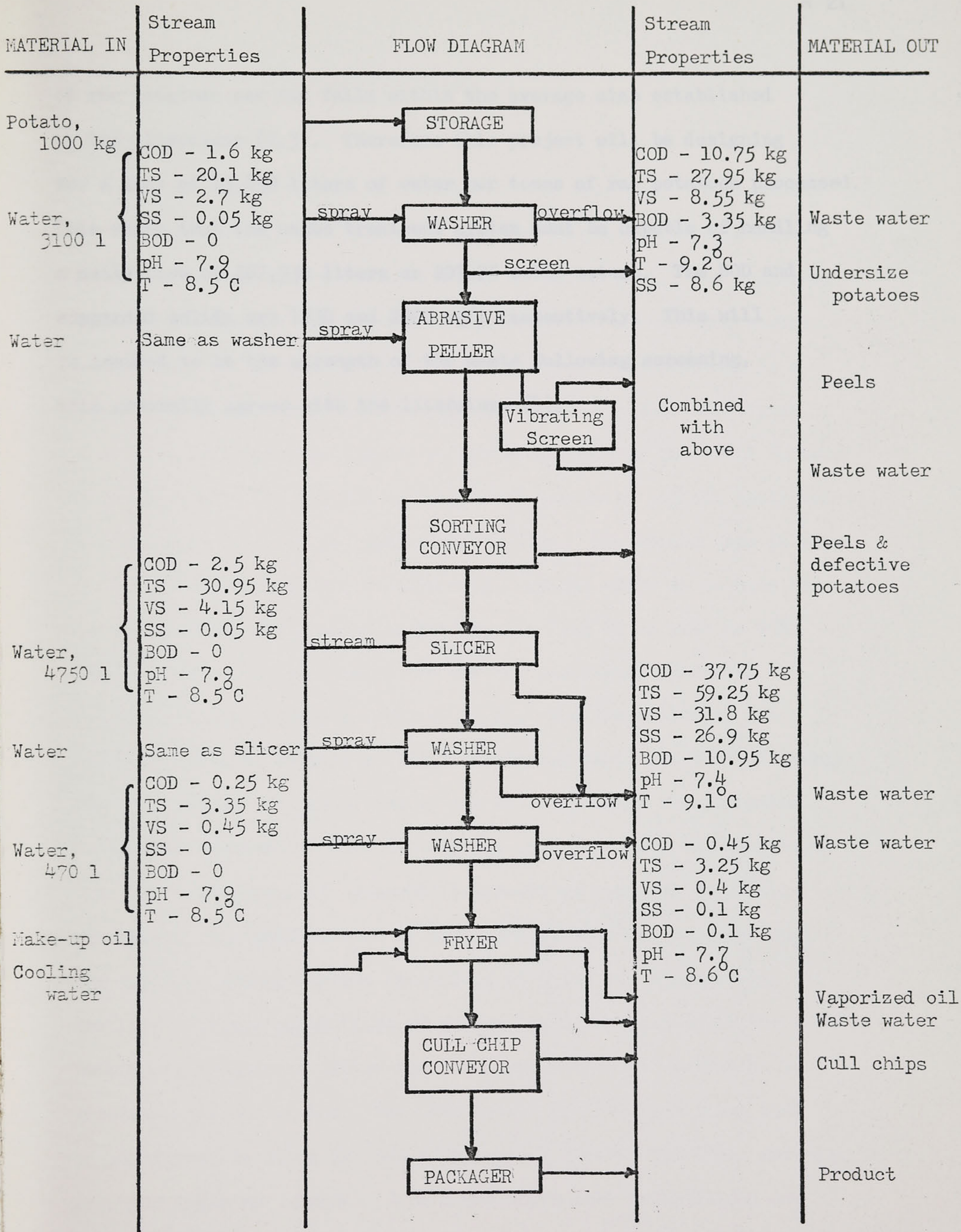
Table 1; Potato Chip Plant Effluent

WATER USAGE (l/t potato)	BOD (mg/l)	SUSPENDED SOLIDS (mg/l)	COD (mg/l)	pH	REFERENCE
20700	730	820	-	-	2
16860	1560	2140	-	-	2
16690	1850	2190	-	-	2
12100	1200	1700	-	-	2
8345	1700	860	3650	6.75	3
8345	3500	7170	9400	7.4	3
9430	1750	3580	4700	7.4	12
16690	880	-	-	-	12
14270	1660	1870	-	-	12
16770	-	-	6000	-	12
8430	3000	3000	-	-	12
17690	1450	1740	-	-	12
13860	1750	2500	5940	7.2	AVERAGE

the waste that is most difficult to treat, the dissolved starch. It contributes less to the BOD but can be removed only by some form of secondary treatment. The dirt is usually composed of inorganic solid material which is often removed separately to prevent damage to pumps and valves. Cooley (3) gives a flow diagram for a typical potato chip plant, it is reproduced in a modified form in Figure 2.

