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INDUSTRIAL BIOGAS: A FEASIBILITY STUDY OF WASTE UTILIZATION FROM AGRO-INDUSTRY IN THAILAND

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EXECUTIVE SUMMARY

With the energy crisis and the deficit in foreign exchange, research and development on nonconventional energy technologies has been initiated in Thailand. Biogas, which is one of the well known technologies, has been demonstrated in most of the developing countries by utilizing animal dung as a biogas source for cooking, lighting, water pumping, etc. Most of these biogas plants are family sized plants. There are very few large-sized biogas plants that still use animal dung.

However, it is realized that some types of industrial wastewaters with high organic concentration can also be utilized for biogas production and be treated simultaneously. The National Energy Administration (NEA) initiated the Industrial Biogas Project with the purpose of trying to demonstrate the technique, as well as economic feasibility of biogas technology for industrial wastewaters. The laboratory scale test was carried out by Mahidol University under contract with the NEA. Five types of wastewaters, namely, tapioca waste, sodium monoglutamate waste, canning food waste, and dairy waste were selected for preliminary testing to find the most suitable one for gas production and gas composition.

In the preliminary test based on chemical oxygen demand (COD) and biochemical oxygen demand (BOD), it was found that sodium monoglutamate waste and tapioca waste are suitable for laboratory scale experiments. The anaerobic filter process was applied to sodium monoglutamate waste. The results of gas composition indicated that the biogas produced from sodium monoglutamate waste is not suitable. Moreover, the clogging of the system showed that the process is not practical.

The contact anaerobic process was applied to tapioca waste and it was found that gas production from tapioca waste is possible. However, in analysing the data obtained from Mahidol University, the author found that the gas production from tapioca waste is much lower than that stated by Mahidol University--20 cubic meters of gas produced per day, rather than 150 cubic meters of gas produced per day.

For the economic analysis, Mahidol University recommended that the minimum size of the digestion system was to be about 5,000 cubic meters with an investment return back period of 12 years. However, the investment cost is too high for tapioca factories in Thailand. With 50 cubic meters of digester, as was proposed for the demonstration plant, it was found that the return back period could not be obtained within 30 years, even with 8 percent interest without inflation. In addition, the production cost of biogas based on 30 years of equipment service life is still higher than that of fuel oil.

However, because of Thailand's interest in energy conservation, as well as the concern for treatment of industrial wastewaters, this plant should be constructed. Yet, in the future, the ones who invest for biogas construction systems are individuals who would be interested in a return of investment. Of course, the results of this experiment for consideration by individuals for this type of biogas production is not economically feasible. The cost of the minimum size of the digestion system to get a return back period is too

high and the return back period is too long. Thus, the demonstration of the biogas plant might fail even though the technology is feasible.

CONCLUSIONS

6.1 In the preliminary analysis and laboratory scale experiment, tapioca waste was found to be the most suitable waste for generating biogas in terms of quantity of gas produced and quality of methane gas composition.

6.2 The anaerobic filter process is not suitable for high concentrations of waste. The system is not able to resist the high organic loading.

6.3 The variation of temperature during the laboratory scale experiment was not controlled.

6.4 The gas production from the contact anaerobic process is about 3 times the volume of feeding waste with 75 percent of methane gas produced.

6.5 The gas production for 50 cubic meters of digester could not be more than 25 cubic meters of gas per day, rather than 150 cubic meters per day as reported by Mahidol University.

6.6 The minimum size of a contact anaerobic system is 2,500 cubic meters for a return back period. However, the size of digester for a 12 year return back period is 5,000 cubic meters of digester.

6.7 The comparison of production cost between fuel oil and biogas produced from 50 cubic meters of biogas plant calculated at various interest rates showed that biogas produced from tapioca waste is not competitive with fuel oil. In addition, it is not possible to have an investment return back period within 30 years.

6.8 Although these results indicate that the treatment of industrial wastewaters by the anaerobic system is not economically feasible at this time, the results indicate that the technique is possible.

6.9 This research adds to the knowledge of the NEA officials in their search for adequate treatment and utilization of Thailand's industrial wastewaters using the anaerobic process.

6.10 The production of industrial biogas from high organic load factory wastewaters by anaerobic systems is probably the most cost effective method for treatment and utilization of Thailand's industrial wastewaters.

RECOMMENDATIONS

7.1 The surrounding conditions for the experiment should be the same, so that the results are reliable and can be used to study the effect of the process.

7.2 The parameter which should be emphasized for this experiment is the control of various temperatures.

7.3 The anaerobic contact process system designed by Mahidol University consisted of a gas holder made of stainless steel which is very expensive. It might be advisable to use a compressor for collecting gas at certain levels of pressure and use a smaller gas holder as a pressure control.

7.4 The tapioca biogas demonstration plant should be constructed to explore technical feasibility of this type of biogas plant. It would be the prototype for a biogas treatment plant utilizing industrial wastewater in the future. This phenomenon might gear up individuals, institutes and other concerned agencies to find or seek new technologies concerning biogas and the treatment of industrial wastewaters at a feasible economic level.

7.5 NEA should continue to explore the use of high organic load factory wastewaters by importing cost effective anaerobic systems.

7.6 The pollution of the environment is of major concern to the Government of Thailand, therefore, the research in the treatment and utilization of industrial wastewaters should be continued until solutions to the problems are found.

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TERMS AND ABBREVIATIONS

BOD	=	5-days biochemical oxygen demand
BOD_L	=	Ultimate biochemical oxygen demand
Ca^+	=	Calcium
CN^-	=	Cyanide
COD	=	Chemical oxygen demand
HRT	=	Hydraulic retention time
Na^-	=	Sodium
$NaHCO_3^-$	=	Sodium bicarbonate
pH	=	Acidity and alkalinity
SO_4^-	=	Sulfate
SRT	=	Sludge retention time
STP	=	Standard temperature and pressure
NEA	=	National Energy Administration
RTG	=	Royal Thai Government
USAID	=	United States Agency for International Development

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Chapter 1

Introduction

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INTRODUCTION

As an oil-importing country, Thailand has been facing a serious and deteriorating energy situation over the past decade. The Royal Thai Government (RTG) through the National Energy Administration (NEA), has formulated a ten-year National Alternative Energy Development plan with the goal of reducing the energy share of imported oil from the present level of 75% to 45% by 1989. With this stated goal, efforts will be made to diversify the energy base through replacing oil with other alternative energy resources such as wind, solar energy and biomass--including biogas.

The biogas plan set a goal of 106 community-sized plants and 60,000 family-sized plants to be built in rural areas. In addition, the work plan for industrial energy consumption is being prepared. With this alternative means of renewable energy, a significant reduction in consumption of non-renewable energy such as oil, wood, charcoal, etc., can be expected.

With these facts in mind, the Renewable Nonconventional Energy Project was conceived by the Royal Thai Government and the U.S. Agency for International Development. Industrial Biogas: A Feasibility Study of Waste Utilization from Agro-Industry is one component of 14 separate components involved in the Project and implemented by the National Energy Administration under the Ministry of Science and Technology. The components in the project are:

- Industrial Biogas
- Biomass Gasification
- Charcoal Improvement
- Energy Master Plan Support
- Micro-Hydro Project
- National Energy Information Center
- Pyrolysis of Rice Husks
- Regional Energy Centers
- Solar Thermal Processes
- Solar/Wind Assessment
- Stove Improvement
- Village Survey
- Water Lifting Technology
- Village Woodlot

The Project is jointly funded by the United States Agency for International Development (USAID) and the Royal Thai Government with institutional support from the National Energy Administration, Ministry of Science, Technology and Energy. It is the responsibility of the National Energy Administration (NEA) to recommend to the Government of Thailand optimum policies, strategies and plans for development of an energy system in Thailand.

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A. HISTORICAL BACKGROUND

Biogas as another source of energy has been used in the rural areas of Thailand for a decade. Results of a survey conducted by NEA in 1978, showed that these were approximately 300 family-sized biogas plants in operation. Their acceptance has been met with mixed success. However, the NEA under a carefully planned program, is currently subsidizing 1,500-2,000 (US$ 65-87) baht for family-sized biogas plant construction and is demonstrating 4 community-sized biogas plants. The biogas produced is used for cooking, lighting and running internal combustion engines. Technical problems that occur during operation can be easily solved by the owners or promotional personnel and extension workers. Although the initial cost of construction is high relative to the income of most rural families even with one-third of the construction cost subsidized by the government, the financial saving is viable and the technology is expected to gain nation-wide acceptance within 5 years.

From the experience gained so far, it can be said that biogas technology is a proven technology. Community-sized biogas plants are therefore, technically feasible. Moreover, the concept of biogas can be extended and applied to industrial wastes with high-organic loadings. The methane gas produced could be utilized for steam production, heating and/or use in internal combustion engines. As the first step of introducing biogas technology to industries, the demonstration and evaluation of small of medium industrial scale production of biogas in terms of techno-economical feasibility was to be conducted. Dissemination of the results would follow if biogas plants proved economically feasible and technically reliable.

B. OBJECTIVES

The objectives of the study were:

1. To increase the knowledge of the officials involved in the biogas component concerning the characteristics of industrial wastewaters in Thailand, as well as the technical aspects of industrial biogas production.

2. To demonstrate and evaluate the techno-economic feasibility of small to medium industrial scale production of biogas.

3. And, if economically and technologically feasible, to disseminate the results to private enterprise and individuals who could promote or implement this technology.

C. SIGNIFICANCE

This study is the starting point to convert oil-based energy to biogas, of industrial scale quantity rather than household scale quantity. The gas produced from wastewater, which is usually treated with no return-of-

investment, can be utilized in the production process. This means that the reduction of oil based energy is possible for some types of industries by utilizing undisposed of materials. However, the capital investment for an industrial biogas plant is still questionable. This study concerns the feasibility of both the technical and economical aspects of industrial biogas technology. It is hoped that it will arouse industries to search for alternative ways to utilize their wastes by modifying the existing wastewater treatment plant with the promise of some return-of-investment cost.

D. SCOPE

This Project involved the study of the characteristics of selected wastewaters concerning gas production and gas composition by simulating a laboratory scale unit operation of an industrial biogas plant. The parameters for the laboratory scale test included:

1. Suitable chemical oxygen demand of selected wastewater for bacterial digestion

2. Suitable detention time for maximum gas production

3. Gas production and methane gas composition for desired size of digestion system

Then, the prototype(with the capacity to comply with the desired quantity of biogas produced)was to be designed with the purpose of demonstrating the techniques involved and the economical feasibility of converting industrial wastewaters into biogas.

E. ORGANIZATION OF THIS REPORT

This report will briefly discuss the literature concerning Anaerobic Digestion Theory in Chapter 2 and the original Project Design in Chapter 3. Chapter 4 will include Techniques and Procedures of actual research done and the Analysis of Results and Discussion will be covered in Chapter 5. Conclusions and Recommendations are listed in Chapters 6 and 7, respectively.

The reader will find the Plant Design Calculations, Cost Analysis and Project Budget Summary and Activities included in the Annexes.

Chapter 2

Anaerobic Digestion Theory

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ANAEROBIC DIGESTION THEORY

This chapter will discuss Anaerobic Digestion Theory. It includes a discussion on the microorganism mechanism involved in the digestion process, factors affecting anaerobic waste treatment, unit operation of the 3 types of anaerobic filter systems, and a brief discussion of biogas calorific value.

A. MICROORGANISM MECHANISM

Anaerobic digestion of organic matter is considered to be a procedure in which anaerobic and facultative microorganisms liquify,gasify, mineralize, and humify the organic solids to obtain energy and certain elements(such as carbon)for synthesis of their body protoplasm. In the liquification step, saprophytic bacteria attached to the sludge particles secrete extracellular enzymes which,in turn,liquify and hydrolyze the complex molecules of the solids into simpler components. These, in turn, are used by the microbial cells for energy and cell production. The volatile acids (mainly acetic, propionic, and butyric) produced in the liquification-hydrolysis step, are then acted upon by organisms which secrete intracellular enzymes to aid the acid breakdown and formation of methane and carbondioxide as shown in Fig. 2.1.

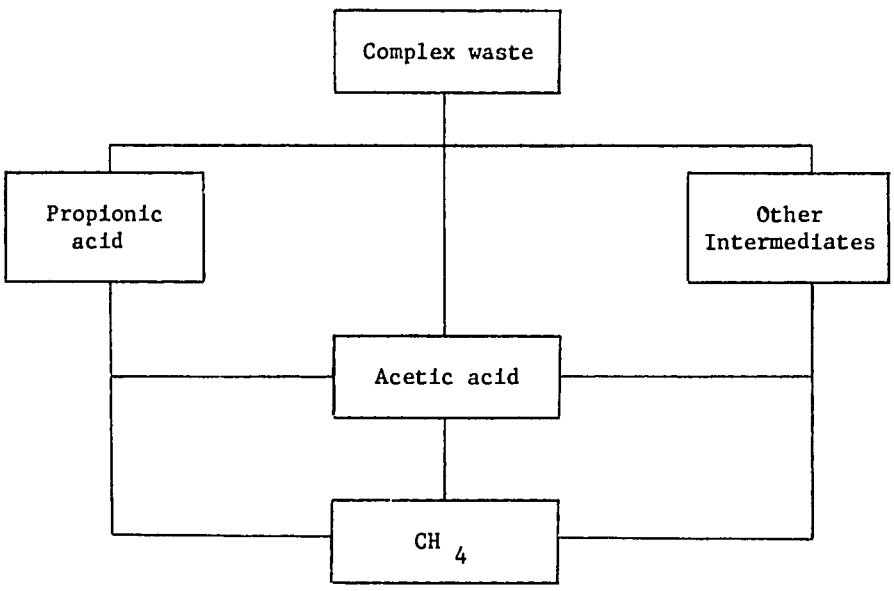

Fig. 2.1 Pathways in methane fermentation of complex wastes

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The quantity of methane evolved from the stabilization of a given waste can be estimated quite closely from the oxygen equivalent of methane gas.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2\,H_2O$$

Each 16 grams of methane produced and lost to the atmosphere corresponds to the removal of 64 grams of oxygen equivalent from the waste stream. Converting to gas volume, 5.62 cubic feet of methane produced (STP) corresponds to the stabilization of one pound of ultimate biochemical oxygen demand or chemical oxygen demand.

B. FACTORS AFFECTING ANAEROBIC WASTE TREATMENT

There are many factors affecting bacterial digestion. These factors are bacteria, food, contact, time and temperature, pH, and toxic materials.

Bacteria

The methane forming bacteria are the most important in anaerobic digestion. They are much slower growing and more sensitive to environmental changes than the acid formers. The unusual properties of the methane forming bacteria are due to several reasons. Firstly, they are strictly anaerobic, and therefore, thrive in the complete absence of molecular oxygen. Secondly, they are slow growing compared with most other organisms. The time required for a methane forming bacteria to regenerate depends on temperature. At 35° C some species can regenerate in about 4 days, while other species require as long as ten days. Decreasing the temperature will result in longer regeneration periods. Thirdly, the methane formers are pH sensitive; their range of pH tolerance is about 6.5 to 7.6. Former research indicated that the optimum pH for the growth of the methane organisms is 7.0. Finally, the methane formers are at a further disadvantage because of their low number. The reason for their low population is related to the principal end-product which they produce, methane gas. Because methane gas is a high energy end-product, subject to further combustion to carbondioxide and water, the energy is lost to the bacteria and is not available for growth.

Food

The organic matter in wastewater is food for bacteria. In anaerobic digestion, the food often consists of very complex organic materials. The operator has to control of the organic charcteristics of the waste. However, two factors related to the food can be controlled, the concentration of solids or viscosity and the rate of feeding.

Contact

The contact of bacteria and food can take place in the digester in several ways, but the most affective is by thorough mixing. Mixing can be done by mechanical mixer or by natural means. Mechanical mixing can be achieved by using an agitator and natural mixing can be done by gas produced in the digester. The gas tends to form in the sludge and is released occasionally. However, if the rate of producing gas is too slow, artificial mixing is needed. Artificial mixing can be used to increase the bacteria to food contact ratio, as well as to provide a uniform environment throughout the digester contents.

Time and Temperature

The time required for sludge digestion or stabilization depends on the temperature of digestion. The rate of bacterial growth and food stabilization increase and decrease with temperature within certain limits. The maximum rate of fermentation has been reported at 26°C - 37°C and about 50°C - 55°C. But these maxima are not generally accepted.

The temperature effects were reported by Fair and Moore in 1937, (Visuthirangsi - Urai, 1983) who showed the time for digestion at various temperatures (Table 2.1 and Fig. 2.2).

Table 2.1 Time required for digestion at various temperatures

Temp.	Digestion Time (days)
15	67.8
20	46.6
25	37.5
30	33.3
35	23.7
40	22.7
45	14.4
50	8.9
60	18.6

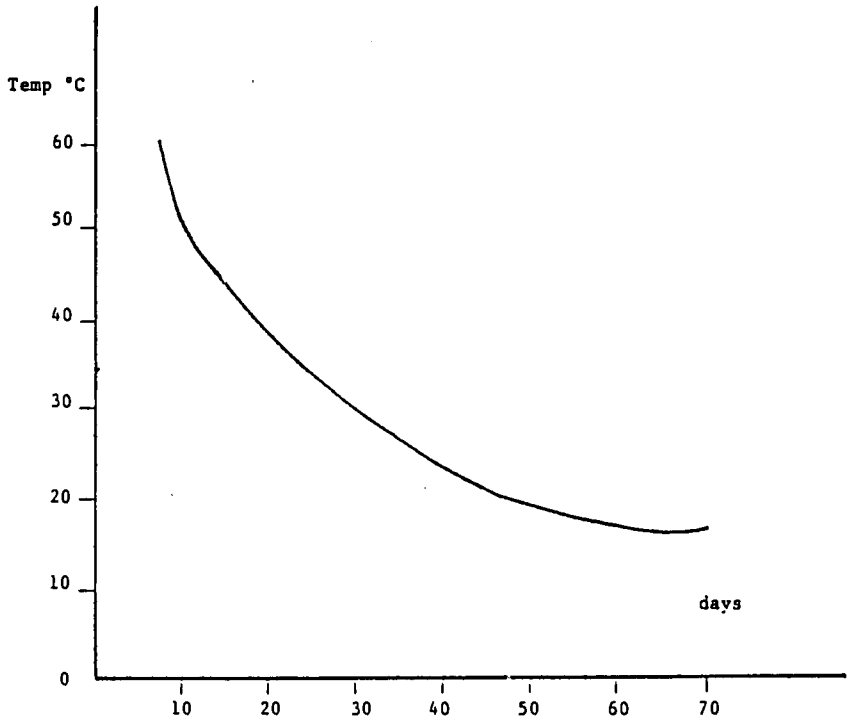

Fig. 2.2 Graph showing the time required for digestion at various temperatures

That an increase in temperature reduces the time required for digestion has been accepted as fact. There is no reason to question this now. However, later research has shown that an important relationship regarding time and temperature was not considered in earlier studies. It has been established that digesters can be operated at liquid retention time as low as two days, or lower, *as long as the solid retention time is longer than critical time.* This critical solid retention time (SRT_C) is the time below which digestion becomes inhibited as a result of wash-out of the slowest growing, essential methane formers. For instance, the generation rate of the slowest growing methane formers is about 10 days at 35°C thus, if the digester is operated at a solid retention time less than 10 days,the system will be inhibited. Below SRT of about 10 days, methane production drops off rapidly until complete failure of the process occurs due to the wash-out of all methane forming bacteria. Complete failure occurs at an SRT of about three or four days. The effect of reducing the solid retention time in a digester operated at 35°C is shown in Fig. 2.3.

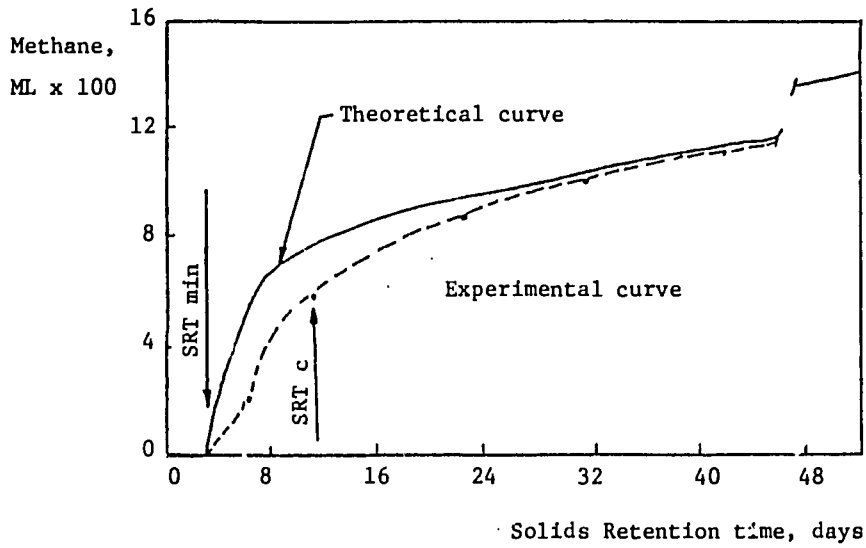

Fig. 2.3 Theoretical and experimental methane production for various solid retention times

Numerous earlier reports stated that the minimum retention time for anaerobic digestion at 35°C was from 5 to 10 days. Also the reports stated that operation above a 10 day retention period produces satisfactory results and stable operation. Below a 10 day retention period, volatile acid determination would be required to monitor the effect of higher loading. It is concluded that digesters could be operated at liquid retention time lower than 10 days if the solid retention time is longer than 10 days.

pH

The pH of the contents of a digester depends on the relationship among the volatile acids, alkalinity, and percentage of carbondioxide in the digester gas (Table 2.2).

Table 2.2 Effect of Changes in Various Factors of pH

Factor	Change	Effect of pH
Volatile acids	Increase	Decrease
	Decrease	Increase
Bicarbonate Alkalinity	Increase	Increase
	Decrease	Decrease
Percent CO_2	Increase	Decrease
Digester Gas	Decrease	Increase

Many reports have indicated that the optimum pH for the digestion of wastewater sludge is in the range of 6.8 to 7.2 with the limit of the range for operation without significant inhibition being 6.5 to 7.6.