For the purposes of this project the average values from Table 1 will be used for the design waste characteristics and an average size plant will be considered. A potato chip plant using 15 tonnes

Figure 2: Process Flow Chart (adapted from Cooley(3))



of raw potatoes per day falls within the average size established in the literature (2,3). Therefore this project will be designing for a flow of 13,850 liters of water per tonne of raw potatoes processed. This means that the waste treatment system must be capable of handling a daily flow of 207,750 liters or 207.75 cubic meters. The BOD and suspended solids are 1750 and 2500 mg/l respectively. This will be assumed to be the strength of the waste following screening, this generally agrees with the literature (4).

Anaerobic Processes

Background

The anaerobic process has been used for many years in treatment of municipal sewage, and prior to that the products of its natural occurance in lake sediments were known as 'marsh gas'. The organisms responsible for the organic matter conversion to methane are strict anaerobes. The process by which organic matter is decomposed is a complex biological one, believed to occur in two steps. The first step is accomplished by a group of bacteria known as the 'acid formers' which breakdown the various organic constituents to organic fatty acids, in this step there is no waste stabilization. The second step involves the 'methane formers' which convert the organic acids to methane and carbon dioxide, while reducing the organic load by as much as 95%. The anaerobic process reduces the BOD and associated pollution potential while producing a usuable fuel. The conversion of the organic solids to methane yeilds a relatively small quantity of energy for this reason the production of new cells is small when compared to aerobic treatment. This fact is the source of both the advantage and the disadvantage of anaerobic treatment as compared to aerobic treatment. The small amount of cell production eliminates the need for frequent sludge wasting associated with the aerobic process, but the lack of large populations of active organisms means that the process is inherently slower and more susceptible to variations in environmental conditions. For this reason optimum conditions must be maintained to allow for the most rapid breakdown possible, reducing required digester volumes. Conditions which must be optimized are temperature, alkalinity, pH, and nutrient balance. The optimum temperature range depends on the specific bacteria involved but two ranges of high activity have been found. The mesophilic range from 30° to 38° C is generally the most economical, but if the waste is warm, operation in the thermophilic range, 49° to 57° C, may prove to be more efficient. The importance of alkalinity is based on the ability of the system to maintain pH in the 6.6 - 7.6 range, therefore buffering capacity of between 2500 and 5000 mg/l as $CaCO_3$ has been recomended by McCarty (13). The nutrient balance especially the C:N ratio has been observed to influence the quantity and quality of gas produced. The recomended ratio is 30:1 for optimum production although this is not as important as other parameters. The absence of toxic or inhibitory substances is also a prerequisite for adequate treatment. Several substances which exhibit inhibitory effects and their critical levels are given in Table 2. Heavy metals also have been shown to have detrimental effects on the anaerobic organisms.

Table 2: Toxic Substances (concentrations in mg/l)

SUBSTANCE	INHIBITORY	TOXIC
Sodium (Na^{+})	3500 - 5500	8000
Potassium (K^{+})	2500 - 4500	12000
Magnesium (Mg^{++})	1000 - 1500	3000
Calcium (Ca^{++})	2500 - 4500	8000
Ammonia	1500 - 3000	3000 +

The gas produced during the anaerobic fermentation is composed predominantly of methane and carbon dioxide with traces of hydrogen sulfide, hydrogen, and water vapor. Methane in its pure form is an odorless, colorless gas which is lighter than air and explosive in concentrations of 5 - 14% in air. The digester gas is approximately 60% methane and has a heating value of 22.58 kJ/l (600 Btu/cu ft), which makes it a rather poor quality fuel.

There are several anaerobic processes, varying in technical and economic feasibility, which are currently available for treatment of potato processing waste waters. The systems can be divided into two general types, those using a large container for digestion and those using a form of biological contact. The first type have as their main component a large tank where the waste is stabilized. Operated generally by displacement with raw wastes displacing an equivalent volume of treated waste. The second type have been developed for use with dilute wastes. Raw waste is pumped through a tank containing active biological material, the organic matter and organisms are mixed in suspention where stabilization occurs. With this system it is necessary to settle out the solids and bacteria for return to the digestion tank to prevent loss of the active organisms. The major tank digester and contact system designs are considered below with respect to their ability to treat potato chip plant wastes.

Tank Digesters

The conventional digester consists of a tank with a fixed or floating cover to maintain an oxygen free environment. The waste

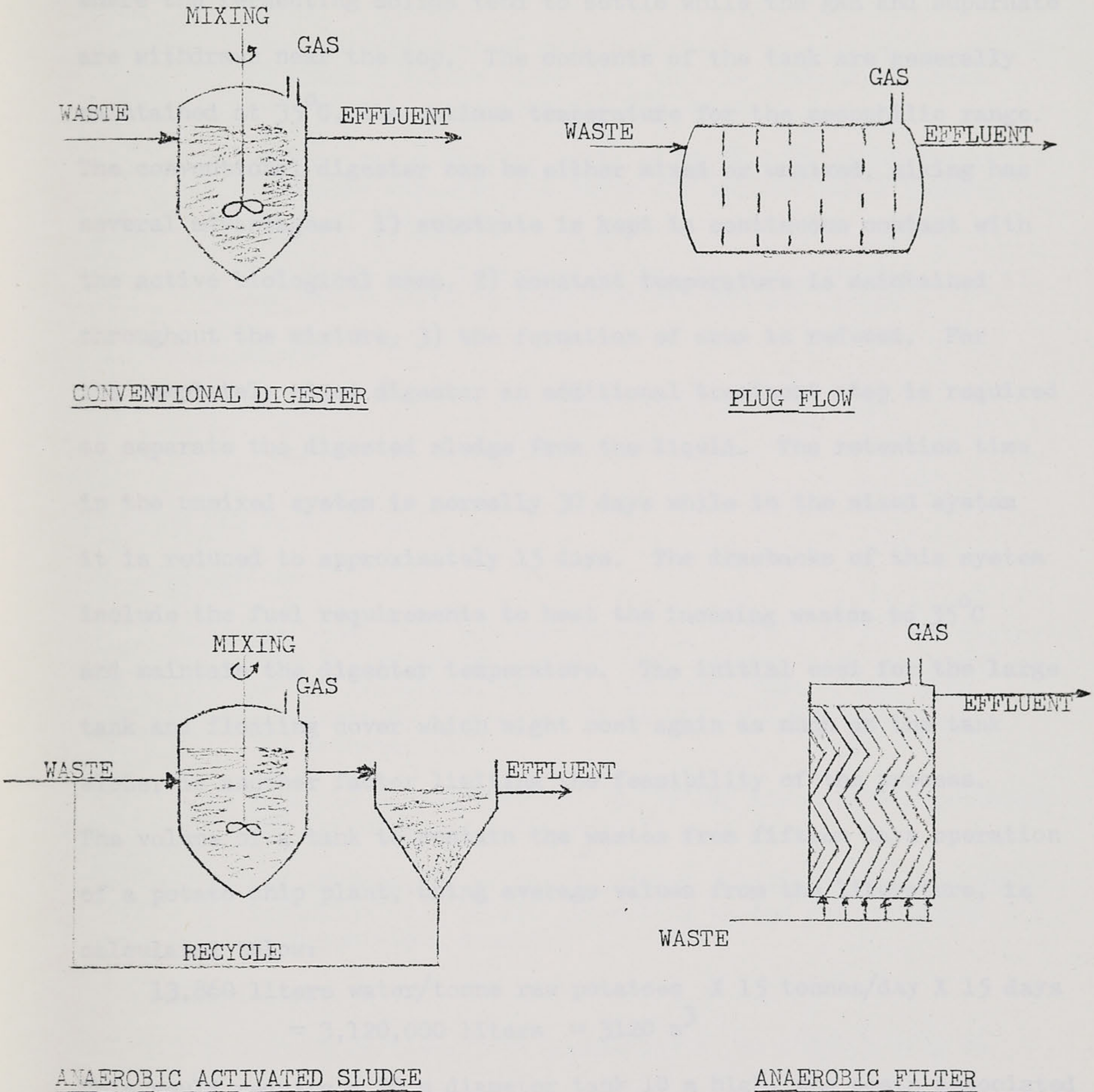


Figure 3: Various Anaerobic Processes

with an optimum solids concentration of 10% is pumped into a tank where the fermenting solids tend to settle while the gas and supernate are withdrawn near the top. The contents of the tank are generally maintained at 35°C, the optimum temperature for the mesophilic range. The conventional digester can be either mixed or unmixed, mixing has several advantages: 1) substrate is kept in continuous contact with the active biological mass, 2) constant temperature is maintained throughout the mixture, 3) the formation of scum is reduced. For the completely mixed digester an additional treatment step is required to separate the digested sludge from the liquid. The retention time in the unmixed system is normally 30 days while in the mixed system it is reduced to approximately 15 days. The drawbacks of this system include the fuel requirements to heat the incoming wastes to 35°C and maintain the digester temperature. The initial cost for the large tank and floating cover which might cost again as much as the tank alone, is another factor limiting the feasibility of the process. The volume of a tank to contain the wastes from fifteen days operation of a potato chip plant, using average values from the literature, is calculated below:

13,860 liters water/tonne raw potatoes X 15 tonnes/day X 15 days

$= 3,120,000$ liters $= 3120\ m^3$

This would require a 20 m diameter tank 10 m high, the costs associated with a tank of this size would require substantial production of energy to balance the cost. An estimated energy balance is given below, just considering the energy required to heat the waste stream from 9°C to 35°C, and the energy produced in digester gas.

Heating Requirement

Assumptions:

1. The specific heat of potato waste is equivalent to that of water (4.1818 kJ/kg-^oK), this is reasonable since the waste is approximately 95% water.

2. Methane has a heating value of 37.64 kJ/l (1000 Btu/ft^3) therefore digester gas being 60% methane has a heating value of 22.58 kJ/l.

3. The plant uses 15 tonnes of raw potatoes per day, the water usage is approximately 208,000 liters.

Calculations:

$Q = C_p \dot{m}(T_2 - T_1)$ $\qquad$ $Q = 4.1818 \text{ X } 208{,}000 \ (35 - 9)$

$= 22{,}615{,}174$ kJ/day

Digester Gas Production

Assumptions:

1. Gas production has been found to be 13.3 ft^3/lb VS destroyed (830.3 l/kg VS destroyed), this assumes that one pound of COD stabilized yields 5.62 cubic feet of CH_4 with a conversion factor for VS to COD is 1.42, and gas is 60% methane. (17)

2. Volatile solids (VS) are 68 lbs/ton raw potatoes processed (28 kg/tonne raw potatoes) (3).

3. 90% of volatile solids destroyed, Hindin(9) found a 95% reduction when potato processing wastes were combined 3:1 with municipal sewage.