Toxic Materials

Toxic materials in digesters have inhibitory effects on digestion if their concentrations become too high. They include the alkalinity and alkaline cation(such as sodium, potassium, calcium and magnesium),heavy metals (such as copper, nickel and zinc),ammonia and ammonium ion, sulfide, and some organic compounds.

C. UNIT OPERATION

Perry L. McCarty has described 3 types of anaerobic systems: the conventional process, the anaerobic activated sludge process and the anaerobic filter process. Fig 2.4 illustrates the three processes. The conventional process is the flow-through type with no special attempt made to keep a high mass of microorganisms in the system. There is a mechanical mixer centrally located and the sludge is not recirculated into the digester. In the 1950's, several systems were designed with a large anaerobic biological mass maintained in the digester for more efficient and rapid treatment. For example, in the anaerobic activated sludge process as shown in Fig. 2.4, parts of biomass in the sedimentation tank were circulated to the digester and completely mixed. Using this system the solid retention time (SRT),which is the ratio of suspended solids in the system to suspended solids removed per day, increases. As SRT decreases, the concentration of waste in the effluent increases and efficiency decreases. There is the minimum SRT below which the treatment process fails. This point is reached when the microorganisms are removed from the system faster than they can reproduce themselves.

Another process shown in Fig. 2.4 is the anaerobic filter process. The principle involves using rock or other types of materials as a media for bacterial attachment. The organic matter passing through the void of the media will be digested by microorganisms. This process is perhaps applicable for diluting soluble wastes. D.L. Wise (1980) performed the experiment on whey permeability with the production of a 9×10^6 pounds per year from a dairy farm cooperative. It was found that whey permeability is largely lactose, a disaccharide sugar , glucose and galactose, and is among the most readily fermented materials known. The amount of lactose solids and mineral salts produced from whey permeability of 9×10^6 pounds are 7.3×10^6 and 1.7×10^6 pounds per year. The methane production from this waste stream alone is approximately 46×10^9 BTU/year. However, the capacity of the digester was not mentioned. Wise also reported the experimental results conducted by Morris, Jewell, and Casler (1975) in tabular form as shown in Table 2.3.

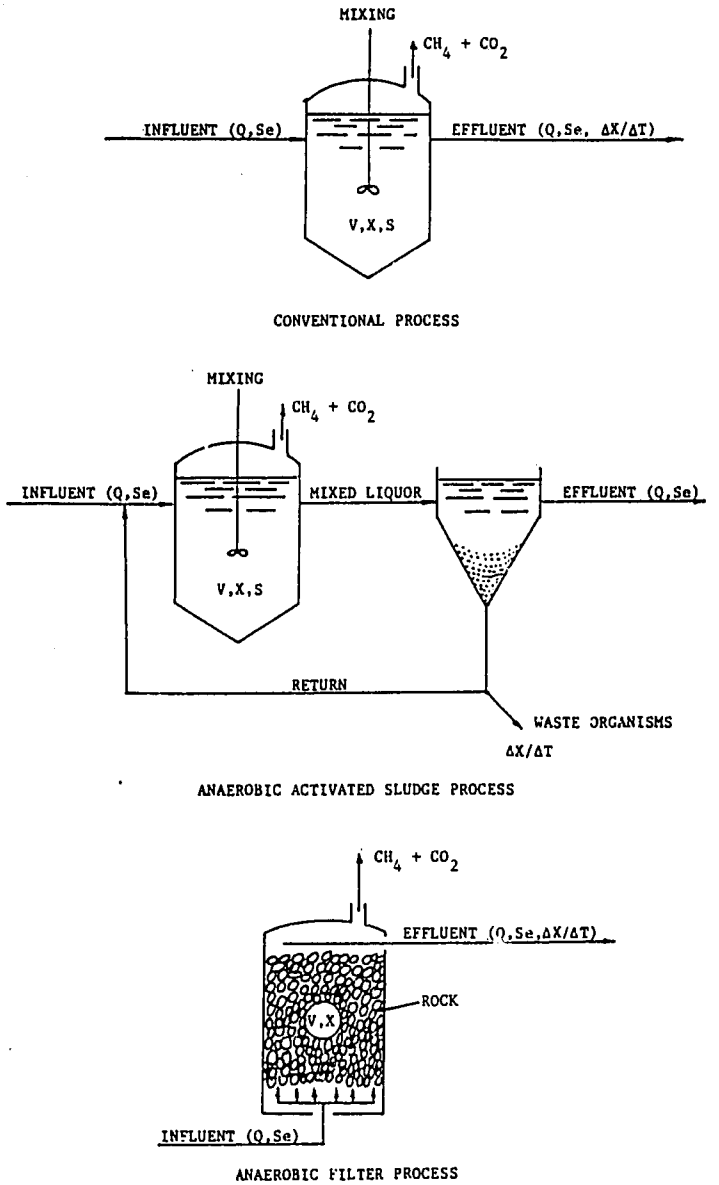

Figure 2.4 Basic anaerobic process designs

Table 2.3 Estimated Manure Production and Potential Gas Generation (Basis: 1,000 pound live weight)

	Beef Cattle	Dairy Cattle	Swine	Poultry
Manure Produced, lb/day	58.0	85.0	50.0	59.0
Total solid, lb/day	7.4	10.6	7.2	17.4
Volatile solids, lb/day	5.9	8.7	5.9	12.9
Digestive efficiency percent of VS	50.0	35.0	55.0	65.0
Gas potential ft^3/day lb/animal	39.5	40.9	43.1	110.9

M. Tanticharoen (1981) initiated an experiment on biogas production from pineapple waste by using an anaerobic filter reactor made of acrylics with a tubular shape and 200 liters working capacity. As the initial pH value of the pineapple waste is low, it was treated with chemicals to neutralize pH value. Another alternative way to neutralize the pH is mixing the waste with the effluent. The results indicated that the pineapple waste mixed with the effluent 1:1 (wt./vol.) without preincubation at room temperature is better in terms of gas production. However , the results were not consistant since uniform mixing of the materials in the digester is not possible. S. Chavadej (1980) inititated a project using an anaerobic filter with a bamboo ring as the media for treating piggery waste. The bamboo ring was 2.3 centimeters in diameter and 2.0 centimeters in length. The COD chemical concentration was about 30,000 mg/l. It was found that the acceptable loading was 7.299 kilograms COD/m^3/day. The detention time was about 4.23 days with gas production of 0.212 m^3/kg., COD added. The COD destroyed was about 77%. There was no doubt that the anaerobic filter process could be applied for low COD concentration and soluble wastes. However, clogging was still a problem.

D. BIOGAS CALORIFIC VALUE

Visuthirungsriurai (1983) reported that biogas, even as a 50:50 methane/carbondioxide mixture, is combustible. The argument concerning the removal of carbondioxide for improving the calorific value and flame temperature disclosed that there seems relatively little incentive for purification. Table 2.4 shows the calorific value of biogas compared with the other types of fuel.

Table 2.4 Comparison of the calorific value of biogas and other types of fuel (Visuthirungsriurai, 1983)

Item	Calorific value J/cm^3
Coal gas	16.7 - 18.5
Biogas*	20.0 - 26.0
Pure methane	33.2 - 39.6
Natural gas	38.9 - 81.4
Propane	81.4 - 96.2
Butane	107.3 -125.8

Chapter 3

Project Design

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PROJECT DESIGN

This chapter will briefly discuss the planning that was behind the implementation of the Project as it was originally conceived by the National Energy Administration (NEA). Much of this material was taken directly from the original work plan that was submitted to USAID for funding. A budget summary of money requested and money spent on the Project and an activity schedule of projected time to be spent and actual time spent on the Project, are included in Annex III.

A. PROJECT APPROACH

As stated in the first chapter, the original objectives of this project were:

1. to provide training for Thai government officials in biogas technology,

2. to demonstrate and evaluate the techno-economic feasibility of small to medium industrial scale production of biogas,

3. and, if economically and technologically feasible, to disseminate the results to private enterprise and individuals who could implement this technology.

In order to meet these objectives, this Project was designed to explore the techniques involved in the production of biogas from selected wastewaters through laboratory experimental analysis and to design an industrial biogas treatment prototype that could be technologically and economically feasible.

The wastewaters to be selected were the ones in which treatment facilities were needed for pollution control. These criteria were originally conceived to demonstrate and prove that pollution could be controlled and biogas produced simultaneously. The biogas produced could be utilized by the factories instead of imported fuel, and thus provide the return of investment needed to make biogas technology feasible and attractive to industry.

B. TRAINING

The purpose of training is to strengthen the experience of NEA officials in biogas systems planning, operation, maintenance and those organizational aspects necessary for managing activities related to biogas technology.

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C. TECHNO-ECONOMIC FEASIBILITY

Essentially, three steps are involved in determining and evaluating the techno-economic feasibility of small to medium industrial scale production of biogas. These are the selection of appropriate wastewaters to be used in biogas production, the design of the industrial biogas treatment prototype, and the cost estimation and economic feasibility of constructing the prototype for industrial use.

Selection of Industrial Wastes

The goal in the anaerobic digestion of wastewater is to reduce the strength of the wastewater which will not create nuisances or hazards in the environment. This goal can be achieved by production of methane gas. To effectively control the digestion process of the specific industrial wastewater, the factors which govern the biological production of methane must first be understood.

The requirements and indices of anaerobic digestion have been outlined and discussed in Chapter 2. With these factors in mind, the question is: what kind of wastewater should be investigated to generate methane gas? Because there are so many kinds of industrial wastes in Thailand which create the pollution problem, only those which would produce a sufficient amount of high quality methane gas were to selected.

The chemical, biological and physical parameters listed below were to analysed following the Standard Methods for the Examination of Water and Wastewater (1975).

chemical oxygen demand
biological oxygen demand
acidity and alkalinity
suspended solids
total solid
total nitrogen
sodium
potassium
calcium
sulfate
cyanide

In addition, one of the selected industrial wastewaters was tested in the anaerobic filter process using bamboo rings as media to study technical problems such as the clogging of the system by bacterial growth on the media and chemical oxygen demand reduction and gas production. If this system is technically sound, other types of suitable wastewater will also be tested using the anaerobic filter process. If this system is not technically sound, the anaerobic contact process will be used as an operational unit for testing other types of selected wastewater.

In-plant investigation on the processing, the energy demand and the quantity and characteristics of the waste to be utilized were conducted to establish optimum design parameters and operating conditions. With these data the biogas plant and other facilities were designed.

Anaerobic Digestion Designs

A laboratory scale anaerobic filter was to be designed, constructed and used in the experimental study. Laboratory studies have shown that a wide range of organic matter is biodegradable by anaerobic fermentation. However, one single design is unlikely to cope adequately with all possible substrates because of the different rates of fermentation that are involved. The more soluble and easily degradable the substrate, the more simple the design and operation. Low density of waste material may form an impenetrable scum on the surface of the digester, increasing the difficulty of digester design.

Strong wastewater with solid contents of about 10 percent is likely to be quite paste-like, and the design to handle concentrated slurries efficiently would minimize digester volume.

The most frequently used measure of the biodegradable proportion of the feed is the volatile solids content which is a close approximation to the potential substrate. However, with a mixed substrate any overall measure is likely to be over-simplified. The conditions in the digestor itself will depend on both the concentration and mean retention time of the feed. In the case of a continuous digester of volume V, feed rate Q (m^3/day), and feed concentration C (kg VS/m^3) loading rate can be defined as:

$$LR = \frac{CQ}{V} \text{ kg VS/m}^3 \text{ digester volume/day}$$

$$= \frac{C}{C}$$

in which = hydraulic retention time.

This is often used as a basis for comparing different digesters. If one digester operates at a higher loading rate than another, then either it can process a greater quantity of substrate in the same retention time or handle the same quantity in a smaller volume.

Batch versus continuous

Digesters can be broadly divided into either "batch" or "continuous flow." In a batch operation, the raw materials are charged into the digestion vessel and the fermentation process can be considered in three stages.

In stage I, the bacterial population begins to establish itself, and following a lag, gas evolution begins. The gas is usually hydrogen sulfide. In stage II (2-4 weeks) the gas production rate increases, passes through a maximum and then begins to decrease. In stage III the gas production rate falls off gradually. The total time for virtually complete digestion is about 60-90 days.

In a continuous process, the substrate is fed to the digester continuously, so that, once the operation is established, the rates of gas production, and input and output are steady with time. It is often claimed that continuous digestion is more efficient than batch operations.

Mixing

Mixing reduces stratification and improves contact between the organisms and the substrates; it has also been suggested that mixing increases the rate of decomposition by releasing small trapped gas bubbles from the microbial cell matrix, but there is no direct evidence for this assumption. In the absence of mixing the materials stratify.

The degree of mixing varies considerably in both batch and continuous processes. The simplest situation is pure mixing. Some digesters are mixed by a centrally located stirrer.

Stirring breaks the scum layer which, if undisturbed, can lead to inefficient digestion and can even provide a seal on the digester. Unstirred digesters can be extremely inefficient. With long retention times and low loading rates the digester will perform adequately.

Temperature and its control

The digester temperature is a key variable in determining the rate of fermentation. In rough terms, fermentation starts at about 10°C, and increases rapidly with increasing temperature up to the normally recommended operating temperatures of 30°-35°C. At high temperatures (50°-60°C) thermophilic bacteria take over and the rates are substantially higher.

Anaerobic digesters are extremely sensitive to fluctuations in temperature. Failures can result from temperature changes of only a few degrees centigrade caused by the addition of cold water feed, a rapid drop in external temperature, etc. Thermal stability control is therefore, very important.

The process only generates a little heat which is insufficient to keep the temperature at 35°C if the input and surrounding temperatures are more than 5°C. Therefore, some the designs have heating mechanisms.

It is generally accepted that operation under thermophilic conditions is better than mesophilic conditions for soluble industrial wastes. Clearly, there is a trade off between capital savings and increased efficiency at higher temperatures and the costs of maintaining the temperature.

Loading rates

The loading rates of digesters vary widely. The advantages of operating at a high concentration are to minimize digester volumes at the same overall retention time, cut down heat load on the system, and reduce water requirements and water disposal problems.

Alternative gas handling and uses

The gas stream leaving the digester contains methane, carbondioxide, negligible traces of other gases, e.g., H_2S, H_2, and is saturated with water. This gas cools along the pipeline and water condenses out in the line or in the gas holder. It is extremely important, then, that the pipes be at a slight horizontal angle and that provision be made for draining off the condensate.

In conclusion, all of the above foregoing factors were considered when designing the prototype. The specifications of the biogas plant and other facilities were then be submitted to NEA for bidding.

Cost Estimation and Economic Feasibility

The cost of biogas plant construction and other facilities were estimated. In addition, a feasibility study was conducted to determine the payback period, as well as the production cost of biogas as compared with fuel oil.

D. IMPLEMENTATION AND MONITORING

After the laboratory scale analysis, the data of the most suitable wastewater in terms of quantity of gas produced and composition of methane gas,were to be used for designing the pilot scale of a 50 cubic meter digestion system, including pumping and control board housing.

The technical monitoring,in view of workability and efficiency of the plant was carried out by NEA with the advice of the contracting agency, in this case, Mahidol University. With this approach, NEA officials were be trained locally in plant operation. Simultaneously, the overall financial and economic feasibility of the biogas production would be analyzed by Mahidol University.

E. DISSEMINATION

Finally,the dissemination of information concerning the techno-economic feasibility of the Project would be distributed to industry, government agencies, and interested parties by distribution of printed materials and video tapes.

Chapter 4

Techniques and Procedures

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TECHNIQUES AND PROCEDURES

This chapter will discuss the techniques and procedures that took place during the industrial biogas project. The analysis of wastewater using monoglutamate waste, the anaerobic contact process using tapioca waste, the engineering design of the biogas demonstration plant and economic analysis, as well as Project cost activity and training will be discussed.

A. PRELIMINARY ANALYSIS OF WASTEWATER CHARACTERISTICS

Five types of wastewaters namely tapioca waste, noodle waste, sodium monoglutamate waste, food canning waste and packing milk waste were selected for preliminary analysis based on their chemical and biological characteristics. These wastewaters were selected for laboratory scale tests because they contain a high concentration of chemical oxygen demand. They were stored at room temperature in plastic containers.

Chemical oxygen demand, biological oxygen demand, acidity and alkalinity, suspended solids, total solids, total nitrogen, sodium, potassium, calcium, sulfate, and cyanide were analysed for these selected wastewaters to study the inhibition parameters of the biogas production process. The results are shown in Table 4.1

Table 4.1 Preliminary analysis of industrial wastewaters

Industrial waste	BOD (mg/l)	COD (mg/l)
Tapioca	15,000	25,000
Noodle	200	250
Sodium monoglutamate	37,000	150,000
Food canning	600	850
Packing milk	200	280

From the analysis of these 5 wastewaters, it was found that the sodium monoglutamate waste and tapioca waste have the potential to be used for biogas production due to their high concentrations of BOD and COD. These two wastes were then selected for more detailed characteristics analysis. The results are shown in Table 4.2.

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Table 4.2 Characteristics of Sodium Monoglutamate and Tapioca Wastewaters

Characteristics	Sodium Monoglutamate waste	Tapioca waste
Temperature	29 - 31°C	29 - 31°C
pH	2 - 3	3.5 - 5.0
Suspended solids	40 mg/l	30 - 70 mg/l
Total solids	300 - 400 mg/l	-
Total nitrogen	20,000 - 30,000 mg/l	80 - 150 mg/l
Na^-	2,600	63.5 mg/l
K^+	1,537	370 mg/l
Ca^+	3,620	70 mg/l
SO_4^-	2,300	125 mg/l
CN^-	-	40 mg/l

B. ANAEROBIC FILTER PROCESS, SODIUM MONOGLUTAMATE WASTE

Experimental Apparatus

A laboratory scale anaerobic filter was constructed and used in the experimental study. Fig. 4.1 shows the flow diagram of the process. The filter, made of polyvinyl chloride (PVC), was a 1.50 m. high round column having a diameter of 0.20 m. The top and bottom were covered with a PVC sheet. A gas vent pipe was set to the top for collecting gas samples. The volume of the filter was 47 liters.

The design was to give uniform distribution of the influent over the cross-section of the column. The column was baffled at every 30 cm. interval with a 4 cm. wide rubber sheet attached horizontally to the column walls. The baffles were to eliminate short-circuiting of the influent through large void spaces formed between the media and the column wall. Three thousand pieces of media, 0.5-1 inch diameter and 1 inch long of bamboo rings, were filled in the filter. The surface area of the media was 190 m^2/m^3. The filter filled with the media was found to have a liquid volume of 45 liters.

The outlet pipe was about 20 cm. depth from the top of the column and the effluent overflowed to the settlement tube while the gas passed the vent pipe through the gas meter. The settlement tube could prevent the gas lost with the effluent.

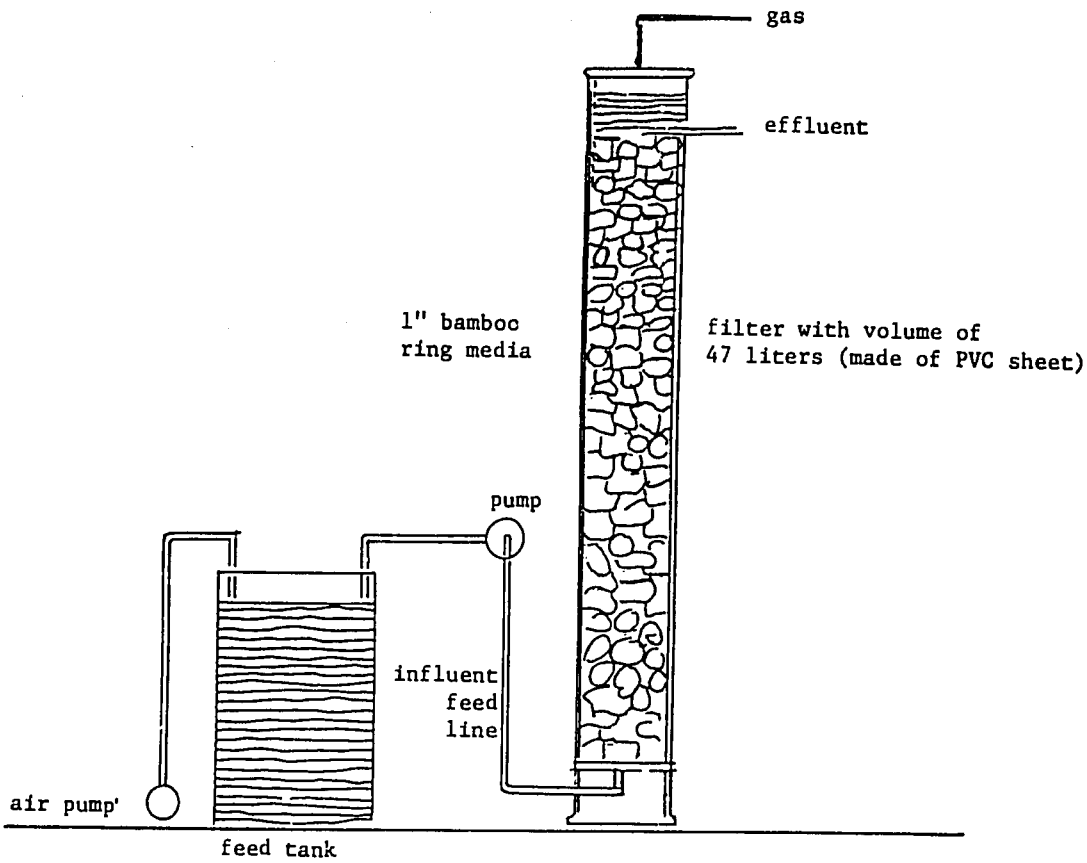

Fig. 4.1 Schematic diagram of anaerobic filter and feed system

A peristatic pump was used to feed the influent into the column by upward flow at a rate of 3 liters/day.

Wastewater Used in the Study

The wastewater used in the experimental study was collected from Thai Fermentation Industry, Ratchaburi province.

In each sample, about 50 liters of the wastewater were collected in 25 liter plastic containers. A new sample was collected every two weeks.

Experimental Program

The experimental study was designed to evaluate the feasibility of the anaerobic filter in treating fermentation waste into biogas. The major operational variables studied were retention time and COD loading. The process performance was evaluated from percent COD removal, the effects of pH, gas production and gas analysis.

The retention time studied was selected at 15 days. The organic loading was varied from 0.175 to 0.90 kg. COD/day.

The organic loading fed into the filter depended on the feed rate and the waste strength. The feed rate determined the retention time. The organic loading was varied by diluting the waste strength with water. Table 4.3 shows the waste strength flow rate, retention time and organic loading in the experiment.

Table 4.3 The experimental conditions of the anaerobic filter process for monoglutamate waste.

Influent COD mg/l	Flow rate liters/day	retention time days	kg COD loading/day
300,000	3	15	0.9
150,000	3	15	0.45
100,000	3	15	0.3
50,000	3	15	0.175

The pH in the reactor was controlled in a range between 6.5 to 7.0 using sodium bicarbonate and little sodium hydroxide.

Sampling and Analysis

In each experimental run the influent was kept in a container at room temperature. The volume used was for approximately three days feeding. To determine the efficiency of the process due to bacterial activities, pH and COD of the influent and the effluent were analysed every day and three times a week, respectively. In addition, once a week, the influent and the effluent were analysed for suspended solids and volatile acid. All analyses were carried out as recommended in *Standard Methods for the Examination of Water and Wastewater* (1975).

Filter Start-Up

For the start-up the filter was fed with sodium monoglutamate wastewater which has the COD concentration of about 325,000 mg/l. The feeding rate was kept at 4.5 liters per day or 14.5 kilograms per day of loading. The pH was not controlled to investigate the response from the system. Results of the preliminary investigation showed that the system did not work because the strength of the waste was too high and the pH in the filter was too low. The next step was to adjust the pH of the feeding up to 6.5-7.0 by adding $NaHCO_3$ which will retard the pH fluctuation. It took about 14 days for the first bubble of gas produced by the filter. But the rate of producing gas always fluctuated and the pH of the effluent was dropped to about 4.0-4.5 which indicated the unsteady condition of the system.

To improve the working situation of the system, about 15 liters of anaerobic sludge was added to increase the work ability of the system. The results showed that the gas bubble was generated within 7 days and reached the steady state very fast. The volume of the gas produced and percent methane content were recorded in the last period.

COD Removal

The preliminary experiment was conducted on the raw waste of COD 300,000 mg/l. This gave unsatisfactory results on low percentage of reduction. The concentration of the raw waste might have been too high for bacterial growth and also for the toxic substance, e.g., CN content in the raw waste which inhibited the bacteria in the system. Then the raw waste was diluted gradually and the concentration of influent and effluent were analysed daily. The results are shown in Fig. 4.2 and Fig. 4.3. The percentage of COD reduction of the system was observed at a maximum of only 30%, while the average of about 20% was obtained. The percentage of reduction fluctuated when the COD was higher than 100,000 mg/l. The effluent of the system showed steady value when the COD of the influent was about 50,000 mg/l COD. However, the overall results of the anaerobic filter experiment were unsatisfactory because the efficiency of COD destroyed was too low, even though the retention time in the filter was as long as 15 days.

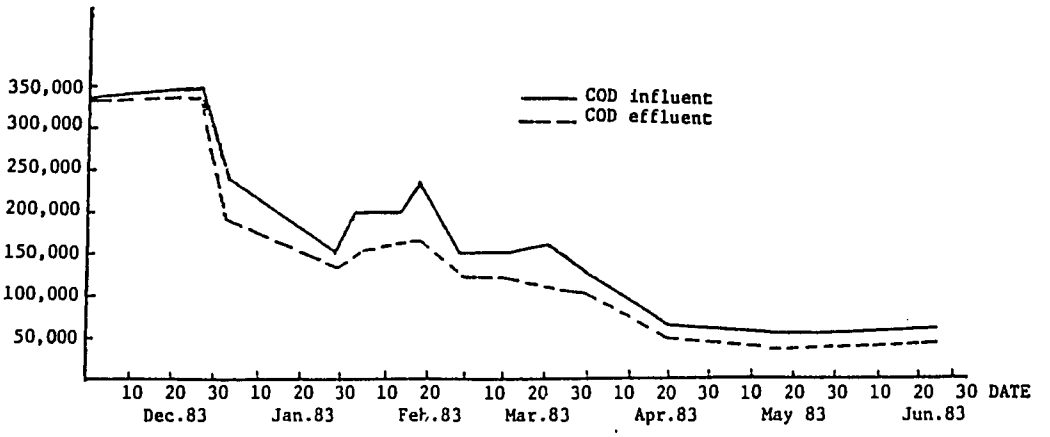

Fig. 4.2 The variation of COD influent and effluent in the anaerobic filter

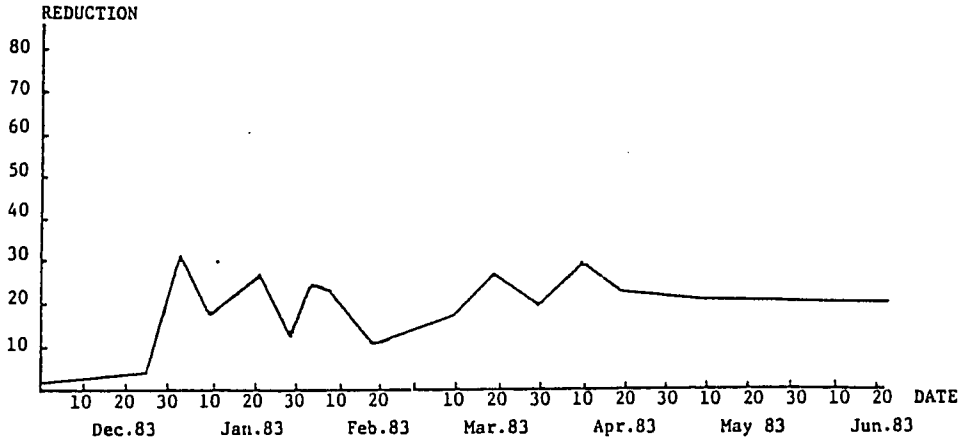

Fig. 4.3 Percentage of COD reduction in the anaerobic filter

Gas Production

Fig. 4.4 presents the variation of gas volume and the COD concentration of feeding. The gas production during December,1982,to January,1983,was not steady when the COD concentration of feeding was above 300,000 mg/l. At the high concentration or high loading of waste, bacterial digestion might have been too slow as the results showed that the rate of gas production obviously fluctuated. However, when the COD concentration of feeding waste was diluted to the range of 150,000 - 200,000 mg/l, the gas production smoothly generated about 12 liters per day, and the rate of production was steady.

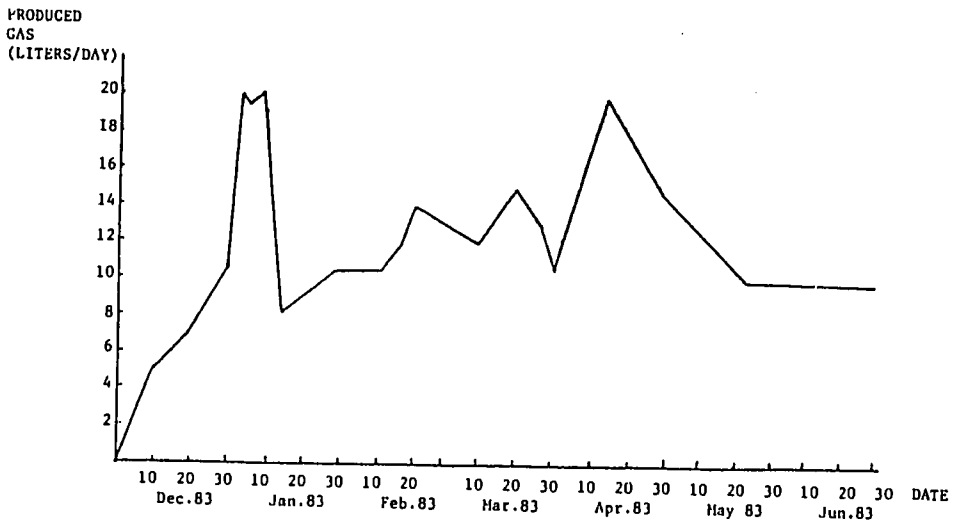

Fig. 4.4 Daily gas produced by anaerobic filter

pH

The raw waste from tapioca industry has the pH value of about 3.0-4.0 which is too low to operate the anaerobic condition. To increase the pH, $NaHCO_3$ was added to adjust the pH to about 7.0-8.0. Even though the pH was controlled to the neutral condition, it was found that after one day in the feeding tank, the pH dropped again to about 5.0-6.0. Therefore, the pH must be checked every day to be sure that it is neutral before feeding the digester.

Fig. 4.5 shows the pH of the influent and effluent of the digester system. The pH of the influent sometimes fluctuated but the effluent showed the relative steady condition at 7.0. The pH of the effluent,after reaching

the steady state, was a bit higher than the influent which indicated performance of the system. At pH 7.0, the working condition of methane forming bacterial but at a lower pH it is the acid forming condition.

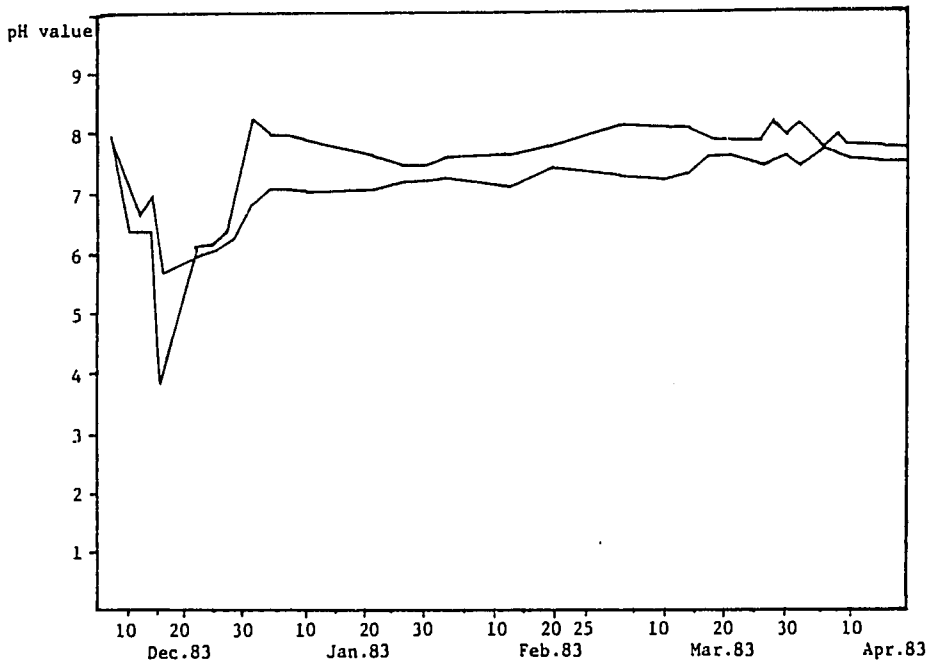

Fig. 4.5 The variation of pH in the anaerobic filter

Volatile Acid

The increase of volatile acid concentration indicated that the population of acid formers increased at a faster rate than the methane formers. Therefore, the volatile acid produced by the acid formers accumulated until the population of methane formers was sufficient for disseminating the excess acids. The concentration of volatile acids then decreased to equilibrium. The volatile acid in the monoglutamate waste was very high level,in the range of 20,000-27,000 mg/l as shown in Fig. 4.6. At a reducing COD loading by diluting the strength of waste could reduce the volatile acid concentration. By controlling the pH of the solution with $NaHCO_3$, alkalinity increases and the acidity is balanced for more efficient gas production.

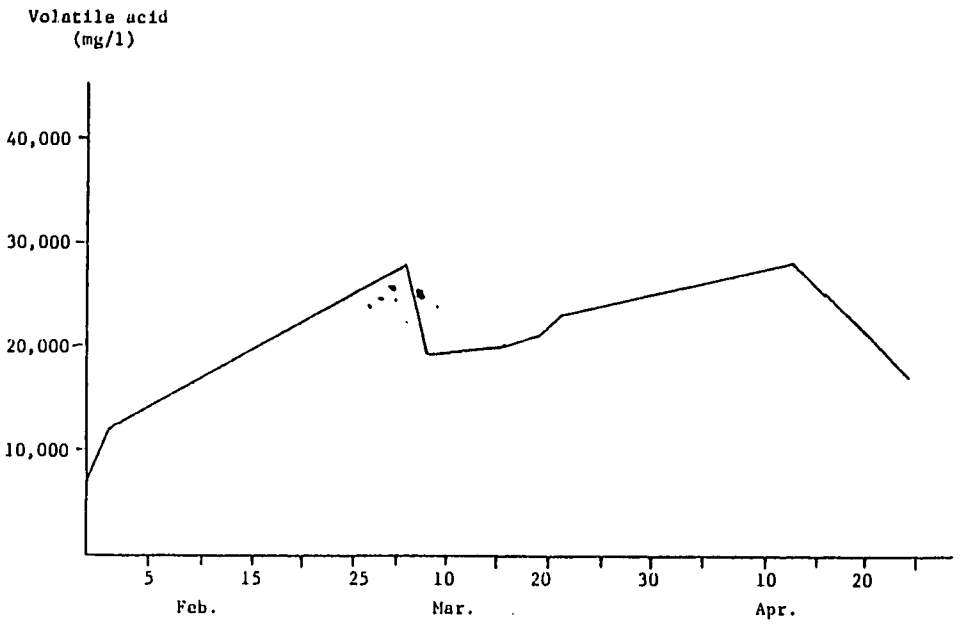

Fig. 4.6 The variation of volatile acid in anaerobic filter

C. ANAEROBIC CONTACT PROCESS, TAPIOCA WASTE

Experimental Apparatus

A laboratory-scale pilot plant of the anaerobic contact process was constructed to carry out the research program. The pilot plant can be described by the flow diagram as shown in Fig. 4.7. Wastewater was collected from the factory and fed into the digester where it was continuously mixed by an agitator at a rate of 150 rpm, sealed with mercury and maintained at a constant temperature with a 200 watt copper coil. The digester was cylindrical, about 0.30 m. in diameter, 0.40 m. high, and made of polyvinyl chloride (PVC). The volume of the digester was 30 liters and the operating volume was 25 liters.

Feed entered the contact unit near the bottom and flowed upward through the sludge into a siphon located at about the one-third depth point. The effluent was allowed to settle in the separator unit made of Plexiglas. The separator unit was a 40 cm. high, square column having a diameter of 80 cm^2 with a cone-shaped bottom. The volume of this unit was 3.3 liters and the

operation volume was 2.5 liters. The supernatant from the outlet was drained out at the top of the separator unit and the sludge which settled to the bottom was recycled to the contact unit.

The flow rates for raw feed and returned sludge were the same and were maintained constant at a rate of 5 liters/day by peristatic pumps. The gas produced in the contact unit was collected and measured with a gas meter.

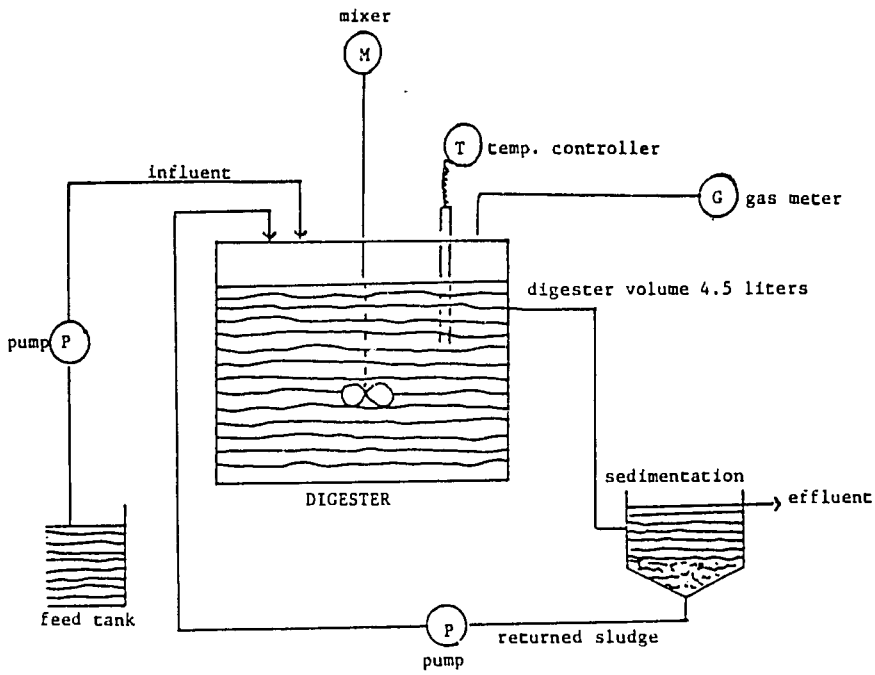

Fig. 4.7 The contact anaerobic digestion system diagram

Wastewater Used in the Study

The raw waste was collected from Banpong Tapioca Flour Industrial Co., Ltd. at Ratchaburi.

Each sample contained about 100 liters of the wastewater that was collected in 25 liter plastic containers. A new sample was collected each week.

Experimental Program

The experimental study was designed to evaluate the probability of the anaerobic contact process in converting tapioca waste into biogas. The major operational variables studied were retention time and COD loading. The process performance was evaluated in terms of percent of COD removal, the effects of pH, gas production and gas analysis.

The hydraulic retention time was selected at 5 days and the solid retention time was controlled for 15 days. The organic loading was varied from 0.075 to 0.025 kg. COD/day.

The organic loading fed into the digester depended on the feed rate and the waste strength. Table 4.4 shows the waste strength used in the experiment, HRT and organic loading.

Inf. COD mg/l	Flow rate liters/day	Retention time days	loading kg. COD/day
15,000	5	5	0.075
10,000	5	5	0.05
5,000	5	5	0.025

Table 4.4 The experimental conditions of the contact anaerobic process for tapioca waste

The pH in the digester was controlled in the range between 6.5 to 7.2 using sodium bicarbonate and a small amount of sodium hydroxide.

Sampling and analysis

In each experimental run the influent was kept in a container at room temperature. The volume used was for approximately three days feeding. To determine the efficiency of the process due to bacterial activities, pH and COD of the influent and the effluent were analysed every day and three times a week, respectively. In addition, once a week, the influent and the effluent were analysed for suspended solids and volatile acid. All analyses were carried out as recommended in *Standard Methods for the Examination of Water and Wastewater* (1975).

Digester Start-up

The tapioca waste was fed into the contact anaerobic filter at the rate of 5.0 liters per day (beginning on the 10th of November, 1982), without any control factors, so that the anaerobic stage would be reached naturally. After about 20 days of operating, there was some gas produced from the digester, but the effluent water was not black as anaerobic processing sludge should be. The pH of the wastewater was about 4.0-5.0. To increase the pH to the 6.5 to 7.0 range, $NaHCO_3$ solution was added. After three weeks the amount of gas increased slowly. The gas produced was about 10.0 liters per day or 8,000 liters/kg. COD/$m.^3$

Results of the preliminary experiment showed that the sludge build up during the start-up period was very sensitive to the pH adjustment. If the

pH of the waste was too low, sludge or the methane forming bacteria was slow to increase. The temperature was also a major factor because, when the outside temperature dropped to about 15°C during the cool season (December,1982), the rate of gas decreased suddenly. Thus,a heater was put into the digester to control the temperature to about 35°C.

The start-up experiment was done again using the contact anaerobic process to find a better way to reach the steady state. The sludge from anaerobic process (from elsewhere) was taken and seeded the digester. The temperature was controlled at 35°C and pH of 7.0. The amount of sludge was about 20% by volume of the wastewater. After only 3 days, the bubble of gas was produced. The steady state was reached after 1 month.

Measurement of the production rate of the gas and its methane content was not made during the start-up period because the unsteady state condition would not provide consistent data. The rate of gas production was found to be relatively constant during the period of constant COD removal and the gas measurement was done after the steady state was reached.

COD Reduction

The COD concentration of tapioca wastes fluctuated depending on the sources (e.g. location grown) of tapioca roots, composition of the tapioca root and the amount of water used in the processes. The COD concentration was in the range of 5,000-18,000 mg/l. The experiment of digester efficiency had been done by varying the COD concentration of the influent. The first stage of the experiment(during December 1982 to March 1983) tried COD of 5,000 mg/l or COD loading of 0.025 kg/d. Results of the experiment showed the average COD reduction was about 30%. The experiment of the COD influent of 10,000 mg/l or 0.05 kg/d COD loading and 15,000 mg/l or 0.075 kg/d loading, presented the best results of 50% reduction as shown in Fig. 4.8 and Fig. 4.9. It is obvious that the percentage of reduction is linear, proportional to the retention time. If the retention time of the waste in the digester is increased, it is possible to reduce the BOD effluent to a lower level, causing an increase in gas production.

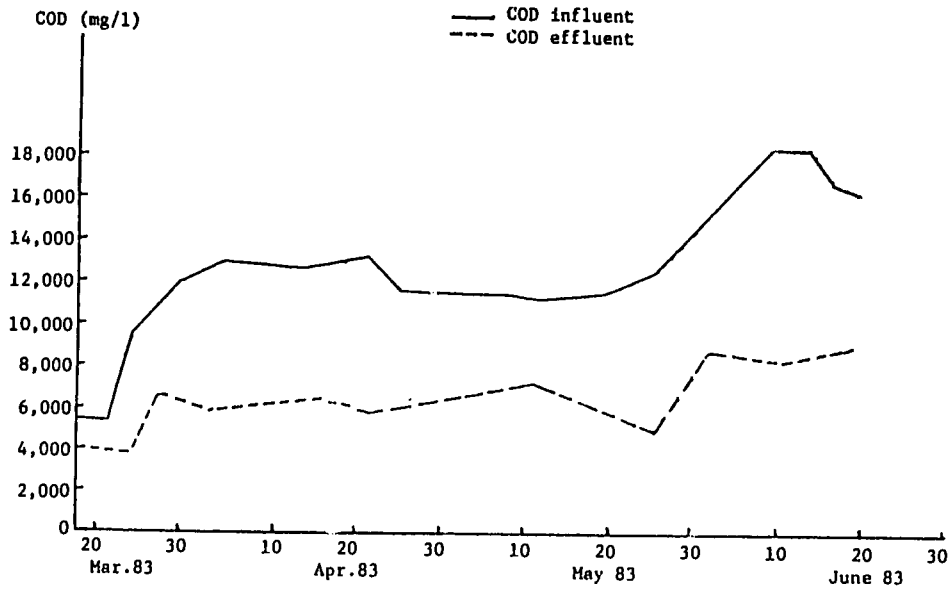

Fig. 4.8 The variation of COD influent and effluent in the anaerobic digestion of tapioca waste.