Calculations:

$V = 28$ kg VS/tonne X 15 tonnes/day X .90 X 830.3 l/kg VS

$= 313{,}853$ l gas/day

$Q_{gas} = 313{,}853$ l/day X 22.58 kJ/l

$= 7{,}086{,}800$ kJ/day

Net Energy Balance

$Q_{net} = Q_{gas} - Q_{heating}$

$= 7{,}086{,}800 - 22{,}615{,}174 = - 15{,}528{,}373$ kJ/day

Cost Analysis

Assumptions:

1. Natural gas is used as an alternate fuel at a cost of \$.07/cu m..

2. Heating value of natural gas is approximately 37.64 kJ/l.

Calculations:

$$V = 15{,}528{,}373 \text{ kJ/day} \times 0.02657 \text{ l/kJ} \times .001 \text{ m}^3\text{/l} = 412.55 \text{ m}^3\text{/day}$$

$$\text{Annual Cost} = 412.55 \text{ m}^3\text{/day} \times \$.07/\text{m}^3 \times 260 \text{ work days/year} = \$7510.$$

These calculations only consider the fuel required to heat the influent, the heat lost through the tank walls would be an additional heating requirement. Since the cost is already above a reasonable level calculations will not be made to determine this added quantity but due to the extensive surface area of the tank these losses would be high. It can be concluded that the conventional digester is simply not suited for treatment of this high volume waste.

Although also having the high operating costs the plug flow digester (14,30) deserves mention as a means of reducing the initial capital costs. The plug flow digester consists of a long horizontal tank, with raw waste being added at one end and treated effluent removed at the other. It requires little mixing and operates by displacement with larger solids moving more slowly and thus having a longer detention period. The hydraulic retention time is about twenty days requiring a large volume reactor, but the need for an expensive cover has been eliminated. Large diameter concrete and galvanized culverts have been used as the fermenter. These systems have been successfully operated at 25°C but due to large surface areas the heating requirements are too great for the system to be energy self-sufficient for dilute wastes, such as the ones from the potato chip industry.

Anaerobic Contact Processes

The initial development in this area was a process similar to the activated sludge process used in aerobic treatment, it is often called the anaerobic activated sludge process. This system was developed to treat dilute wastes, primarily from the meat packing industry. It allows for large volumes of waste to be passed through the system while providing a long solids retention time by utilizing a recycle loop. The contact tank is basically a completely mixed conventional digester which is followed by a separator to remove the sluge containing solids and active microbes. The sludge is returned to the tank while the liquid supernate is removed from the surface. This system Provides a BOD removal of 90 - 95%, with a hydraulic detention time of 6 - 12 hours. A problem with the process was the difficulty in settling the solids and microbes due to buoyancy caused by gas being produced within the mass. This has been solved by vacuum degasification prior to settling. Although this system has greatly reduced capital costs since the volume of the digester is only one eighth of that required for the conventional digester, the heating requirement is still a problem. This is associated with dilute wastes, insufficient organic matter to produce enough gas to heat the large volumes. Laboratory experiments have shown that gas production and efficiency are significantly reduced at 25°C as compared to 35°C (13,20).

Another form of the contact process is the upflow contact process. The waste enters at the bottom of a tank flowing upward through a layer of active microbes where digestion occurs. The layer acts as a filter for the suspended solids which are trapped and slowly decomposed. This process has been used for treatment of wine distillery wastes in a full-scale plant (19,20). The effluent to be treated had a BOD of 12,000 - 18,000 mg/l and a flow rate of 20,000 gal/day. The system was operated as 33°C with a hydraulic detention time of seven days. The system was equiped with a sludge recycle loop and produced enough gas to maintain the operating temperature. Although this system proved to be feasible for a high strength waste it again would not produce enough energy for treatment of potato chip plant wastes. The reason for this is that while the wine distillery waste has a large volume it also has a correspondingly high organic matter content, the potato chip plant waste has more than twice the daily flow with only one sixth of the organic load.