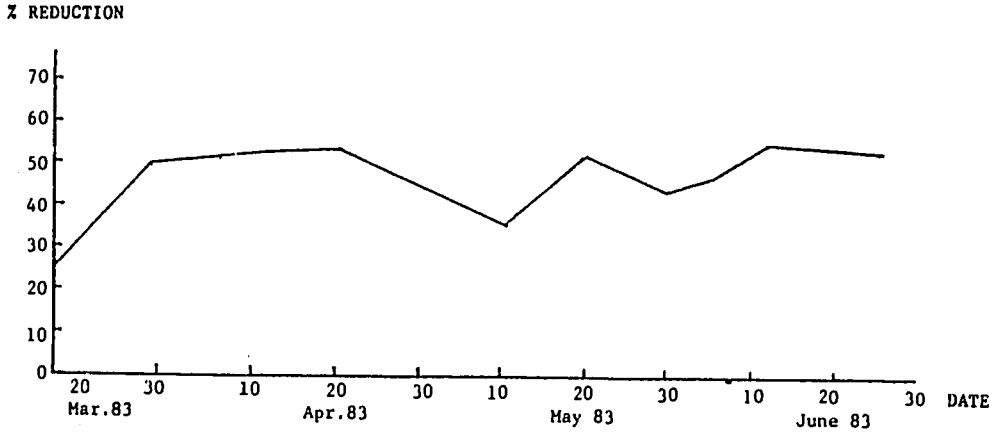

Fig. 4.9 Percentage of COD reduction in contact anaerobic digestion.

Gas Production

Fig. 4.10 shows the daily rate of gas production from the contact anaerobic digester. The concentration of the gas was varied. It can be seen that the rate of gas production increased immediately in direct proporation to the destroyed COD. The sudden increase in the gas production rate when changing the organic loading signified that there were sufficient bacteria to cope with the increased load to reach the steady state of 11 liters/day at the 50% COD reduction efficiency or equivalent to 0.5 m^3/kg COD destroyed.

The experiment showed that the rate of gas yield per unit of COD destroyed was highest when the COD influent was about 10,000 mg/l. But when the COD influent was higher, the amount of gas production per unit of COD destroyed decreased.

For practical work, if the digestion tanks are separated into 2 stages, the total efficiency of COD reduction will be 75% and the gas production will be 25 l/d or 5 times the amount of waste(or equivalent)to water 2.4 m^3/kg COD destroyed.

It is interesting that the calculation shows that the amount of gas production will be about 5,000 m^3/d if the rate of feeding wastewater is about 1,000 m^3/d but the digester tank must be extremely large.

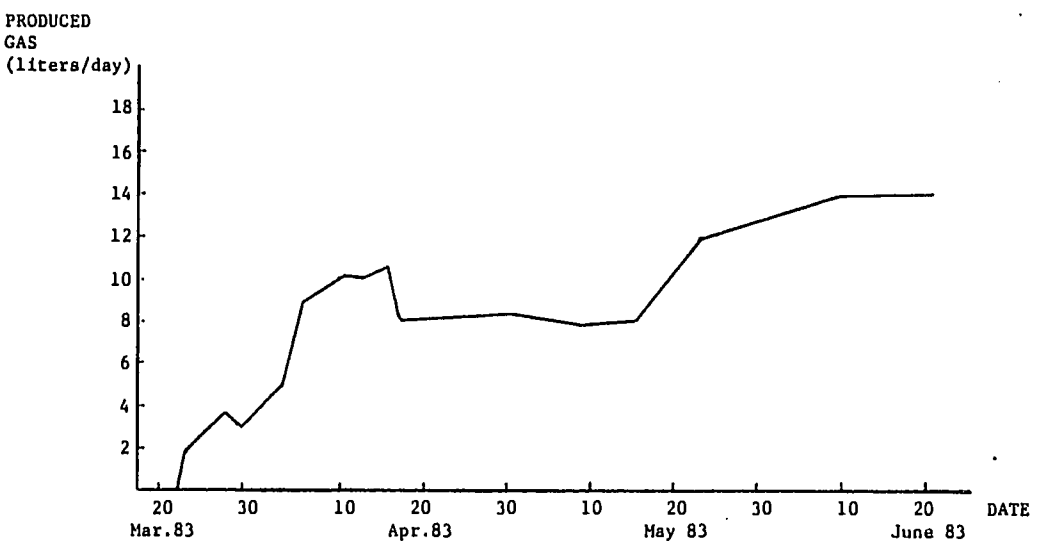

Fig. 4.10 Gas production from contact anaerobic digestion.

pH

The raw waste from the tapioca industry has the pH value of about 3.0-4.0 which is too low to operate the anaerobic condition. To increase the pH, $NaHCO_3$ was added to adjust the pH up to about 7.0-8.0. Even though the pH was controlled to the neutral condition, it was found that after one day in the feeding tank, the pH dropped again to about 5.0-6.0. Therefore, the pH must be checked every day to be sure that it is neutral before feeding the digester. A pH of 7.0 is the working condition of methane forming bacteria but a lower pH will produce the acid forming condition.

Fig. 4.11 shows the pH of the influent and effluent of the digester system. The pH of the influent sometimes fluctuated but the effluent maintained a relatively steady condition at 7.0. After reaching the steady state the pH of the effluent was a bit higher than the influent which indicated good performance in the system.

The pH was a major factor in controlling the steady state of the system, but the cost of the chemical to adjust the pH was very expensive. A study was done to investigate whether a sufficient buffer was present in the digester by stopping neutralization before the end of study. The observable criterion was the change in the amount of gas production. If a sufficient buffer was not present, the pH would drop and conversion of acetate to methane would be inhibited as shown by the following equation.

$$CH_3\ COONa + H_2O \longrightarrow CH_4 + NaHCO_3$$

Results of the experiment showed that after stopping the neutralization in the digester, the rate of gas yield was not inhibited unless the volatile acid to alkalinity ratio was lower than 0.35.

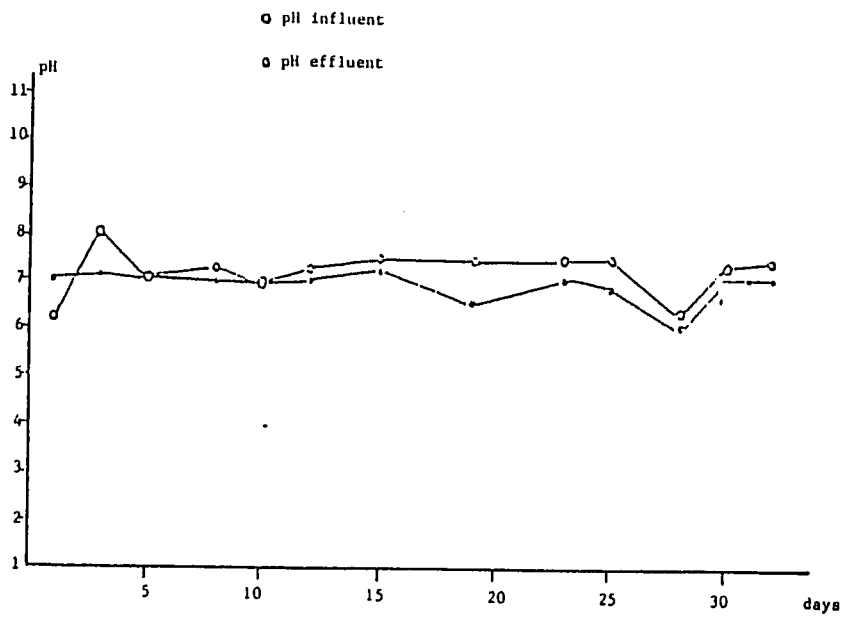

Fig. 4.11 The pH of influent and effluent at steady state

Volatile Acid

Volatile acid in the digester system reflects the stability of the process. The amount of volatile acid in the batch operation will increase after 2-3 days of feeding and decrease for the next 4-5 days. These are the 2 stages of acid forming and methane forming activity. For the continuous process, a small amount of volatile acid in the effluent is expected for the efficient performance of the system.

Fig. 4.12 shows the volatile acid of the effluent of the contact anaerobic system during the steady state condition. The digester was fed with the anaerobic sludge to accelerate the working condition on March 20, 1983. The volatile acid during the period after seeding to the early part of April, was very low due to the unsteady state of the system, but during the steady state in April, the volatile acid was on the average of 2,000 mg/l. This level of volatile acid indicates very good conditions for the anaerobic digestion because the normal level for anaerobic digestion for other wastes is about 5,000 mg/l.

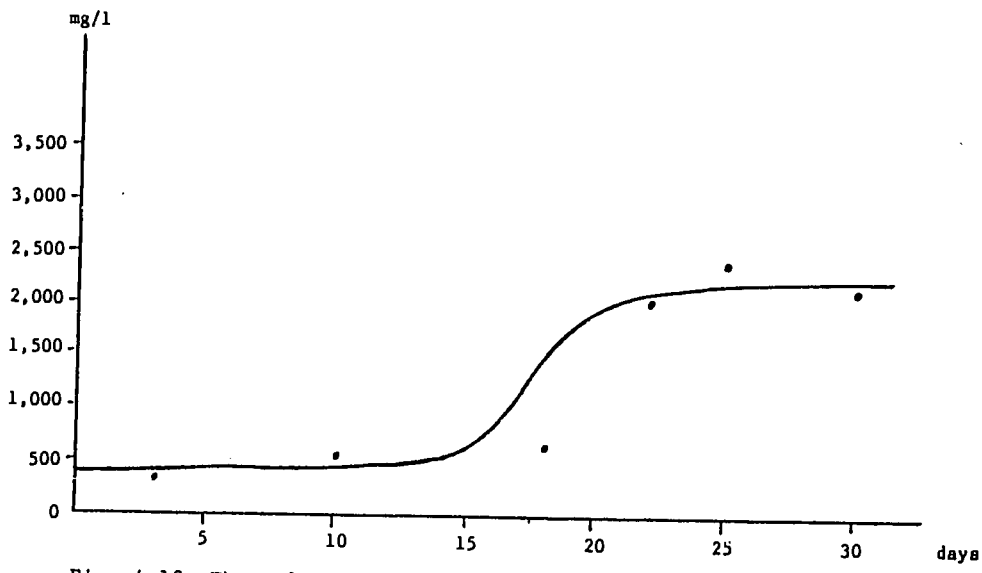

Fig. 4.12 The volatile acid of the digester at steady state

The Methane Content

The biogas leaving the digester contains methane, carbondioxide, negligible traces of other gases (H_2S, H_2) and is saturated with water. The ratio of methane/carbondioxide from digestion of tapioca starch waste is 85:15 which is a very high ratio compared with other biogas sources. The biogas from tapioca starch waste at this ratio is combusible. Therefore, to

purify the gas of CO_2 is not necessary. The argument in favor of removing CO_2 is that this will improve the burning properties of the gas. However, reliable burners for lean methane gases are available and there seems relatively little incentive for purification.

D. ENGINEERING DESIGN

The engineering design that evolved used the contact anaerobic process with the capacity of 10 cubic meters (see Annex I). The plant consisted of a digester with the capacity of 10 cubic meters, sump, sedimentation tank, feeding pump, recirculation pump, gas holder, and control housing, as shown in Fig. 4.13. The design was based on theoretical gas production rather than data obtained from the experiment. In the design, biogas production is about 0.8 cubic meters per cubic meter digester per day assuming 85 percent BOD removal.

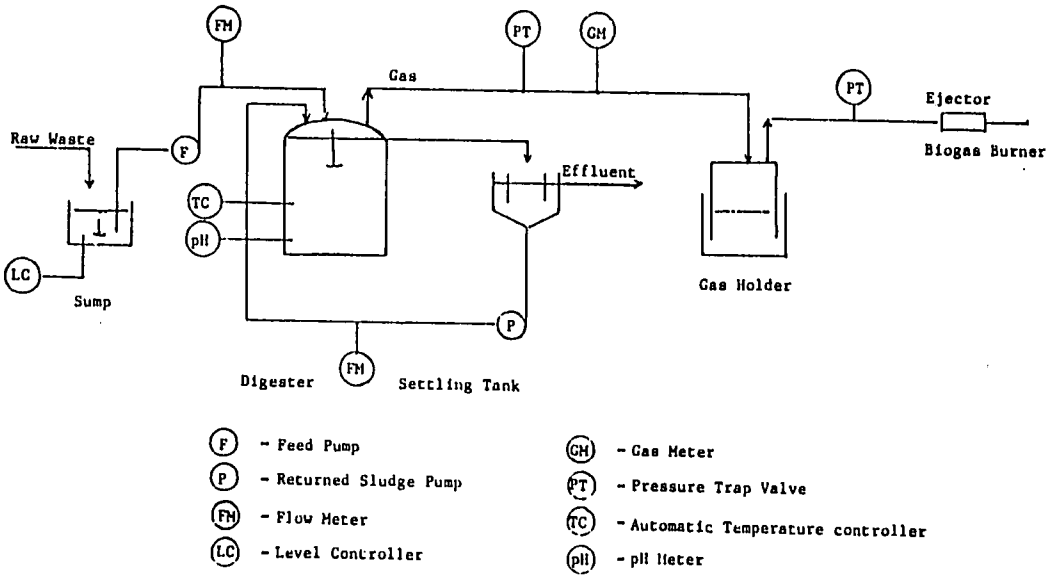

Fig. 4.13 Process Flow Diagram of the Pilot Plant

E. ECONOMIC ANALYSIS

An economic analysis was conducted to determine the feasibility of various sizes of biogas systems. The return back period and production cost were the aim of this analysis. However, due to the limited data, the general curves of capital cost, operation and maintenance cost were used for this analysis as shown in figures 4.14 and 4.15, respectively. These are the results of annual cost as shown in figure 4.16. In addition the saving cost due to biogas generated from various sizes of biogas systems was analysed

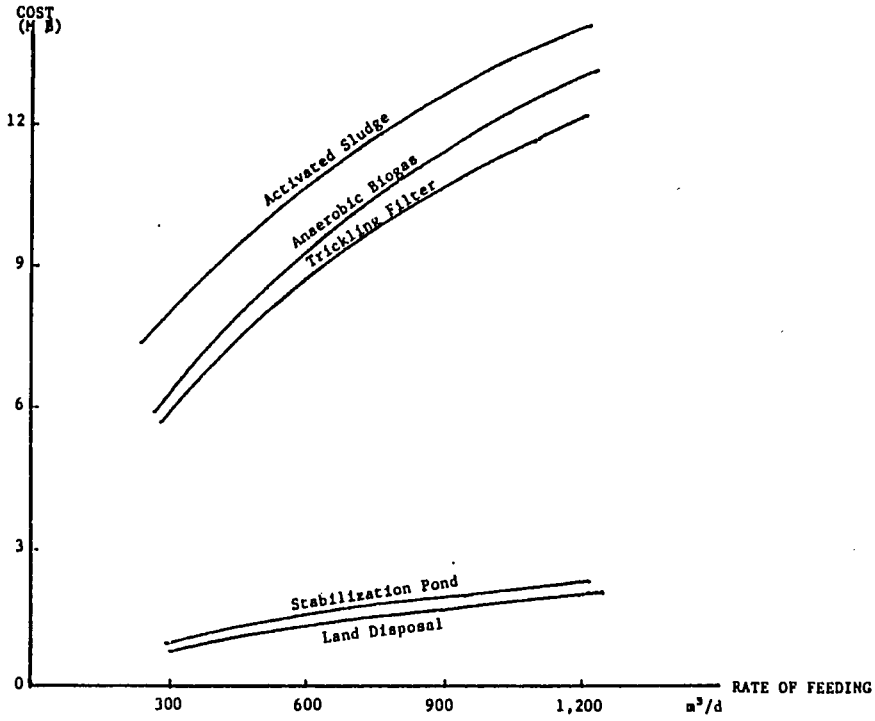

Fig. 4.14 The capital cost of various biological treatments and anaerobic biogas treatment technique.

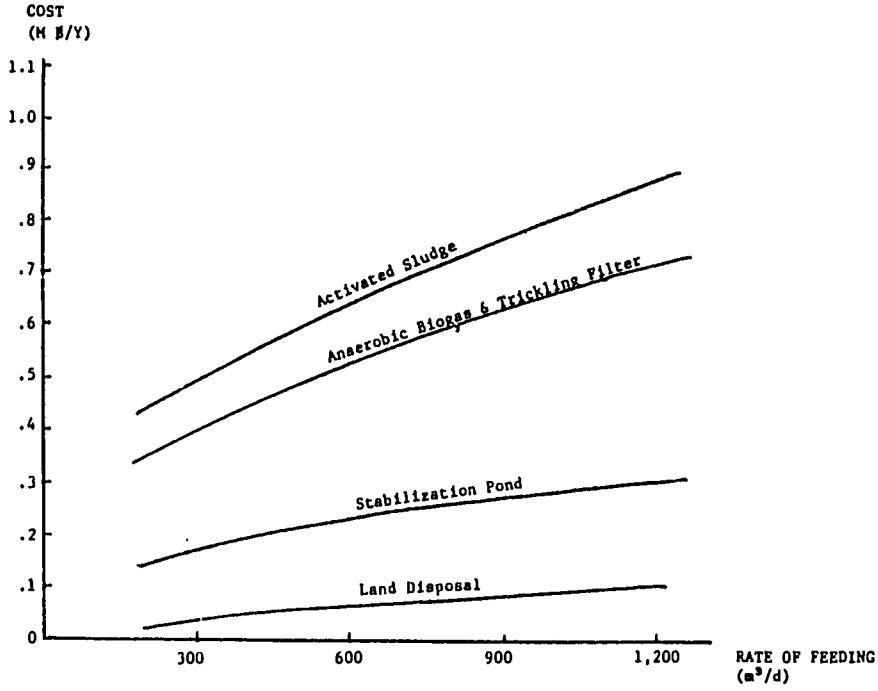

Fig. 4.15 The operation and maintenance cost of various biological treatments and anaerobic-giogas treatment technique.

based on the gas production of 0.6 cubic meter per cubic meter of digester per day or 3 cubic meters of gas per cubic meter of feed waste as shown in Fig. 4.17.

Finally, the benefit from biogas produced and annual cost were compared as shown in Fig. 4.18. It was found that the minimum size for having a return back period was 2,500 cubic meters of digester for serving the waste with the quantity of 500 cubic meters per day. The return back period was calculated at 10% interest rate and is summarized in Table 4.15. This indicates that the minimum size of a biogas system with a return period of not more than 12 years at 10 percent interest would have to be 5,000 cubic meters of digester for serving 1,000 cubic meters of waste per day.

Table 4.5 The return back period of contact anaerobic process at 10% interest

Rate of feeding m^3/day	Return period (Yrs)
600	too long
1,000	12
1,200	8.6

Table 4.5: The return back period of contact anaerobic process at 10% interest

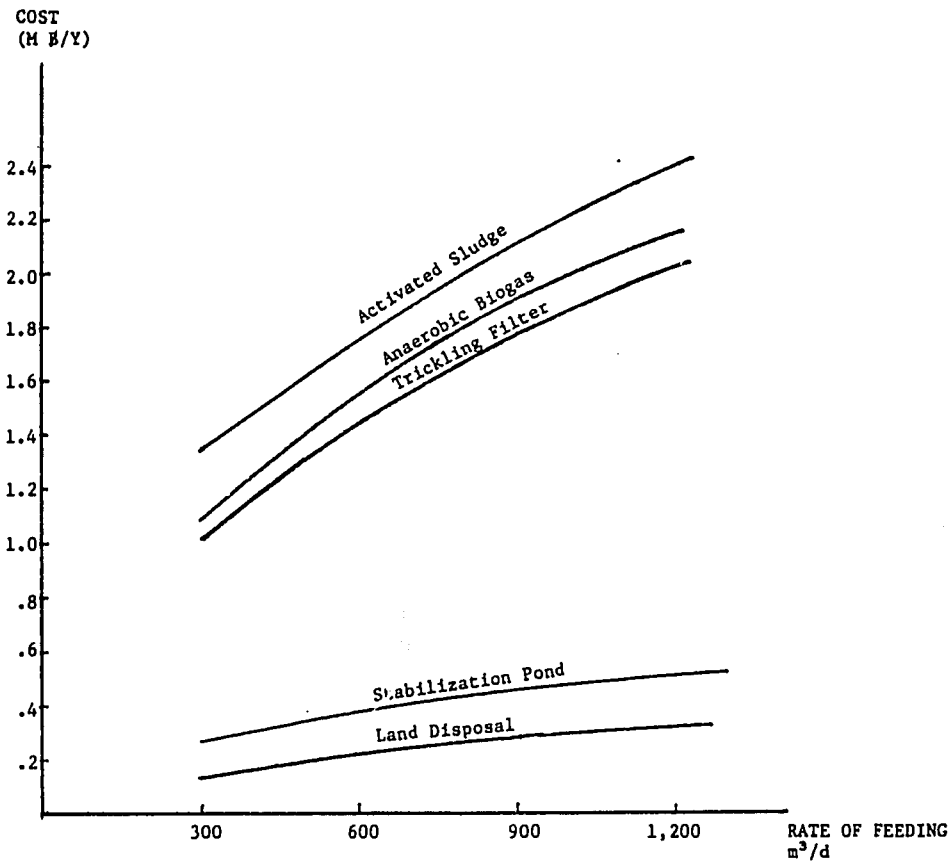

Fig. 4.16 The annual cost of various biological treatment and anaerobic biogas treatment technique.