A further specialization of the anaerobic contact process is the anaerobic filter. It consists of a tank containing crushed stone (3.8 - 5 cm diameter) through which the waste is passed. The surfaces of the stone provide places for attachment of bacteria, the filter therefore allows contact of a large number of organisms with the waste. This allows the anaerobic filter to operate over a wider range of conditions since the number of organisms actually in contact with the waste is much greater than in other systems. The filter was developed to treat dilute wastes at ambient temperatures, it is thought to be able to be operated at temperatures as low as 20°C. This has not been demonstrated but excellent results have been obtained at 25°C (21,22,29). The anaerobic filter operates with an estimated solids retention time in excess of 100 days, but with hydraulic detention time of only 12 - 72 hours. This seems to be an ideal solution to the problem of anaerobic treatment of potato chip plant wastes. The system has proven stable under shock load conditions, the initial cost is competitive with other waste treatment designs, and it should require no additional input of energy, while possibly producing excess energy for plant use, all this while treating wastes to reduce pollution. Young (22) has shown with synthetic waste in the laboratory that a waste with a COD of 6000 mg/l with a hydraulic detention time of 36 and 18 hours has a COD reduction of 97.7 and 86.9% respectively. This is the COD level found in the potato chip plant wastes. A possible problem in using the anaerobic filter to treat potato wastes is plugging due to the presence of starch in the waste water. Although the filter has not been used for potato processing wastes it has been used to treat wastes from a wheat starch plant (26). This was a full-scale treatment plant and no problems associated with plugging were reported, although it was noted that the waste water contained large amounts of dissolved starch. Aerobic trickling filters, which are just inverted anaerobic filters, have been used at McCain's french fried plant (11), and there was no reported problem caused by plugging. From these two cases it can be assumed that plugging caused by starch will not be a problem although verification of this in the laboratory should be considered. An estimated energy balance is calculated on the following page using similar assumptions to those used for the calculations for the conventional digester.

Heating Requirement

Assumptions:

1. Filter maintained at an operating temperature of $20^{o}C$.
2. Hydraulic retention time of 36 hours.
3. 97% of volatile solids destroyed due to long solids retention time.

Calculations:

$Q = C_p\dot{m}(T_2 - T_1)$ $\quad$ $Q = 4.1818 \times 208{,}000\ (20 - 9)$

$= 9{,}567{,}958$ kJ/day

Filter Gas Production

Calculations:

$V = 28$ kg VS/tonne X 15 tonnes/day X 830.3 l/kg VS X .97

$= 338{,}264$ l gas/day

$Q_{gas} = 338{,}264$ l/day X 22.58 kJ/l = 7,638,000 kJ/day

Net Energy Balance

$Q_{net} = Q_{gas} - Q_{heating}$

$= 7{,}638{,}000 - 9{,}567{,}958 = -1{,}929{,}958$ kJ/day

Cost Analysis

Calculations:

$V_{natural\ gas} = 1{,}929{,}958$ kJ/day X .02657 l/kJ X .001 m^3/l

$= 51.27\ m^3$/day

Annual Cost = 51.27 m^3/day X \$.07/m^3 X 260 days/year

= \$935.

Initial calculations show that the anaerobic filter will also require additional energy input but not nearly as much as the conventional digester. The losses from the tank will be minimal since due to the reduced size of the tank it is hoped that it will be located within the plant as opposed to outside where environmental extremes influence the heating requirements. The filter appears to be close to borderline feasibility, for this reason and the fact that it is the most suitable process available a more detailed design will be attempted. It is hoped that certain changes in the detailed process will provide a feasible design.

Process Design

Although this project was predominately concerned with the secondary treatment of wastes from a potato chip plant, a brief system design is shown in Figure 4. This shows the unit operations involved in complete treatment of the plant wastes, not included are the air-borne wastes namely vaporized oil and water vapor. The wastes which require removal to make the effluent suitable for discharge are: dirt, raw potato pieces including peels and pulp, and the soluble starch. A system similar to the one in Figure 4 could be expected to remove 95 - 99% of the BOD depending on the retention time.

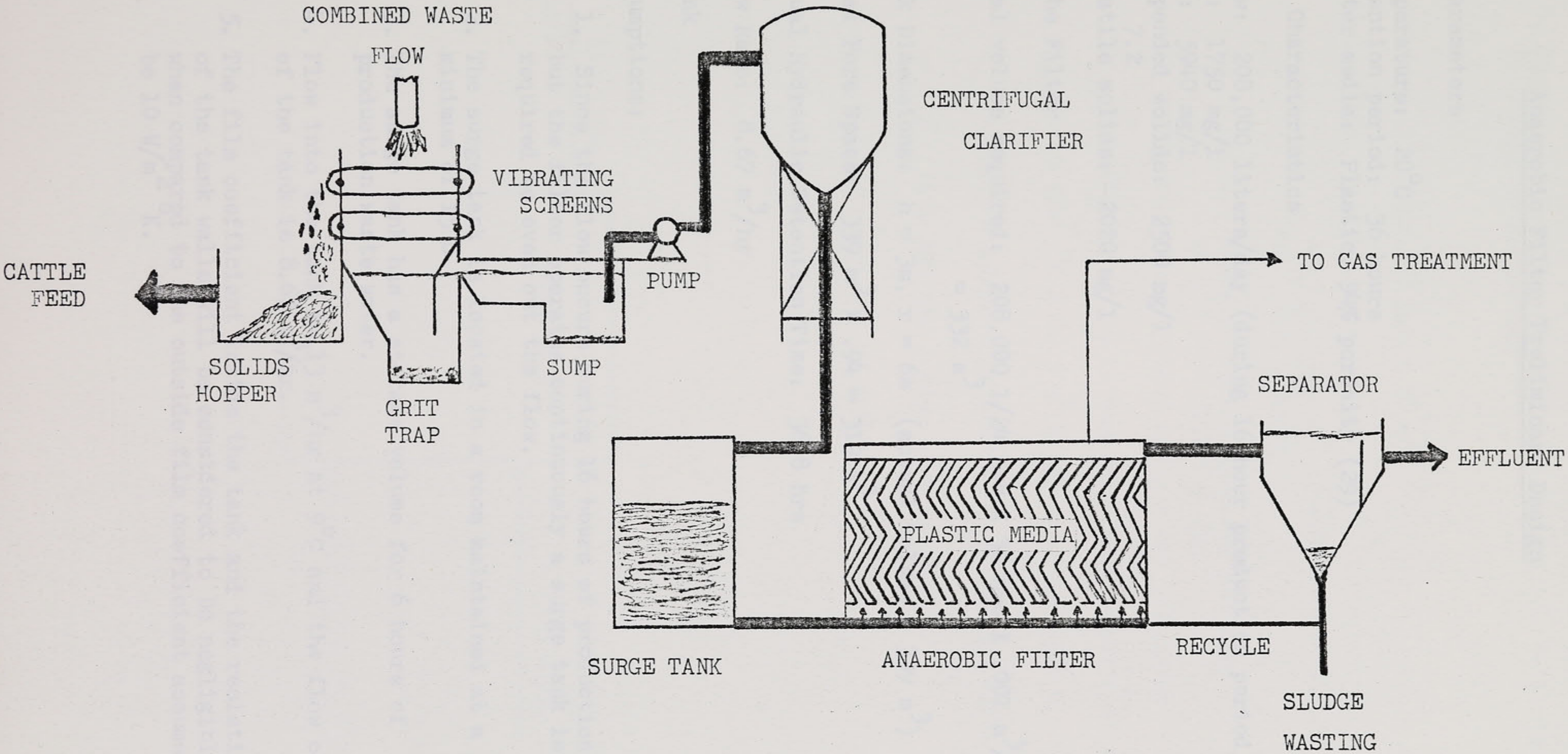


Figure 4: Potato Chip Plant Waste Treatment

Anaerobic Filter Preliminary Design

Design Parameters

Temperature: $20^{\circ}C$
Detention period: 36 hours
Filter media: Plastic, 94% porosity (29)

Influent Characteristics

Flow: 208,000 liters/day (during 16 hour production period)
BOD: 1750 mg/l
COD: 5940 mg/l
Suspended solids: 2500 mg/l
pH: 7.2
Volatile solids: 2020 mg/l

Sizing the Filter

Total volume required: 208,000 l/24 hrs X 36 hrs X .001 m^3/l X 1.06
$= 332\ m^3$

Tank Dimensions: h = 3m, r = 6m (actual volume = 339 m^3)

Total Pore Space: 339 m^3 X .94 = 319 m^3

Actual Hydraulic Detention Time: 36.8 hrs

Flow Rate: 8.67 m^3/hr

Surge Tank

Assumptions:

1. Since the flow occurs during 16 hours of production but the filter operates continuously a surge tank is required to even out the flow.

2. The surge tank is located in a room maintained at a minimum of $15^{\circ}C$.

3. The surge tank has a storage volume for 6 hours of production waste water.

4. Flow into the tank is 13 m^3/hr at $9^{\circ}C$ and the flow out of the tank is 8.67 m^3/hr.

5. The film coefficient inside the tank and the resistivity of the tank walls will be considered to be negligible when compared to the outside film coefficient assumed to be 10 $W/m^2\ {}^{\circ}K$.

6. Changes in kenetic and potential energy of the waste flow will be neglected.

Calculations:

Volume: $13\ m^3/hr \times 6\ hrs = 78\ m^3$

Dimensions: $h = 4\ m$, $r = 2.5\ m$

Heat Balance: $Q_{out} = Q_{in} + Q_{conv}$

$Q_{in} = \dot{m}h^*$ where h^* is the specific enthalpy at 9^oC $h^* = 37.828$ kJ/kg

$Q_{in} = 13,000\ kg/hr \times 37.828\ kJ/kg = 491,764\ kJ/hr$

$Q_{conv} = hA(T_2 - T_1)$ h is the film coefficient = $10\ W/m^2\ {}^oK$

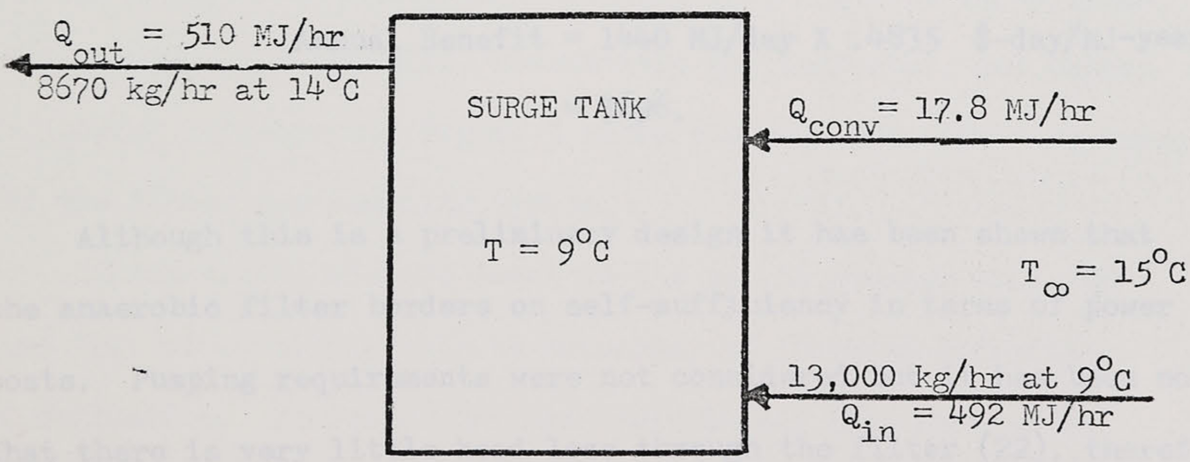
$Q_{conv} = 10\ W/m^2\ {}^oK \times 82.5\ m^2 \times (15 - 9)^oK = 4950\ W$