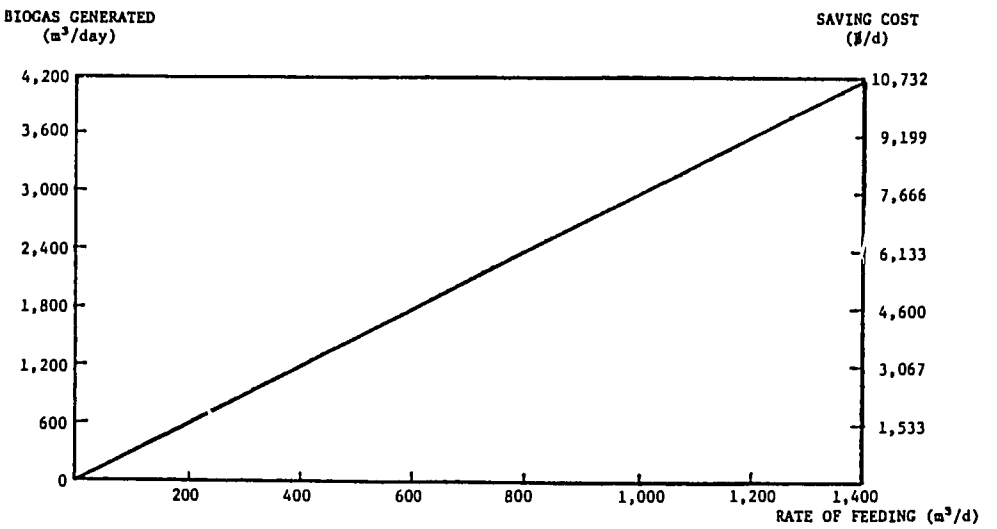

Fig. 4.17 The amount of gas production at various rates of loading and saving cost of fuel oil by biogas

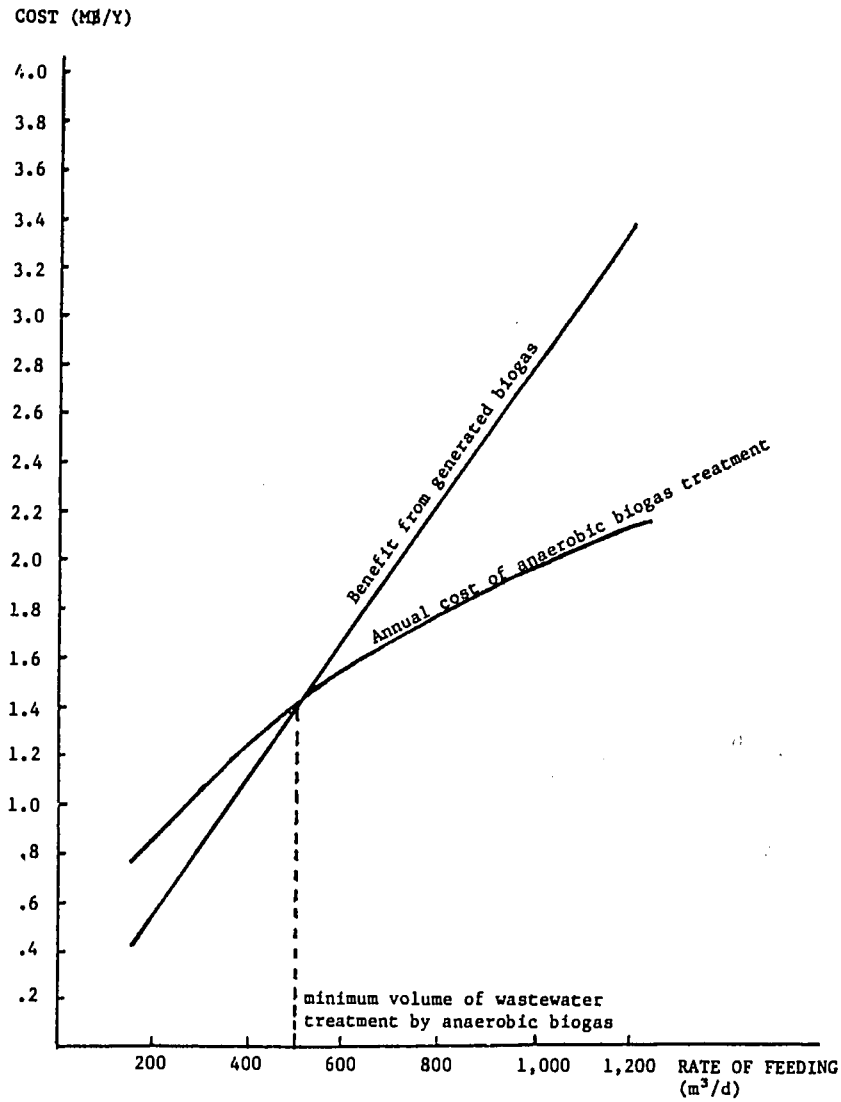

Fig. 4.18 The economic study of minimum volume of hydraulic load of anaerobic biogas treatment technique in which the benefit from the biogas is higher than annual cost of treatment.

Chapter 5

Analysis of Results and Discussion

ANALYSIS OF RESULTS AND DISCUSSION

A. ANALYSIS OF WASTEWATER

The preliminary analysis on the characteristics of 5 types of wastewater were conducted and the results are shown in Table 4.1.

It was shown that the types of wastes having high concentration of BOD and COD are tapioca and sodium monoglutamate wastes. According to the laboratory scale experiment, these two types of wastes were recommended and their characteristics were analysed and shown in Table 4.2.

B. ANAEROBIC FILTER PROCESS, SODIUM MONOGLUTAMATE WASTE

As shown in Figs.4.3 and 4.8 the COD reduction varies with the influent concentration of sodium monoglutamate waste. It is emphasized that the influent concentration of waste, less than 100,000 mg/l of COD, gave the steady concentration of the effluent. The percentage of COD reduction is about 20 percent.

In analyzing the pH (see Fig. 4.5), it was found that the pH value of the effluent does not vary much compared with that of the influent at the influent concentration of waste less than 250,000 mg/l.

To check on the mechanism balance of bacterial activity, the volatile acid was analysed as shown in Fig. 4.6. Even though the pH value of the effluent during February and March, 1983, was stable at the acceptable level, 7-8, the volatile acid concentration was still too high at the level of 20,000-30,000 mg/l. It seems that the COD concentration of influent does not relate to the volatile acid concentration of the effluent. One possible explanation of this phenomenon is that the retention time is not enough for the methane forming bacteria to convert volatile acid to methane gas. Another explanation is that the acid forming bacteria increase at a faster rate than the methane forming bacteria.

The gas production, as shown in Fig. 4.4, varies with the influent COD concentration. However, the relation between volatile acid and gas produced can not be conclusively proven. The gas production is smoothly produced with the average value of 12 liters per day at the influent COD of 150,000-200,000 mg/l. In other words, the gas production is about 0.27 cubic meters of gas per cubic meter of filter per day with methane gas composition less than 30 percent, which is too low in terms of heating value and quantity of methane gas.

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C. ANAEROBIC CONTACT PROCESS, TAPIOCA WASTE

The parameter which should be emphasized for this experiment is the variation of temperature during the experiment which was not controlled. Because of the sensitivity of the anaerobic filter system on high loading and the fluctuation of volatile acid, another type of waste namely, tapioca waste, was used in the contact anaerobic process as shown in Fig. 4.7 with the variation of parameters as shown in Table 4.4. The results in terms of COD removal, pH, volatile acid, and gas production are shown in Figs. 4.8, 4.9, 4.10, 4.11 and 4.12 respectively.

As shown in Figs. 4.8 and 4.9, it was found that the maximum COD removal is about 50 percent at any influent concentration. Unfortunately, the condition of steady state during measuring the pH value and volatile acid as shown in Figs. 4.11 and 4.12 was not recorded. Thus, the effect of increasing organic loading on pH and volatile acid can not be concluded.

The gas production shown in Fig. 4.10 increased as the influent COD concentration increased. This means that the range of organic loading during the experiment was not too high. These bacteria can cope with the desired range. The balance of the system is the result. The gas production and the methane gas composition are 0.45 cubic meters of gas per cubic meter of digester per day and methane 75 percent with 5 days retention time and 35°C.

The engineering design conducted by Mahidol University was based on theoretical gas production rather than that obtained from the experiment which is only 0.45 cubic meters per cubic meter of digester per day. Thus, it is expected that the gas production per day is about 25 cubic meters rather than 150 cubic meters as was calculated by Mahidol University.

D. ECONOMIC ANALYSIS

To confirm the economic analysis conducted by Mahidol University, the author analysed the production cost of the biogas system compared with fuel oil and return back period at various interest rates without inflation, of a 50 cubic meter digester with gas production of 150 cubic meters per day as recommended by Mahidol University. The results of production cost are summarized in Table 5.1. It was found that the return back period of such capacity can not be achieved within 30 years. (Detail of calculations are shown in Annex II.)

Table 5.1 Production cost of a 50 cubic meter biogas plant

Type of fuel	Interest rate %	Production cost Baht/1000 Kcal.
fuel oil	-	0.44
biogas	8	0.60
	10	0.68
	12	0.77
	15	0.91

Chapter 6

Conclusions

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CONCLUSIONS

6.1 In the preliminary analysis and laboratory scale experiment, tapioca waste was found to be the most suitable waste for generating biogas in terms of quantity of gas produced and quality of methane gas composition.

6.2 The anaerobic filter process is not suitable for high concentrations of waste. The system is not able to resist the high organic loading.

6.3 The variation of temperature during the laboratory scale experiment was not controlled.

6.4 The gas production from the contact anaerobic process is about 3 times the volume of feeding waste with 75 percent of methane gas produced.

6.5 The gas production for 50 cubic meters of digester could not be more than 25 cubic meters of gas per day, rather than 150 cubic meters per day as reported by Mahidol University.

6.6 The minimum size of a contact anaerobic system is 2,500 cubic meters for a return back period. However, the size of digester for a 12 year return back period is 5,000 cubic meters of digester.

6.7 The comparison of production cost between fuel oil and biogas produced from 50 cubic meters of biogas plant calculated at various interest rates showed that biogas produced from tapioca waste is not competitive with fuel oil. In addition, it is not possible to have an investment return back period within 30 years.

6.8 Although these results indicate that the treatment of industrial wastewaters by the anaerobic system is not economically feasible at this time, the results indicate that the technique is possible.

6.9 This research adds to the knowledge of the NEA officials in their search for adequate treatment and utilization of Thailand's industrial wastewaters using the anaerobic process.

6.10 The production of industrial biogas from high organic load factory wastewaters by anaerobic systems is probably the most cost effective method for treatment and utilization of Thailand's industrial wastewaters.

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Chapter 7

Recommendations

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RECOMMENDATIONS

7.1 The surrounding conditions for the experiment should be the same, so that the results are reliable and can be used to study the effect of the process.

7.2 The parameter which should be emphasized for this experiment is the control of various temperatures.

7.3 The anaerobic contact process system designed by Mahidol University consisted of a gas holder made of stainless steel which is very expensive. It might be advisable to use a compressor for collecting gas at certain levels of pressure and use a smaller gas holder as a pressure control.

7.4 The tapioca biogas demonstration plant should be constructed to explore technical feasibility of this type of biogas plant. It would be the prototype for a biogas treatment plant utilizing industrial wastewater in the future. This phenomenon might gear up individuals, institutes and other concerned agencies to find or seek new technologies concerning biogas and the treatment of industrial wastewaters at a feasible economic level.

7.5 NEA should continue to explore the use of high organic load factory wastewaters by importing cost effective anaerobic systems.

7.6 The pollution of the environment is of major concern to the Government of Thailand, therefore, the research in the treatment and utilization of industrial wastewaters should be continued until solutions to the problems are found.

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Annexes

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ANNEX I

PLANT DESIGN CALCULATIONS

1. Digester

Design digester volume	=	10	m^3
COD of raw waste	=	10,000	mg/l.
Estimated BOD	=	7,500	mg/l.
Average BOD loading rate	=	2	$kg/m^3/d.$
BOD input	=	20	kg/d.
Volume of feed	=	$\frac{20}{7.5}$	
	=	2.67	m^3/d
Hydraulic Retention Time, HRT	=	$\frac{10}{2.67}$	
	=	3.75	days

Design max. feed rate up to 5 $m^3/d.$ or HRT 2 days

2. Biogas Production

Theoretical methane production	=	5.62	ft^2/lb BOD
	=	0.35	m^3/kg BOD
Estimated BOD removal	=	85%	
	=	17	kg/d.
Methane production	=	5.95	$m^3/d.$
Methane composition in biogas	=	75%	
Total biogas production	=	8	$m^3/d.$

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Heat loss from vapor surface

ΔT = (72) (0.2) = 14.4°F

Factor 0.2 is correction for noncondensing vapor

Unit heat loss = 25 Btu/hr.ft^2

Area = π (7.38) (1.64) + 43

= 81 ft^2

Heat loss = 25 x 81 = 2,025 Btu/hr.

Total heat loss for no insulation = 34,950 + 2,025

= 36,975 Btu/hr

or = $\frac{36,975}{3,410}$ = 10.3 KW.

(1 KW = 3,410 Btu/hr.)

Insulated with 1" calcium silicate

1) Heat loss from liquid surface

Unit heat loss = 20 Btu/hr.ft^2

Area = 233 ft^2

Heat loss = 20 x 233 = 4,660 Btu/hr.

2) Heat loss from vapor surface

Unit heat loss = 10 Btu/hr.ft^2

Area = 81 ft^2

Heat loss = 810 Btu/hr.

Total heat loss for insulated tank = 810 + 4,660

= 5,470 Btu/hr.

or = 1.6 KW.

These calculations clearly indicated that the digester should be insulated with 1" calcium silicate or equivalent.

In this design it is suggested that 2" thickness of micro fibre (trade name) will be used.

DESIGN OF IMPELLER MIXER

From the power factor chart in the reference, an impeller was selected that used a paddle with blades. Details of the calculation are presented as follows:

Tank diameter, Dt	=			2.25 m.
Blade diameter, Di	=	Dt/3	=	0.75 m. (2.5 ft.)
Blade width	=	0.25 Di	=	0.18 m.
Use 4 baffle, width	=	0.10 Dt	=	0.22 m.
Designed tip speed for medium mixing			=	6 ft/sec.
Calculated rotational speed	=	$\frac{TS}{\pi Di}$	=	$\frac{6}{\pi(2.5)}$ = 0.76 rpm.
			=	45.8 rpm.

From AGMA standard for mixer output speed,

Selected a speed of 45 rpm. or 0.75 rps.

Renolds number, Re $= \frac{N\ Di^2 \rho}{\mu}$

N	=	0.75 rps.
Di	=	2.5 ft.
ρ	=	64 lb/ft^3
μ	=	1.2 cp
	=	$1.2 \times 6.72 \times 10^{-4}$ lb/ft.sec.

Reference : BROWN, GEORGE G.
Unit Operation 507, (1950)

AGMA = American Gear Manufacturer Association

$$= \frac{(0.75)\ (2.5)^2(64)}{1.2 \times 6.72 \times 10^{-4}}$$

$$= 3.72 \times 10^5$$

Power factor, Po $= 1.8$

Power dissipated in fluid, P

$$= \frac{Po\ N^3\ Di^5\ P}{gc}$$

$$= \frac{(1.3)\ (0.75)^3\ (2.5)^5(64)}{32.2}$$

$$= 147 \text{ ft.lbf/sec.}$$

$$= \frac{147}{550} = 0.268 \text{ hp.}$$

Corrected for starting torque and motor efficiency

$$= \frac{0.268 \times 3}{0.5}$$

$$= 1.34 \text{ hp.}$$

use 2 hp. motor

HEAT BALANCE

Heat Loss Calculation

Assume the tank was installed above ground

Tank diameter	=	2.25 m.	=	7.38 ft.
Liquid depth	=	2.5 m.	=	8.2 ft.
Free board	=	0.5 m.	=	1.54 ft.
Area of roof or bottom tank	=	$\frac{\pi}{4}(7.38)^2$	=	43 ft^2
Max. liquid Temp.	=	55°C or 131°F (Thermophilic range)		
Min. ambient temp.	=	15°C or 59°F		
ΔT	=	131 - 59	=	72°F

No insulation

1) Heat loss from liquid surface, ΔT = 72°F

Unit heat loss = 150 Btu/hr.ft^2

Liquid surface = π (7.38) (8.2) + 43

= 233 ft^2

Heat loss, qL = 233 x 150

= 34,950 Btu/hr.

Reference : HUGHES, R. and DEUMAGA, V. "Insulation Saves Energy". Chemical Engineering, May 27, 1974

Heat Required for Heating the Feed

Max. feed volume	=	5 m^3/d = 208 l/hr.
Heat capacity	=	1 kcal/kg°C
Assume temp. difference	=	55 - 25 = 30°C
Heat required	=	$\frac{208 \times 30}{0.252 \times 3{,}410}$
	=	7.26 KW.

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY

NATIONAL ENERGY ADMINISTRATION

PILOT PLANT OF INDUSTRIAL BIOGAS

DRAWING NO.	TITLE
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S - 02	PLANT LAYOUT
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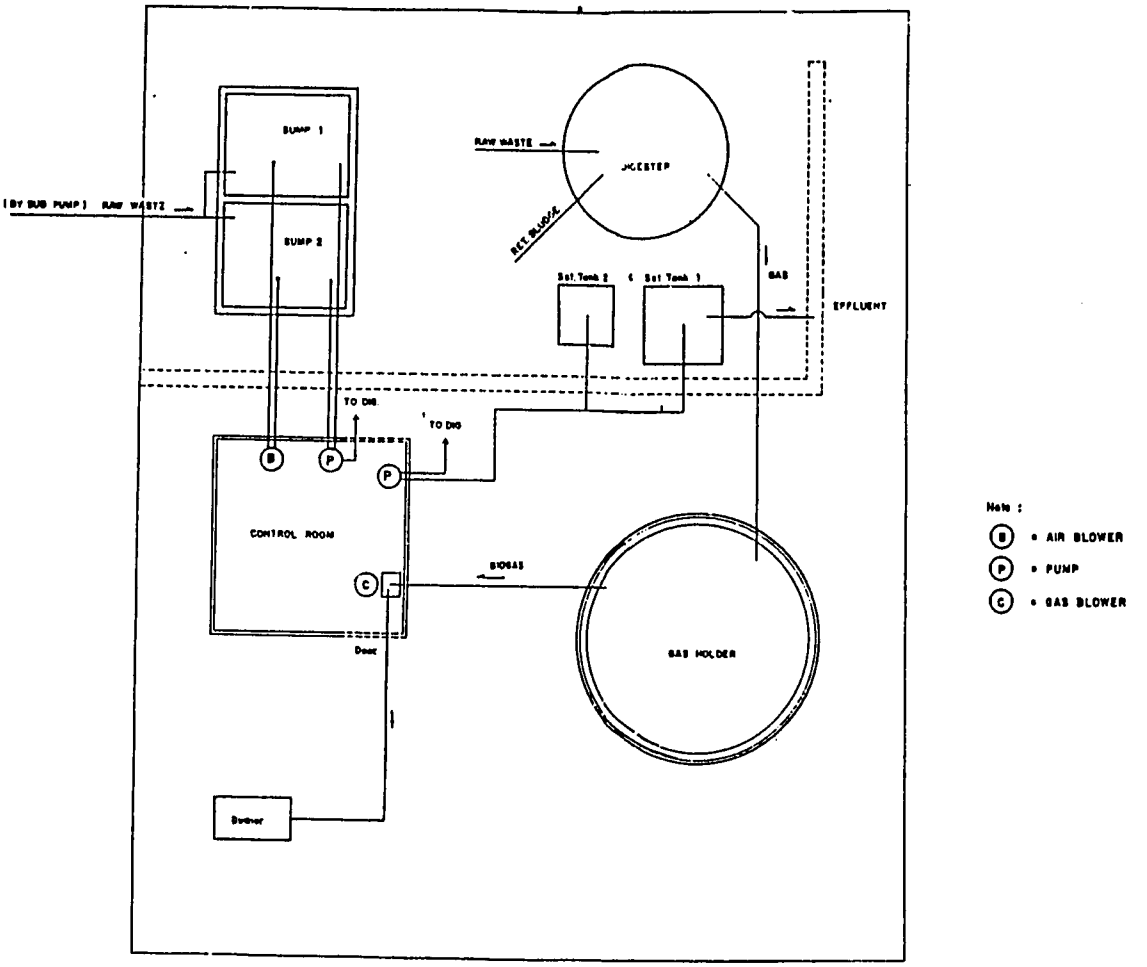
S - 12	CONTROL ROOM
S - 13	REINFORCEMENT DETAIL
S - 14	ELECTRICITY PLAN
S - 15	SINGLE LINE DIAGRAM
S - 16	WIRING DIAGRAM
S - 17	CONTROL CIRCIUT



PLANT LAYOUT

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PILOT PLANT OF INDUSTRIAL BIOGAS	PROJECT ENG.	PREECHA PLOYPATARAPONTO	APPROVED BY	MANIT VISUTHIPUNGSI-URI	
(TAPIOCA STARCH WASTE)	STRUCTURAL ENG.		SCALE	DRAWING NO	TOTAL
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MAHIDOL UNIVERSITY	MECHANICAL ENG.				