$Q_{out} = 491,764\ kJ/hr + 17,820\ kJ/hr = 509,584\ kJ/hr$

$h^* = Q_{out}/\dot{m} = 509,584 / 8670 = 58.78\ kJ/kg$

Temperature of Outflow: $14.0\ {}^oC$

Energy Balance:



Anaerobic Filter

Assumptions:

1. The walls and top of the filter are not insulated, the bottom is insulated and there is virtually no heat lost through the bottom.

2. The filter is located in a room maintained at a minimum temperature of $15^{o}C$.

Calculations:

Energy Balance:

1. Heating of influent.

$$Q = C_p \dot{m} \, (T_2 - T_1) = 4.1818 \times 8670 \times (20 - 14) = 217{,}537 \text{ kJ/hr}$$

$$Q = 5221 \text{ MJ/day}$$

2. Convective heat loss.

$$Q = h\,A\,(T_2 - T_1) = 10 \times 226.2 \times (20 - 15)$$

$$Q = 977.2 \text{ MJ/day}$$

3. Energy produced by filter (previously calculated).

$$Q = 7638 \text{ MJ/day}$$

4. Net energy production.

$$Q = 7638 - (5221 + 977.2) = 1440 \text{ MJ/day}$$

5. Value of the energy produced.

Annual Benefit = 1440 MJ/day X .4835 \$-day/MJ-year

= \$696.

Although this is a preliminary design it has been shown that the anaerobic filter borders on self-sufficiency in terms of power costs. Pumping requirements were not considered but it has been noted that there is very little head loss through the filter (22), therefore power required for pumping would be small. The anaerobic filter has been shown to be very effective for waste treatment, with organic matter removals approaching 99%. For these reasons it seems that the anaerobic filter is a suitable process for treating potato chip plant wastes and deserves further study.

Gas Handling and Safety

A design of an anaerobic treatment process would not be complete without a chapter on safe handling of the gas produced. The operation of an anaerobic system requires adequate safety equipment both due to possible pressure build-up and the explosive nature of the gas produced. Since the anaerobic filter has a fixed cover it is important to not only provide pressure relief but also vacuum relief, to prevent collapse of the top if gas production fails and negative pressure develops within the vessel. Also required are flame traps to prevent a spark from travling back into the filter and causing an explosion. The gas lines must be equipped with drip traps to remove the water which may condense in the lines. Indicators should be placed in the filter room, to warn of the presence of hydrogen sulfide, hydrogen, carbon dioxide, and methane. This requires three types of indicators H_2S ampoules, combustible gas indicator, and oxygen deficiency indicators. Figure 5 shows the required safety equipment for the filter gas handling system.

If the carbon dioxide level in the gas is greater than 30% some form of scrubbing will be necessary to increase efficiency of combustion. Traces of hydrogen sulfide may also have to be removed. The simplest method involves wet scrubbing, passing the gas through water. Additions of chlorine prior to scrubbing have been shown to increase the removals of both gases (31).

LEGEND

FT Flame Trap
VB Vacuum Break
PR Pressure Regulator
DT Drip Trap
M Gas Meter
ER Explosion Relief
Pi Pressure Indicator