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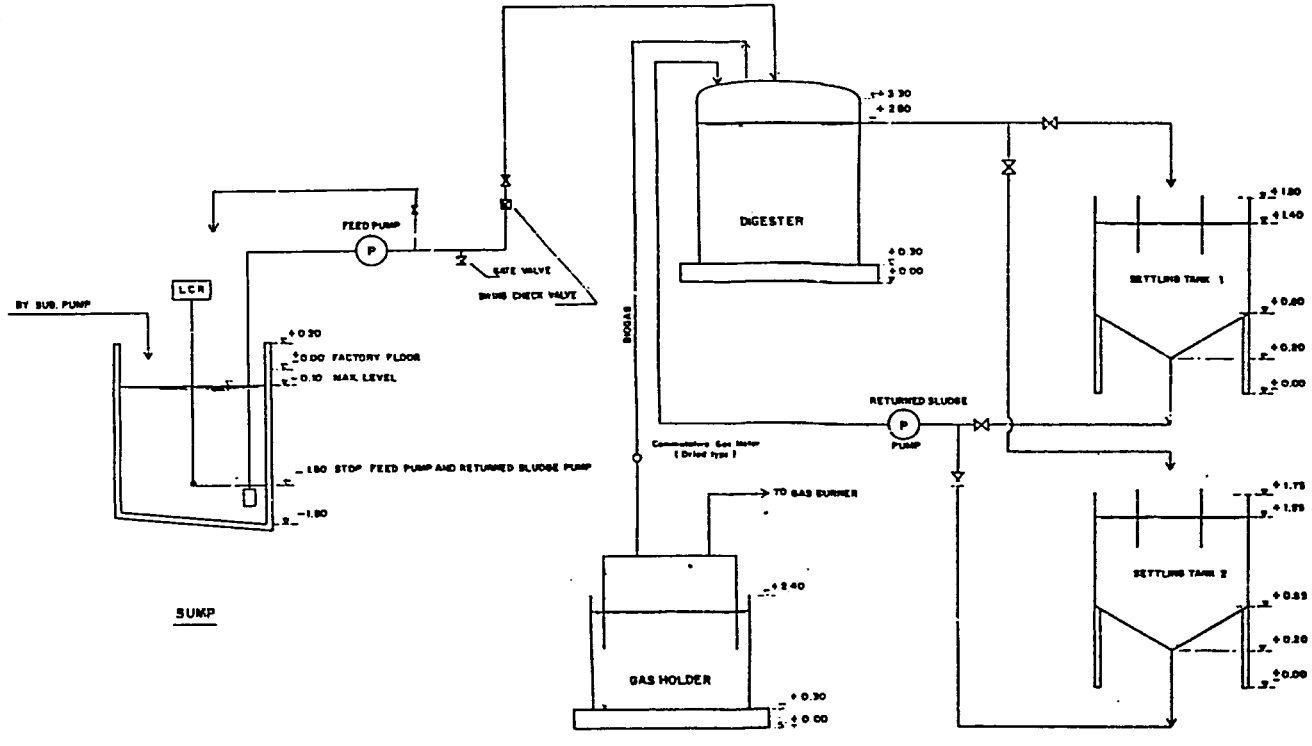

HYDRAULIC PROFILE

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY

NATIONAL ENERGY ADMINISTRATION

PILOT PLANT OF INDUSTRIAL BIOGAS

(TAPIOCA STARCH WASTE)

FACULTY OF ENVIRONMENT AND RESOURCE STUDIES

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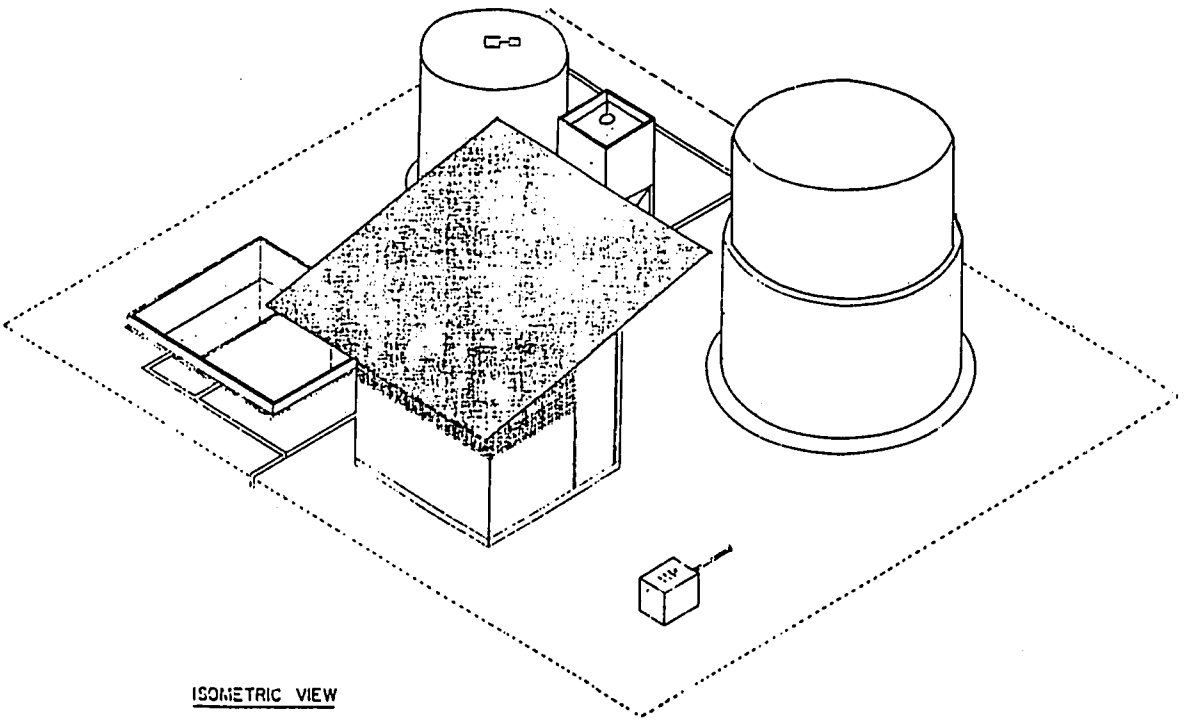

ISOMETRIC VIEW

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PILOT PLANT OF INDUSTRIAL BIOGAS (TAPIOCA STARCH WASTE)	STRUCTURAL ENG		SCALE	DRAWING NO	TOTAL
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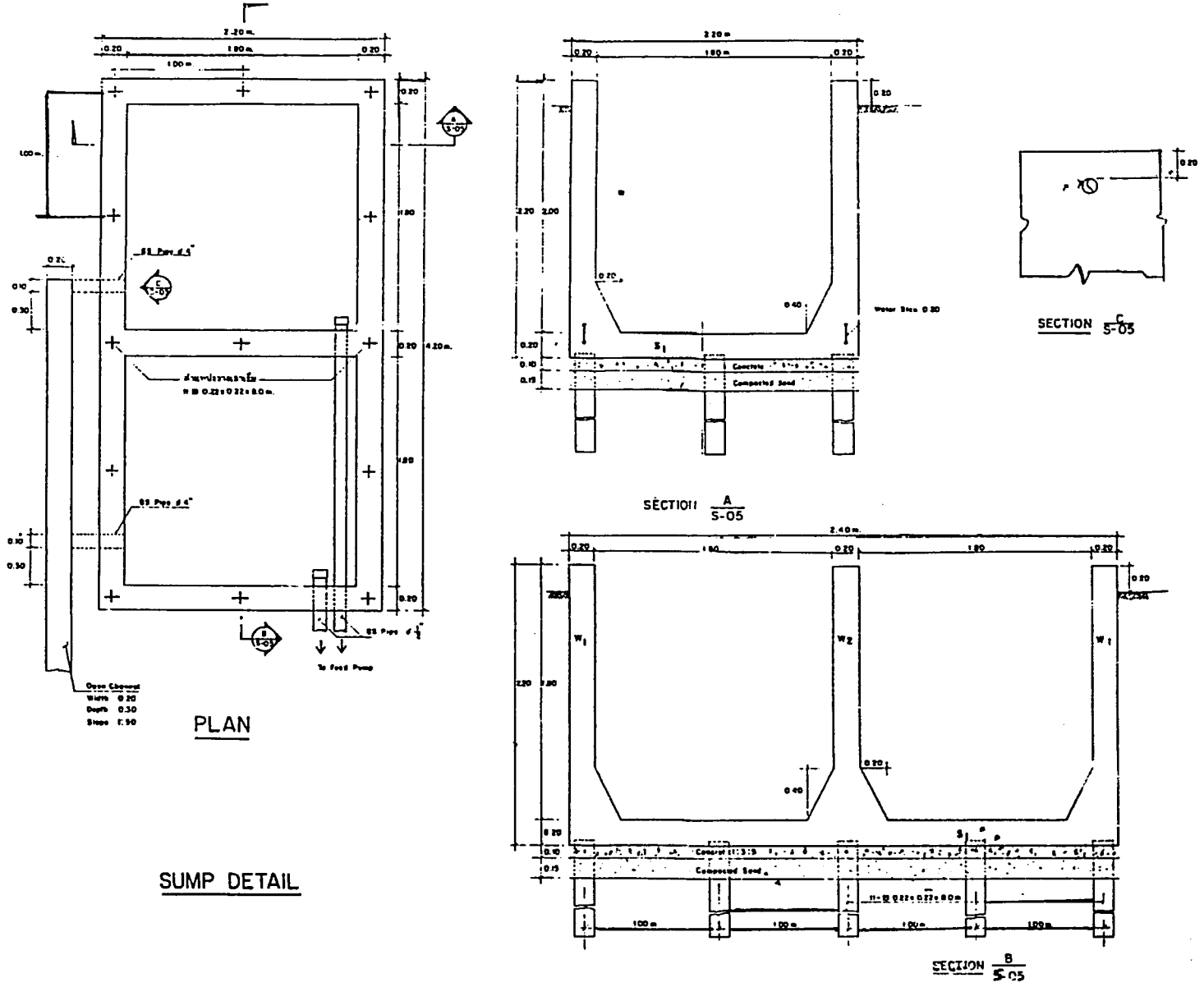
PLAN
SUMP DETAIL
SECTION A/S-05
SECTION B/S-05
SECTION C/S-05
To Feed Pump
Open Channel
Width 0.20
Depth 0.30
Slope 1:50
Concrete
Compacted Sand
Water Stop 0.20
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PILOT PLANT OF INDUSTRIAL BIOGAS
(TAPIOCA STARCH WASTE)
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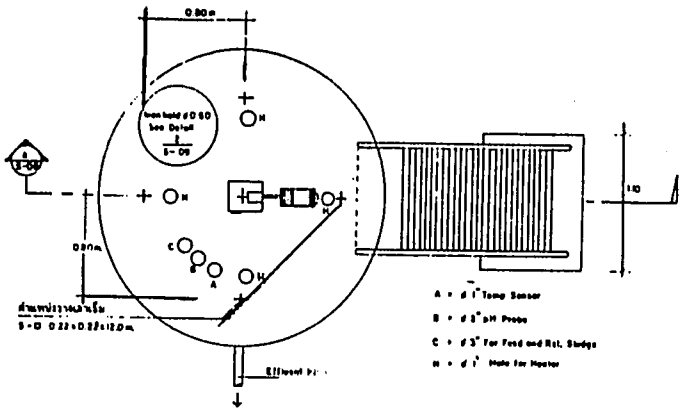

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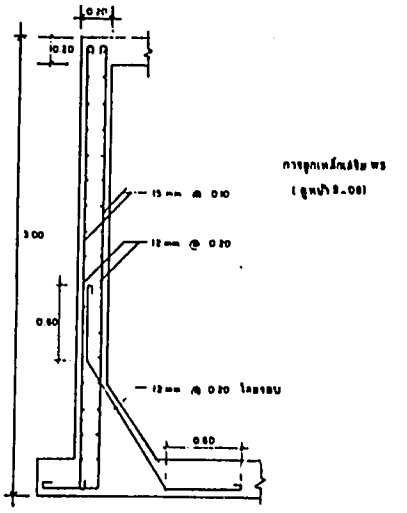
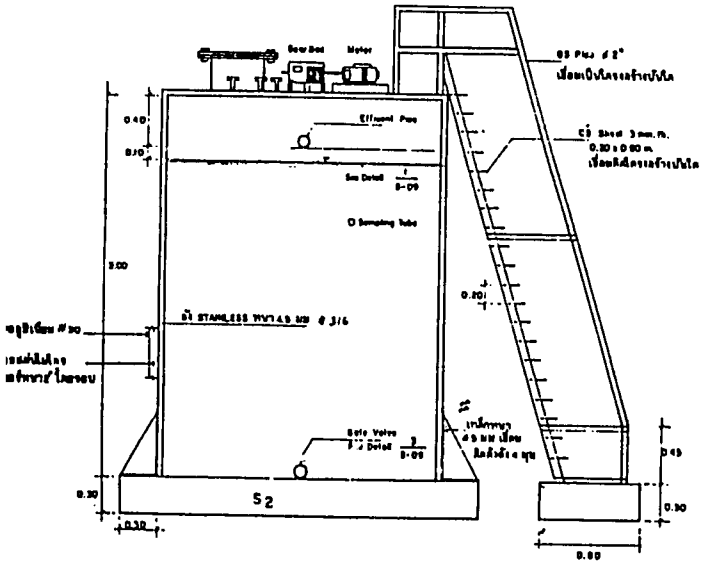
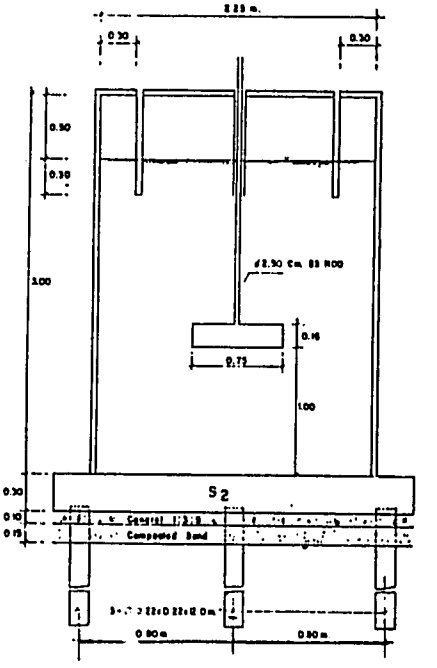




SIDE VIEW



DIGESTER (STAINLESS STEEL)

SECTION $\frac{A}{S-08}$

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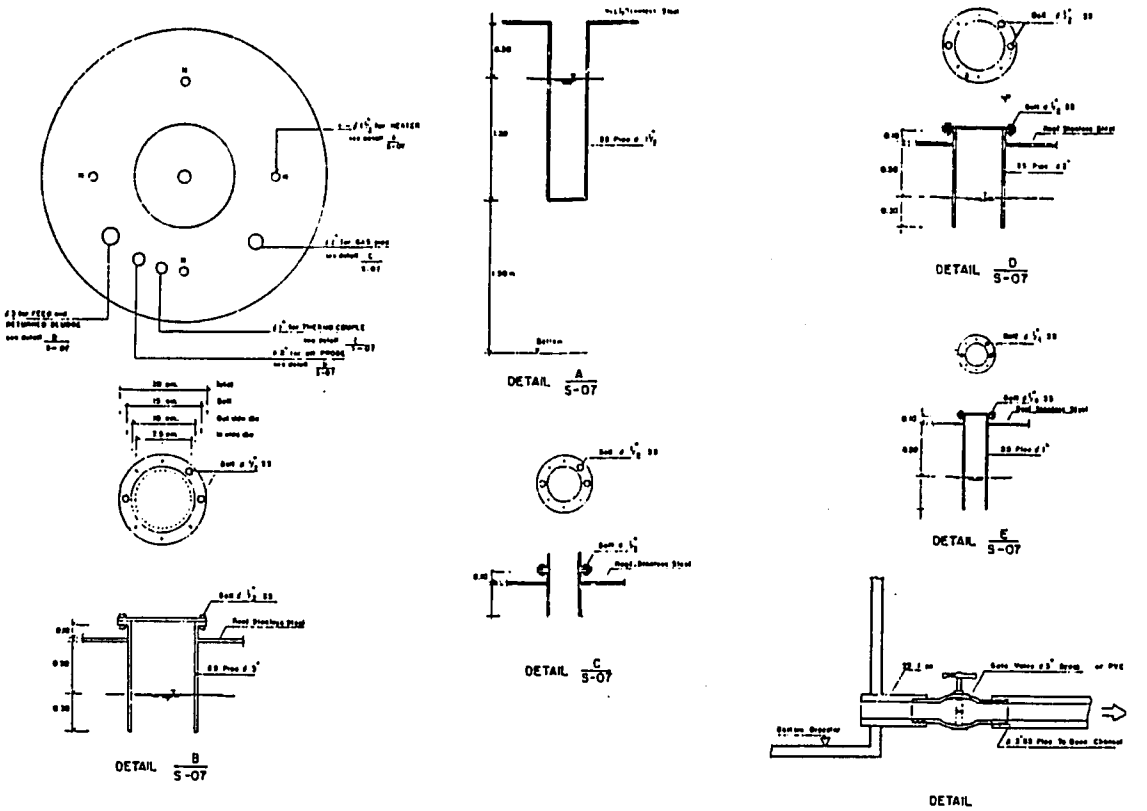

DIGESTER (STAINLESS STEEL)

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY	DRAWING TITLE	DIGESTER (STAINLESS STEEL)	DRAWN BY	KHIRI KRUTTHANON	
NATIONAL ENERGY ADMINISTRATION	DESIGNED BY	PREECHA PLOYPATARAPHYO	CHECKED BY	MANIT VISUTHIRUNGSI-URI	
	PROJECT ENG.	PREECHA PLOYPATARAPHYO	APPROVED BY	MANIT VISUTHIRUNGSI-URI	
PILOT PLANT OF INDUSTRIAL BIOGAS (TAPIOCA STARCH WASTE)	STRUCTURAL ENG.		SCALE	DRAWING NO	TOTAL
FACULTY OF ENVIRONMENT AND RESOURCE STUDIES MAHIDOL UNIVERSITY	ELECTRICAL ENG.		DATE	S – 07	
	MECHANICAL ENG.				

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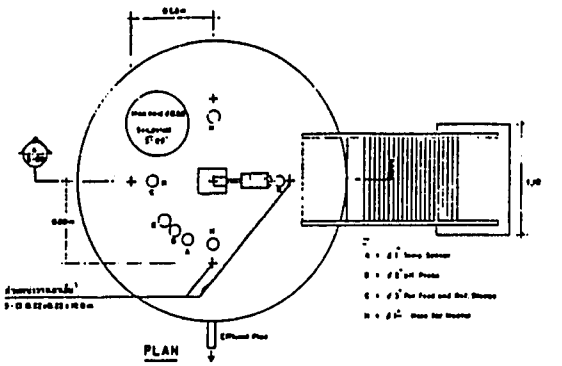

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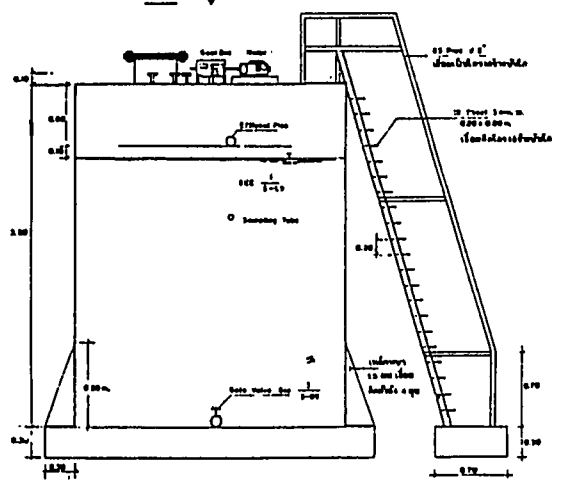
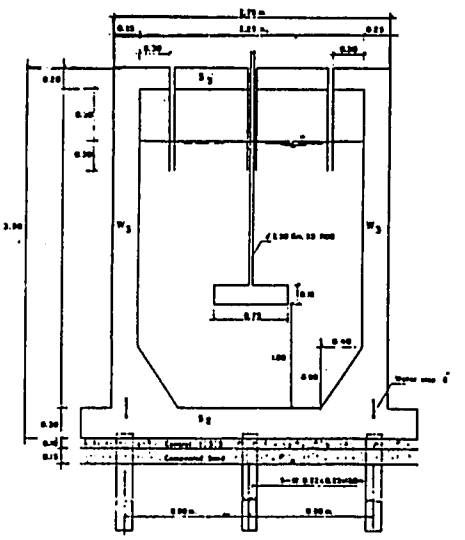


SIDE VIEW



SECTION A/S-08

DIGESTER (R/C)

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY	DRAWING TITLE	DIGESTER (R/C)	DRAWN BY	PHIRI KRUTTHAKON	
NATIONAL ENERGY ADMINISTRATION	DESIGNED BY	PREECHA PLOYPATARAPHYO 1266	CHECKED BY		
	PROJECT ENG.	PREECHA PLOYPATARAPHYO 1266	APPROVED BY		
PILOT PLANT OF INDUSTRIAL BIOGAS (TAPIOCA STARCH WASTE)	STRUCTURAL ENG.		SCALE 1:25	DRAWING NO	TOTAL
FACULTY OF ENVIRONMENT AND RESOURCE STUDIES MAHIDOL UNIVERSITY	ELECTRICAL ENG.		DATE	S – 08	SHEET
	MECHANICAL ENG.				

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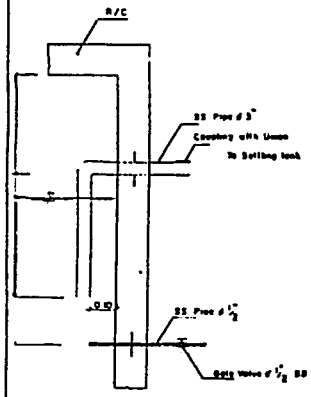
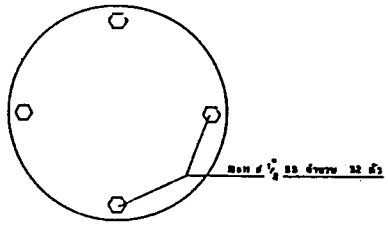
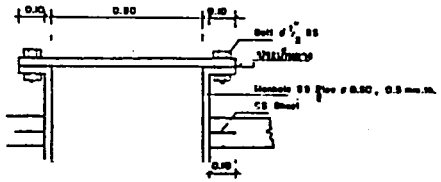
PROVISIONAL PAGE SHEET

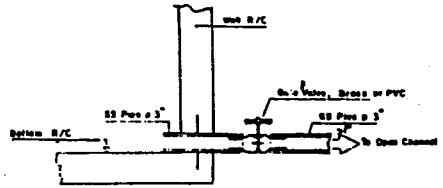


DETAIL $\frac{1}{S-09}$ (EFFLUENT PIPE)

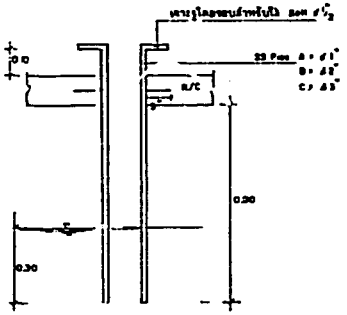


DETAIL OF MANHOLE $\frac{2}{S-09}$

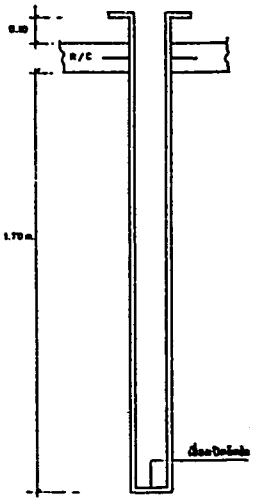




DETAIL $\frac{3}{S-09}$



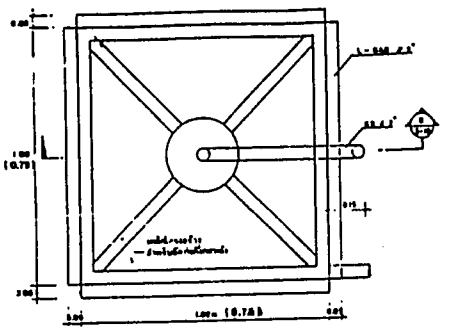
DETAIL OF HOLE A, B, C



DETAIL OF HOLE FOR HEATER

DIGESTER R/ C

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY			
NATIONAL ENERGY ADMINISTRATION			
PILOT PLANT OF INDUSTRIAL BIOGAS (TAPIOCA STARCH WASTE)			
FACULTY OF ENVIROMENT AND RESOURCE STUDIES MAHIDOL UNIVERSITY			
DRAWING TITLE	DIGESTER R/C	DRAWN BY	COMP. SUPITTHANONG
DESIGNED BY	PREECHA PLOYPAISARNPHYO	CHECKED BY	PRAPAT VISUTHIRUNGSI-URN
PROJECT ENG.	PREECHA PLOYPAISARNPHYO	APPROVED BY	PRAPAT VISUTHIRUNGSI-URN
STRUCTURAL ENG.		SCALE 1:125	
ELECTRICAL ENG.		DATE	
MECHANICAL ENG.		DRAWING NO.	S – 09
		TOTAL	



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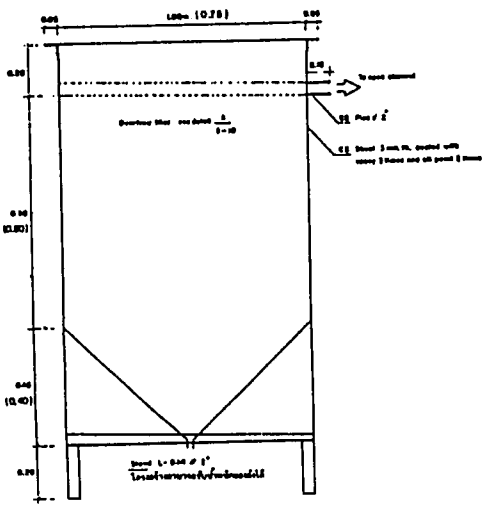
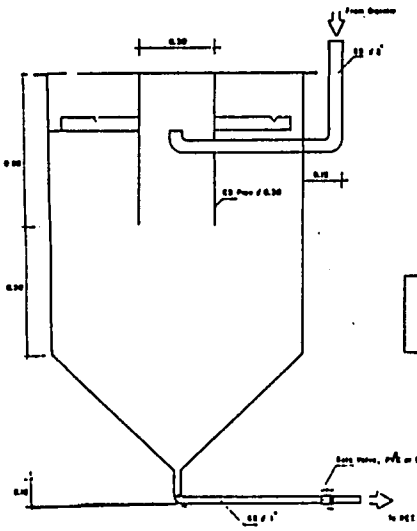


SETTLING TANK



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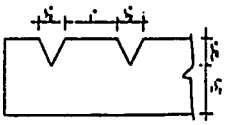

DETAIL $\frac{A}{S-10}$

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY	DRAWING TITLE	SETTLING TANK	DRAWN BY	KHRU SRUTTHAMON	
NATIONAL ENERGY ADMINISTRATION	DESIGNED BY	PREECHA PLOYPATARAPHYO	CHECKED BY	NIMIT VISUTHIPRUMESHURI	
	PROJECT ENG.	PREECHA PLOYPATARAPHYO	APPROVED BY	NIMIT VISUTHIPRUMESHURI	
PILOT PLANT OF INDUSTRIAL BIOGAS (TAPIOCA STARCH WASTE)	STRUCTURAL ENG.		SCALE 1:100	DRAWING NO S — 10	TOTAL SHEET
FACULTY OF ENVIRONMENT AND RESOURCE STUDIES MAHIDOL UNIVERSITY	ELECTRICAL ENG.		DATE		
	MECHANICAL ENG.				

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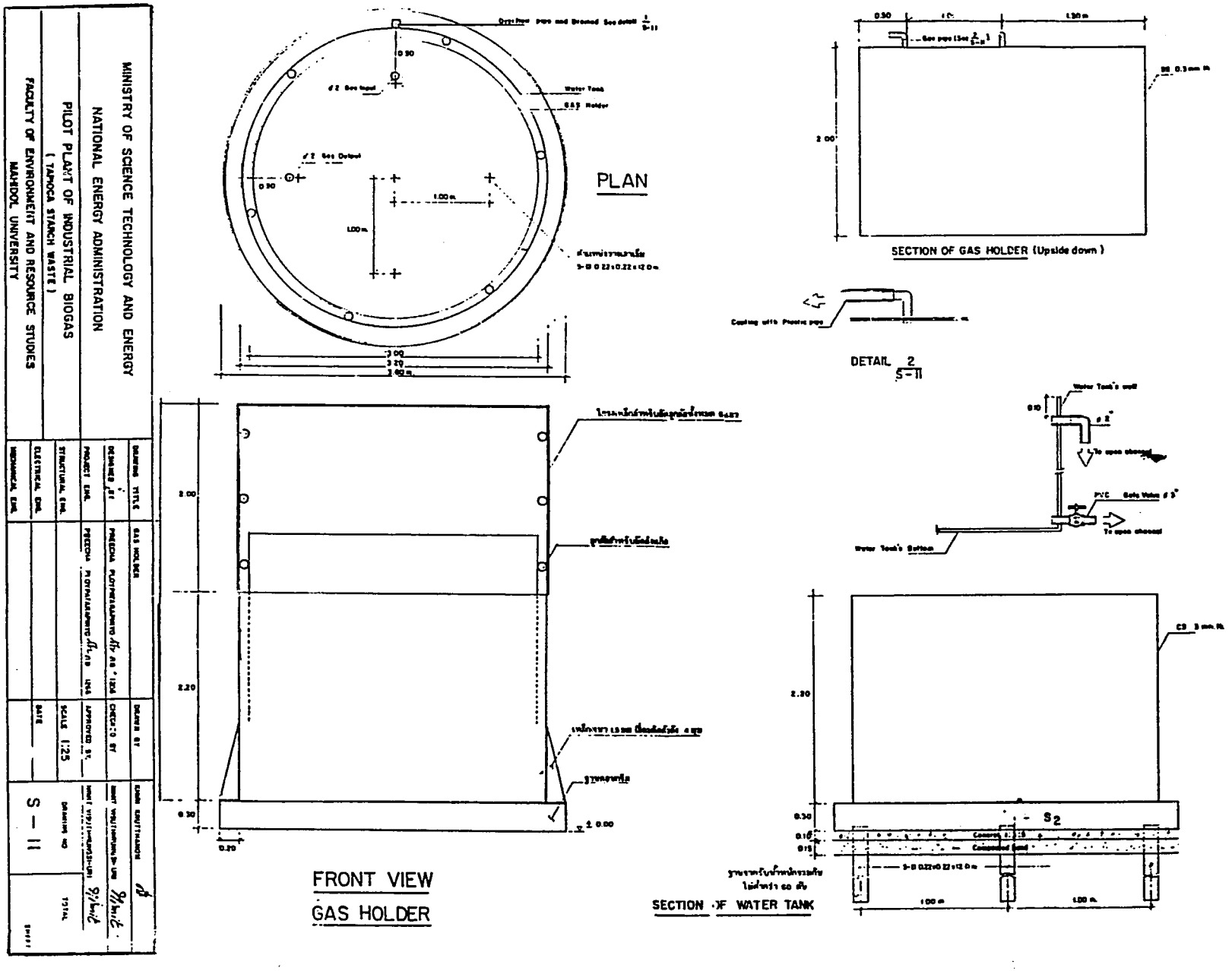
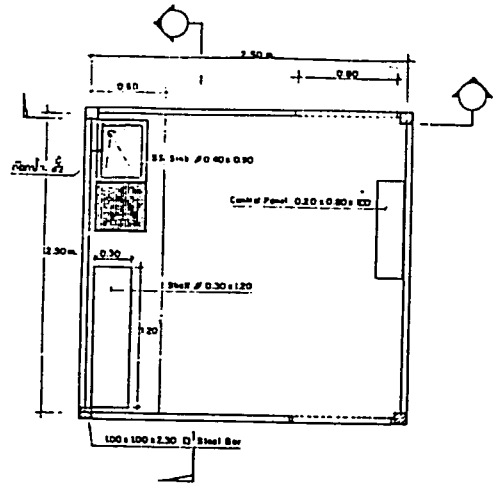
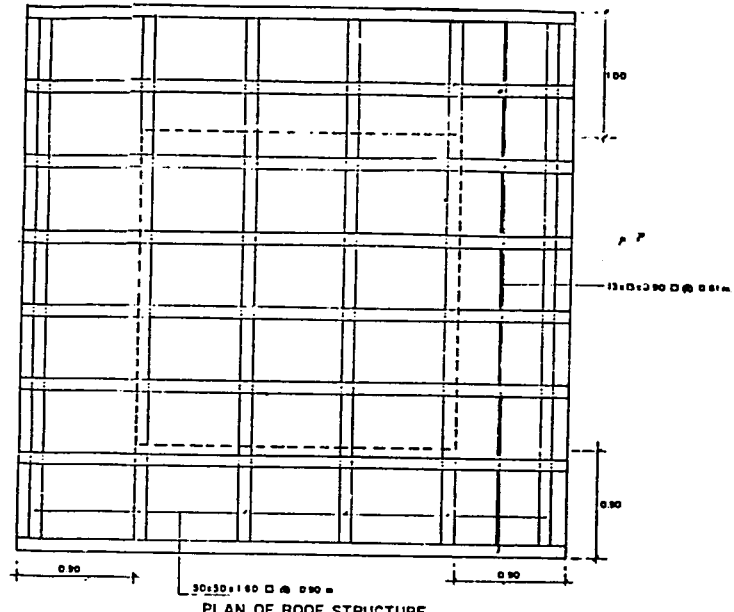
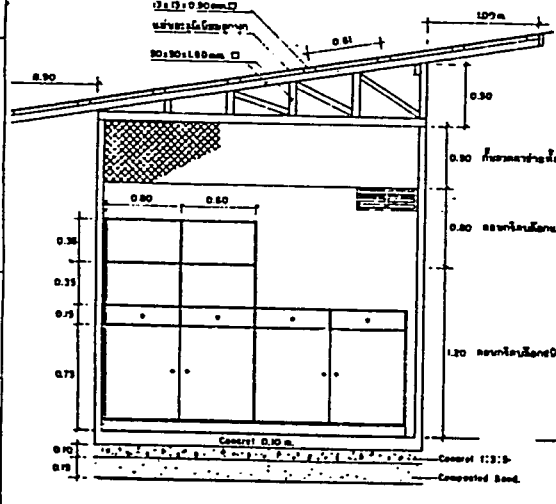

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY
NATIONAL ENERGY ADMINISTRATION
PILOT PLANT OF INDUSTRIAL BIOGAS
(TAPIOCA STARCH WASTE)
FACULTY OF ENVIRONMENT AND RESOURCE STUDIES
MAHIDOL UNIVERSITY
DRAWING TITLE
GAS HOLDER
DRAWN BY
CHECKED BY
APPROVED BY
SCALE 1:25
DATE
DRAWING NO
S — 11
PLAN
SECTION OF GAS HOLDER (Upside down)
DETAIL 2/S-11
FRONT VIEW
GAS HOLDER
SECTION OF WATER TANK
Water Tank
Water Tank's wall
Water Tank's Bottom
PVC Gate Valve
Concrete
Compacted Sand
S2



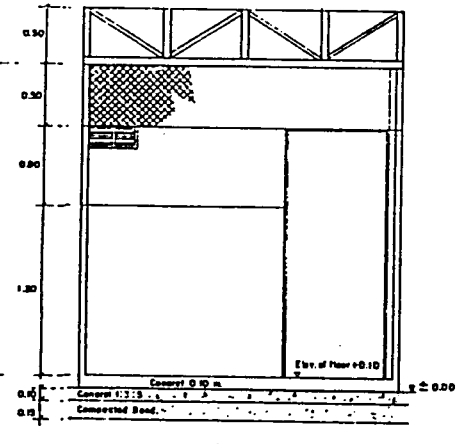
PLAN OF CONTROL ROOM



PLAN OF ROOF STRUCTURE



SECTION - A



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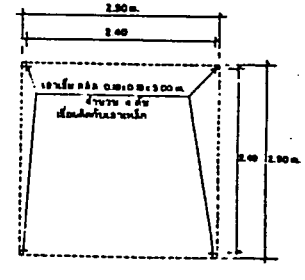

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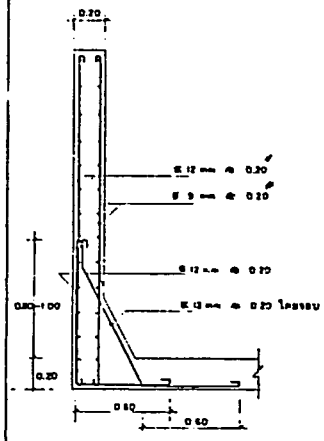
CONTROL ROOM

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY	
NATIONAL ENERGY ADMINISTRATION	
PILOT PLANT OF INDUSTRIAL BIOGAS (TAPIOCA STARCH WASTE)	
FACULTY OF ENVIRONMENT AND RESOURCE STUDIES MAHIDOL UNIVERSITY	
DRAWING TITLE	CONTROL ROOM
DESIGNED BY	PREECHA PUTTHAWANWONG
PROJECT ENG.	PREECHA PUTTHAWANWONG
STRUCTURAL ENG.	1506
ELECTRICAL ENG.	SCALE 1:25
MECHANICAL ENG.	DATE
DRAWN BY	1506
CHECKED BY	
APPROVED BY	
DWG. REVISION	
SHEET VISUTHAMPHAN-UAN	
SHEET VISUTHAMPHAN-UAN	
DRAWING NO	S - 12
TOTAL	



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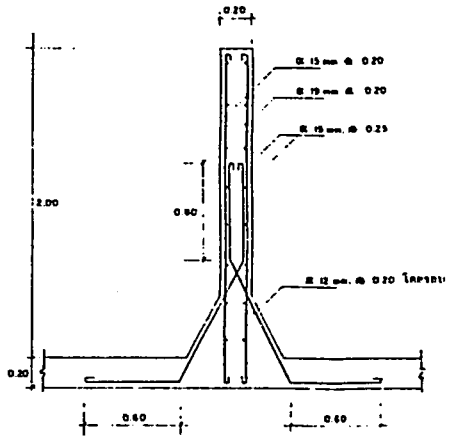

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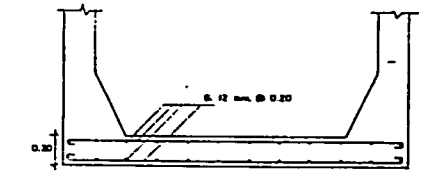

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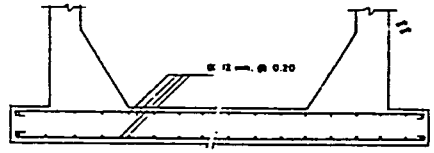
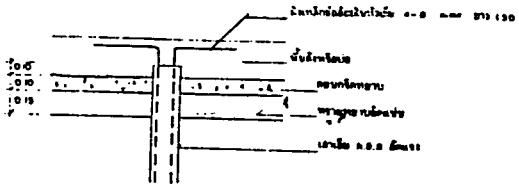


S2

Note: W_3 See Detail S-06



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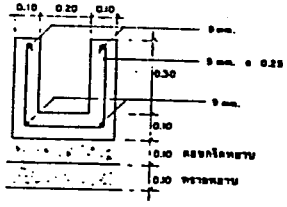

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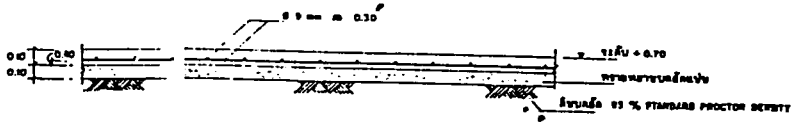
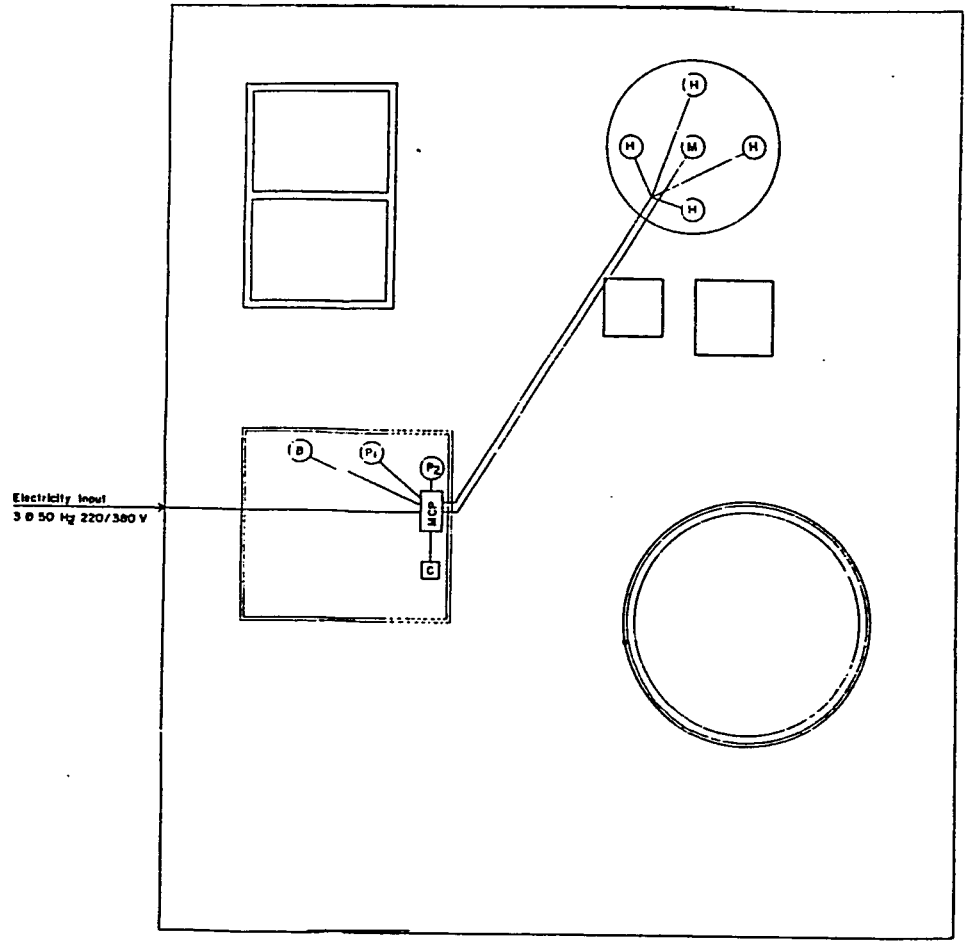


แบบทั่วไปของพื้น ค.ส.ล.

REINFORCEMENT DETAIL

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY			
NATIONAL ENERGY ADMINISTRATION			
PILOT PLANT OF INDUSTRIAL BIOGAS (TAPIOCA STARCH WASTE)			
FACULTY OF ENVIRONMENT AND RESOURCE STUDIES MAHIDOL UNIVERSITY			
DRAWING TITLE	REINFORCEMENT DETAIL	DRAWN BY	DRAWING NO S - 13
DESIGNED BY	PREECHA PLOYPAIRAPHATO	CHECKED BY	TOTAL
PROJECT ENGR	PREECHA PLOYPAIRAPHATO	APPROVED BY	SHEET
STRUCTURAL ENG.		SCALE 1:25	
ELECTRICAL ENG.		DATE	
MECHANICAL ENG.			

LEGEND	ABBREVIATION
(P)	PUMP
(B)	AIR BLOWER
(C)	GAS COMPRESSOR
(M)	MIXER
MCP	MAIN CONTROL PANEL
——	ELECTRICAL WIRE
CF	CARTRIDGE FUSE
K	RELAY
	CONTACTOR N/O
	CONTACTOR N/C
H	PILOT LIGHT
F	THERMAL OVER CURRENT RELAY
M	MOLDED CASE CIRCUIT BREAKER
Ø	TERMINAL JUMP
N	NEUTRAL
PE	POTENTIAL EARTH
+	WIRE CROSS
+	WIRE JUMP
S	SELECTION ON-OF SWITCH



ELECTRICITY PLAN

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY

NATIONAL ENERGY ADMINISTRATION

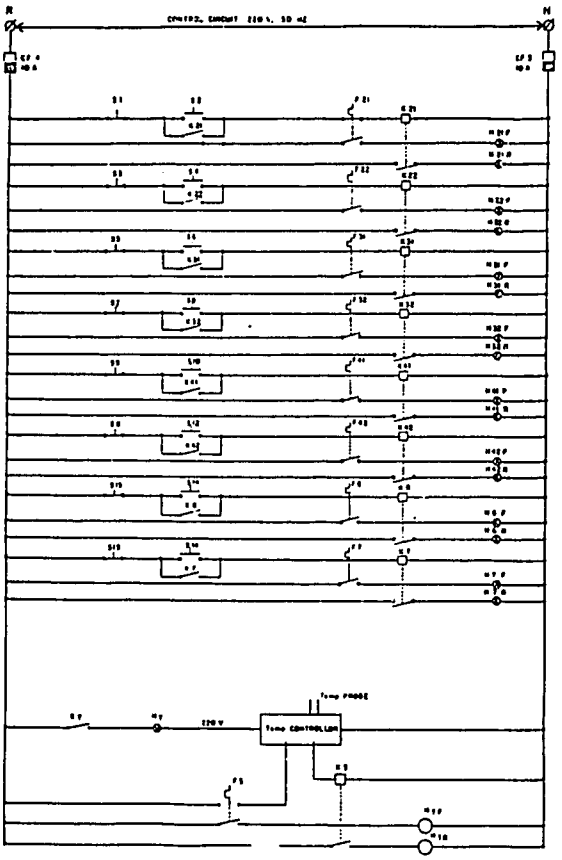
PILOT PLANT OF INDUSTRIAL BIOGAS

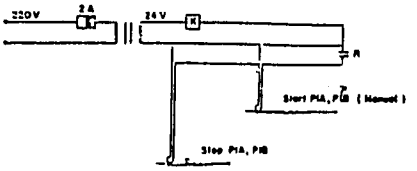
(TAPIOCA STARCH WASTE)

FACULTY OF ENVIRONMENT AND RESOURCE STUDIES

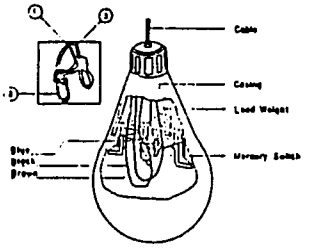
MAHIDOL UNIVERSITY

DRAWING TITLE	ELECTRICITY PLAN	DRAWN BY	SUPR. ABUTHAKIRN
DESIGNED BY	PREECHA PLOTHONGKAMNUAN	CHECKED BY	
PROJECT ENG	PREECHA PLOTHONGKAMNUAN	APPROVED BY	
STRUCTURAL ENG		SCALE	DRAWING NO. S - 14
ELECTRICAL ENG		DATE	TOTAL
MECHANICAL ENG			





WIRING DIAGRAM OF TWO LEVEL LCR.