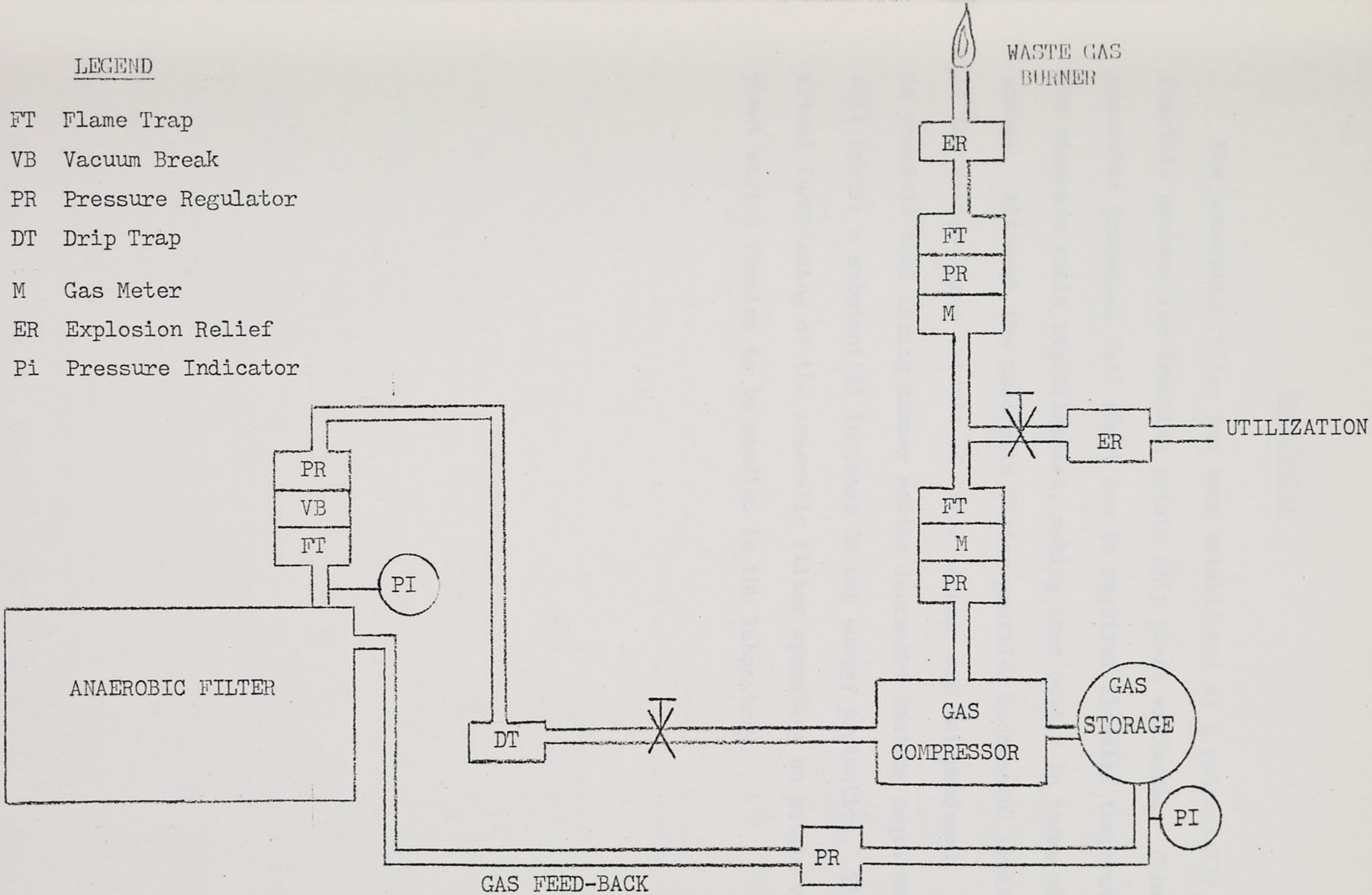


Figure 5: Gas Handling System

Conclusion

The anaerobic filter has been established as a potentially feasible process for treating potato chip plant effluents. Other anaerobic processes fall short due to required elevated temperatures for adequate waste stabilization, making them costly in terms of energy. Although the anaerobic filter provides successful treatment of the wastes large amounts of 'free' energy are not produced. It is possible that during summer months decreased heating requirements will enable a substantial increase in net energy production. The actual functioning of the anaerobic filter operating on potato chip plant wastes remains to be studied in the laboratory.

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APPENDIX B

NUTRIENT REQUIREMENTS

NUTRIENT REQUIREMENT

The purpose of this small experiment was to determine if nutrient additions had an effect on gas production. If so at what level was there the most increase in gas production.

The method used was to obtain 15 identical 125 ml flasks and 15 identical rubber stoppers. The nutrients and seed mixture were added to 100 ml of potato waste, which was then stoppered as tightly as possible.

The level of Nitrogen at .03 g NH_4NO_3 is equivalent to a C:N ratio of 25:1, based on a COD of 6000 mg/l and Organic Carbon = .375 COD (Shady 1973). The phosphorus addition of .0089 g $NH_4H_2PO_4$ corresponds to a C:P ratio of 125:1. Three levels of nitrogen and one level of phosphorus were used.

Due to the simplistic nature of this experiment the only real conclusion that could be drawn was that nutrient additions certainly do not have an adverse affect on gas production and seem to increase it significantly.

Results

Sample	Frequency of pop	Rank
nBP	8	1
nB	4	4
nS	5	2
nSP	4	5
NnBP	5	3
NnB	2	11
NnS	4	6
NnSP	2	12
NBP	2	13
NB	4	7
NS	4	8
NSP	3	10
Control 1	1	14
Control 2	2	9
Control 3	1	15

Key to Above:

N - .03 g NH_4NO_3

Nn - .02 g NH_4NO_3

n - .01 g NH_4NO_3

P - .0086 g $NH_4H_2PO_4$

B - Bacterial Seed Mixture as used to seed filter. (25 ml)

S - Sludge from lab sample maintained under anaerobic conditions for almost 12 months. (10 ml)

Control 1 - 100 ml Potato Waste, 25 ml distilled water.

Control 2 - 100 ml Potato Waste, 25 ml bacterial seed.

Control 3 - 100 ml Potato Waste, 10 ml sludge, 15 ml distilled water.