MERCURY SWITCH LEVEL REGULATOR

CONTROL CIRCIUT

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY	DRAWING TITLE	CONTROL CIRCIUT	DRAWN BY	KHAN KPUTTIRAKON	
NATIONAL ENERGY ADMINISTRATION	DESIGNED BY	PREECHA PLOYPATARAPHYO 1268	CHECKED BY	NAMIT VISUTHIRUNGSI-URI	
	PROJECT ENG.	PREECHA PLOYPATARAPHYO 1268	APPROVED BY	NAMIT VISUTHIRUNGSI-URI	
PILOT PLANT OF INDUSTRIAL BIOGAS (TAPIOCA STARCH WASTE)	STRUCTURAL ENG.		SCALE	DRAWING NO	TOTAL
FACULTY OF ENVIRONMENT AND RESOURCE STUDIES MAHIDOL UNIVERSITY	ELECTRICAL ENG.		DATE	S – 17	
	MECHANICAL ENG.				

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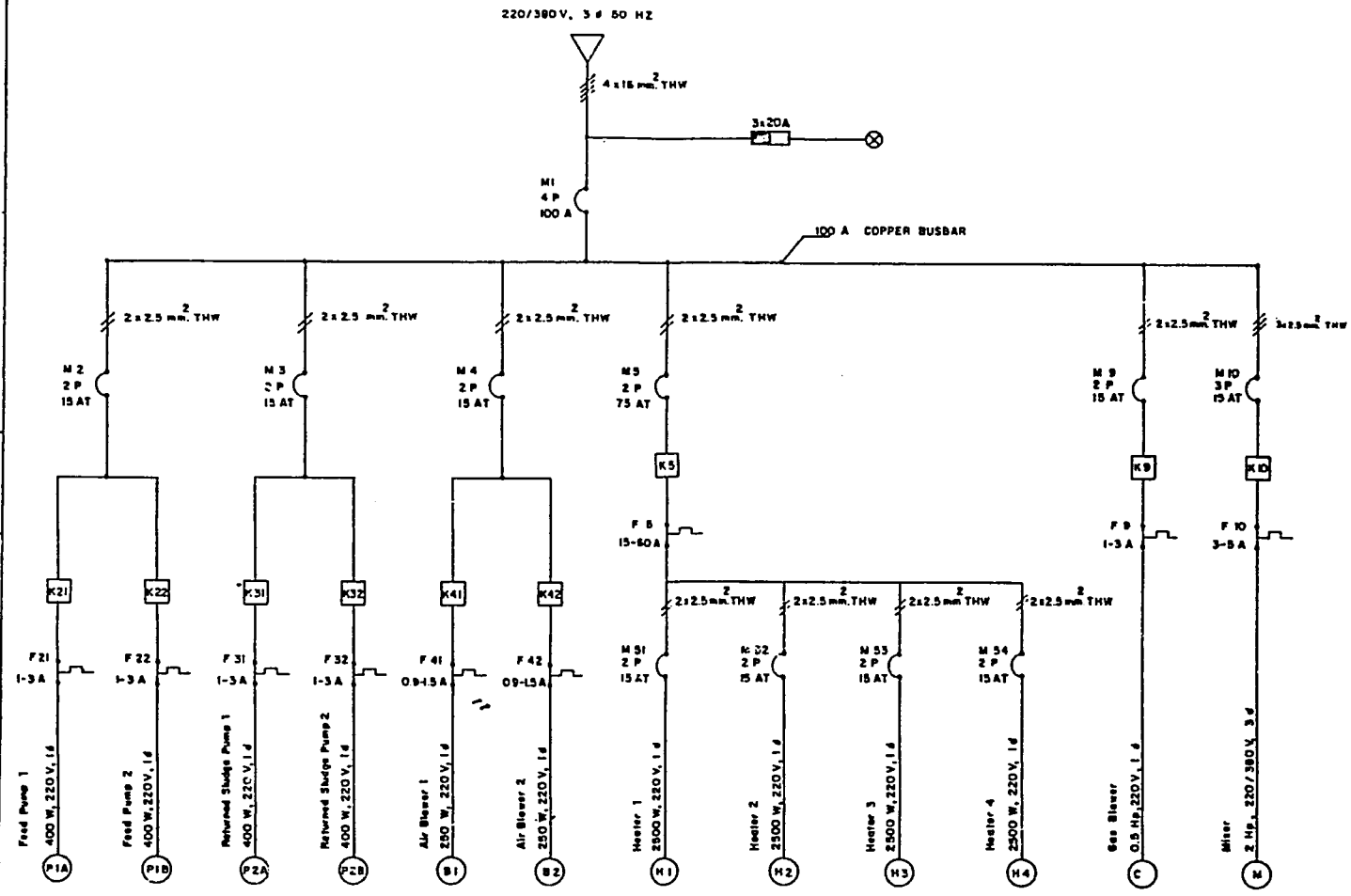


SINGLE LINE DIAGRAM

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY

NATIONAL ENERGY ADMINISTRATION

PILOT PLANT OF INDUSTRIAL BIOGAS

(TAPIOCA STARCH WASTE)

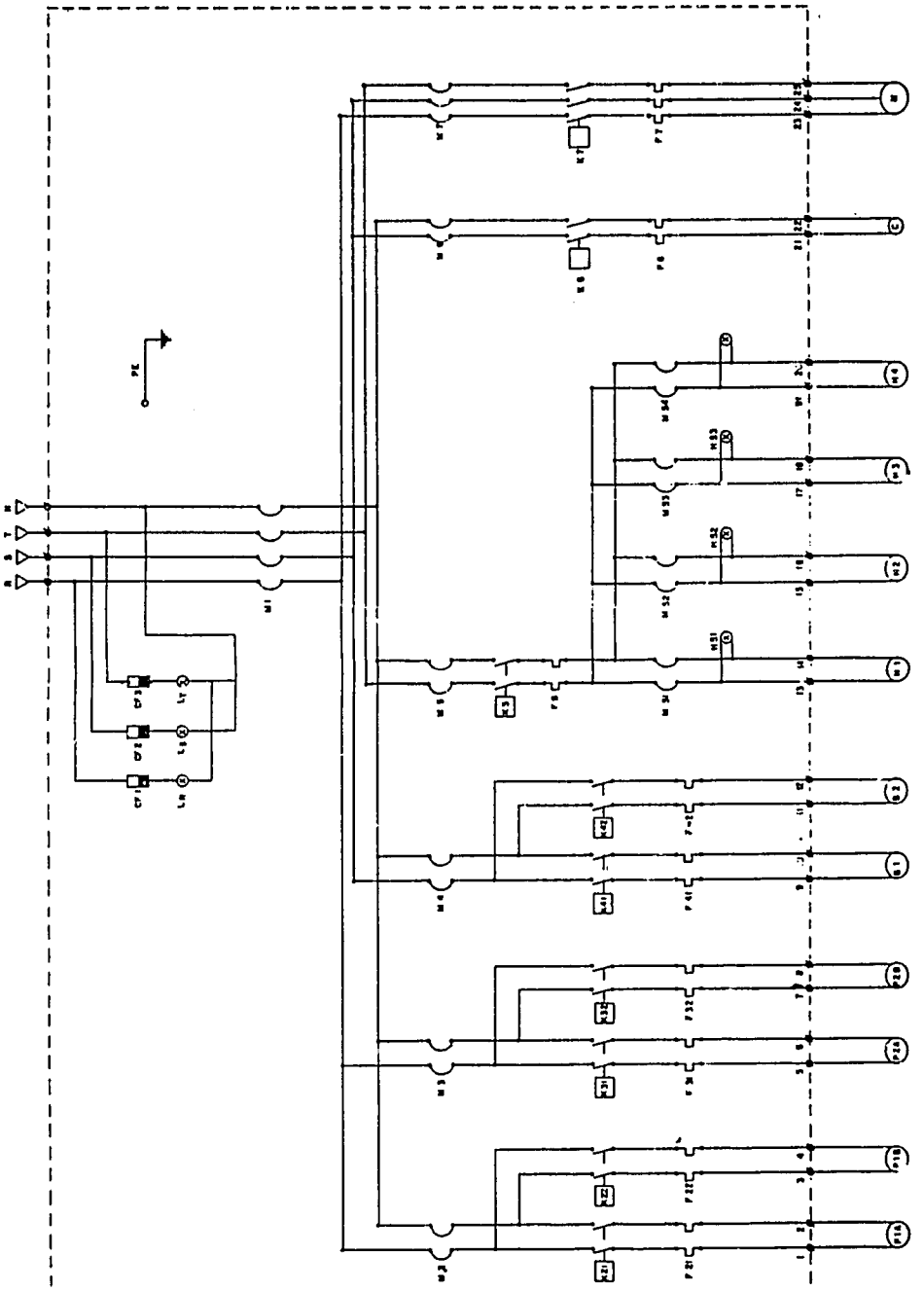
FACULTY OF ENVIRONMENT AND RESOURCE STUDIES

MAHIDOL UNIVERSITY

DRAWING TITLE	SINGLE LINE DIAGRAM	DRAWN BY	
DESIGNED BY	PREECHA PLOYPAISARNPITO	CHECKED BY	
PROJECT ENG	PREECHA PLOYPAISARNPITO	APPROVED BY	
STRUCTURE ENG		SCALE	
ELECTRICAL ENG			
MECHANICAL ENG			

DRAWING NO. S – 15

TOTAL



WIRING DIAGRAM

MINISTRY OF SCIENCE TECHNOLOGY AND ENERGY	DRAWING TITLE	WIRING DIAGRAM	DRAWN BY	SOMRI KRUTTHAROM	
NATIONAL ENERGY ADMINISTRATION	DESIGNED BY	PREECHA PLOYPATARAPHYO AB. 1264	CHECKED BY	WIMIT VISUTHIRUNESH-UNI	
	PROJECT ENG	PREECHA PLOYPATARAPHYO AB. 1264	APPROVED BY	WIMIT VISUTHIRUNESH-UNI	
PILOT PLANT OF INDUSTRIAL BIOGAS (TAPIOCA STARCH WASTE)	STRUCTURAL ENG.		SCALE	DRAWING NO. S — 16	TOTAL SHEET
FACULTY OF ENVIRONMENT AND RESOURCE STUDIES MAHIDOL UNIVERSITY	ELECTRICAL ENG.		DATE		
	MECHANICAL ENG.				

ANNEX II

COST ANALYSIS

1.	Assume gas production	150 m^3/day
2.	Heating value of biogas	6225 Kcal/m^3
3.	Fuel oil saving per day	90 Liters
4.	Heating value of fuel oil	9826 Kcal/liters
5.	Price of fuel oil	4.32 baht/liters
6.	Repair & maintenance	20,000 baht/year
7.	Operation	36,000 baht/year
8.	No inflation rate	

* 1 US Dollar = 23 baht

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Table II.1 Annual capital cost of system at various interest rates

No.	Item	Present life		Present value (baht)	Annual Capital Cost			
		10 years	30 years		8%	10%	12%	15%
1.	Sump		_/	121,918	10,830	12,933	15,135	18,568
2.	Digester		_/	121,462	10,790	12,885	15,078	18,499
	Gas Compressor			50,000	4,442	5,304	6,207	7,615
3.	Settling tank		_/	35,470	3,151	3,763	4,403	5,402
	Mixing motor	_/		4,500	671	732	796	897
4.	Gas holder + tank		_/	534,055	47,440	56,653	66,298	81,337
5.	Pump house		_/	31,395	2,789	3,330	3,897	4,781
6.	Air blower + Pump		_/	482,600	42,870	51,194	59,910	73,500
7.	Const. Cost			276,280	24,542	29,308	34,297	42,077
8.	Land			10,000	888	1,061	1,241	1,523
9.	Repair & maint			20,000	20,000	20,000	20,000	20,000
10.	Operator			36,000	36,000	36,000	36,000	36,000
					204,413	233,163	263,262	310,199

Table II.2 Production cost at various interest rates

Type of fuel	Interest rate %	Production cost Baht/1000 kcal.
fuel oil	-	0.44
Biogas	8	0.60
	10	0.68
	12	0.77
	15	0.91

Table II.3 Net Present Value at 8% interest rate

Costs	Revenue	Cash flow	Discount cash flow at 8% interest
1,667,680	0	-1,667,680	-1,667,680
56,000	141,912	85,912	79,546
56,000	141,912	85,912	73,652
56,000	141,912	85,912	68,197
56,000	141,912	85,912	63,145
56,000	141,912	85,912	58,472
56,000	141,912	85,912	54,142
56,000	141,912	85,912	50,130
56,000	141,912	85,912	46,418
56,000	141,912	85,912	42,973
60,500	141,912	81,412	37,710
56,000	141,912	85,912	36,848
56,000	141,912	85,912	34,116
56,000	141,912	85,912	31,590
56,000	141,912	85,912	29,253
56,000	141,912	85,912	27,079
56,000	141,912	85,912	25,078
56,000	141,912	85,912	23,222
56,000	141,912	85,912	21,495
56,000	141,912	85,912	19,906
60,500	141,912	81,412	18,428
56,000	141,912	85,912	17,071
56,000	141,912	85,912	15,799
56,000	141,912	85,912	14,631
56,000	141,912	85,912	13,548
56,000	141,912	85,912	12,543
56,000	141,912	85,912	11,615
56,000	141,912	85,912	10,756
56,000	141,912	85,912	9,957
56,000	141,912	85,912	9,218
56,000	141,912	85,912	8,540
			-702,602

ANNEX III

The following schedule of activities and estimated budget are from the original work plan submitted to USAID for consideration. Later it was found that Thailand Institute of Scientific and Technological Research (TISTR) would not be able to perform the research and this responsibility was given to Mahidol University.

The Operational and Financial Plans are also included here. The total amount paid to Mahidol University was $20,020 and the total equipment costs were $16,463. Thus, the total amount spent for this Biogas Project was $36,483.

It should be mentioned here that although $18,000 was budgeted for training, no training took place.

Activity Schedule : This project covers 30 months after USAID approval.

Activities	Organization responsible	1982				1983				1984			
		3	6	9	12	3	6	9	12	3	6	9	12
1. Training and Observation tour : 2 NEA officials in Republic of China, Korea, India, Philippines, etc.	NEA				2MO								
2. Demonstration and Evaluation of a small to medium scale industry	TISTR												
2.1 Investigation and Site Selection				2MO									
2.2 Detailed Design					3MO								
2.3 Specification & Cost Estimation						1MO							
3. Report related to the tasks No. 2	TISTR					2MO							
4. Bidding and Plant Construction	NEA							7MO					
5. Plant Start-Up	TISTR								2MO				
6. Technical monitoring	NEA									5MO			
7. Economic feasibility study	TISTR									3MO			
8. Dissemination (including the publications and video type preparation)	NEA											4MO	

Activities	Budget in dollars		
	USAID	MEA	DTEC
5.1.2 2 Scientisits, 4th Grade @ US. $ 600	-	18,000	-
5.1.3 2 Engineers, 4th Grade @ US. $ 600	-	18,000	-
5.1.4 3 Development personnel @ US. $ 375	-	11,250	-
5.1.5 3 Extension workers @ US. $ 375	-	11,250	-
5.2 Materials and Supplies (Printing, Office supplies and miscellaneous)	-	7,500	-
Total 1 - 5	125,000	124,200	7,500

Assistance Requirement

The budget to be requested from various institutes are roughly broken down as tabulated below.

Activities	Budget in dollars		
	USAID	NEA	[illegible]
1. Training and Observation tour : 2 NEA officials in Republic of China, Karea, India and Philippines, etc. (air fare, perdiem/ lodging and training fee)	18,000	3,200	5,000
2. Technical assistance : in terms of Investigation, Design, Estimate, Specification, Bidding doccument preparation, Plant start-up and Monitoring.	31,000	2,500	2,500
3. Demonstration Plant : Three of the mentioned industries will be selected. These are dairy industry with milk and/or cheese processing plant, preserved food industry, poultry industry, slaughter house industry, noodle industry, piggery industry.	48,000	30,000	-
4. Equipments			
4.1 Monitoring equipments	18,000	-	-
4.2 Dissemination equipments	10,000	-	-
5. Technical and Administration Supplies			
5.1 Salaries and Staff Related Expenditure (Estimated based on 75 % of the time)			
5.1.1 Team leader 6th Grade Engineer @ US. $ 750	-	22,500	-

LIST OF AWARD

PIO/C NO. 493-0304-9-90037
INVITATION NO. RNE-075
RNE-N 075(1)
RNE-N 075(2)

BID OPENED: November 10, 1902
February 17, 1903
August 25, 1903

AWARD MADE: December 29, 1902
July 20, 1903
September 21, 1903

CONT NO.	EFFECTIVE DATE	SUCCESSFUL BIDDER	CODE/ ITEM NO.	DESCRIPTION	Q'TY UNIT	AMOUNT US $	SOURCE	DELIVERY ON OR BEFORE
160	Jan 11,1903	International Chemical & Equipment Co.,Ltd.	1	Peristatic Pump	2 Sets	000	U.S.A.	May 11, 1903.
			2	Stirrer	2 Sets	1,200	U.S.A.	
159	Mar.15,1903	VWR Scientific,Inc.	3	Spectronic Spectrophoto meter	1 Set	2,254	U.S.A.	90 days after confirmation of letter of commitment
			4	Reflux Apparatus	1 Set	1,510	U.S.A.	
162	Feb.10,1903	Siam & Co Co.,Ltd.	5	Muffle Furnace	1 Set	฿10,900	U.S.A.	March 14, 1903.
161	Feb.10,1903	Siam & Co Co.,Ltd.	6	PH Meter	1 Set	003	U.S.A.	May 11,1903.
103	Aug.2,1903	Thanee Logistic Network Ltd.,Part.	3.1	Slide Projector and Tape Recorder	1 Set	฿20,000	W.Germany	Sept.1,1903.
			0.3	Amplifier	1 Set	฿12,900	Japan	
			0.5	Tripod Screen	1 Set	฿ 1,000	U.S.A.	
195	Oct.25,1903	Precision Equipment Co.,Ltd.	7	Orsat Gas Apparatus	1 Set	฿153,000	U.S.A.	Nov.24,1903.
194	Oct.19,1903	Krung Siam Enterprise Co.,Ltd.	3.2	Microphone Set	1 Set	฿ 9,000	Japan	Nov.10, 1903.
			3.4	Lound Speaker Set	1 Set	฿ 2,000	Thailand	

REMARK:

RNE-075
Items 2, 3, 4 and 5 are awarded to the lowest bid.
Items 1 and 6 are awarded to the 3rd low bid, which meets requirement.
Items 7 and 0.1 - 0.5 no bid submitted.

RNE-N 075(1)
Item 0.5 is awarded to the lowest bid.
Item 0.3 only one bid submitted and meets requirement.
Item 0.1 is awarded to the 2nd low bid, which meets requirement.
Items 7, 0.2 and 0.4 no bid submitted.

RNE-N 075(2)
Item 7 is awarded to the lowest bid.
Items 0.2 and 0.4 only one bid submitted and meets requirement.

Tawanut Prapapant

DIRECTOR, PROCUREMENT AND TAX CLEARANCE DIVISION.

Attachment A1

List of Goods

Item No.	Quantity	Description	Unit Baht	Total Baht
7	1 Set	Orsat Gas Apparatus "BURELL" Model 211 1. General Specifications It used to analyze the composition of fuel gas and products of combustion thereof by the volumetric method involving oxidation or selective absorbtion in liquid reagents of the various components. 2. Detailed Specifications. 2.1 The quantity of the gas mixture are determined:- 2.1.1 Carbondioxide, oxygengas, carbon monoxide and gas in illuminant group by absorbtion method. 2.1.2 Hydrogengas, methane and ethane by oxidation method. 2.2 In the absorbtion method the component from the mixture gas was removed by treatment with suitable liguid absorbing reagents. 2.3 In the oxidation method the combustible components was subjected to oxidation. 2.4 The essentials of a gas analysis apparatus are 2.4.1 Burette assemblies: quantity 2 2.4.2 Absorbtion Pipette comprise of (a) contact pipette: quantity 2 (b) autobubbler pipette: quantity 4 2.4.3 Oxidation assemblies comprise of (a) Perma-Therm Copper-Oxide heaters: quantity 1 (b) Copper oxide tube: quantity 2 (c) Perma-Therm Catalyst-heaters: quantity 1 (d) Catalyst tube: quantity 3 2.4.4 Gas Manifold quantity = 6 2.4.5 Gas expansion bag: quantity = 5 2.4.6 Gas reservoir: quantity = 4 2.4.7 Levelling bottles: quantity = 2 2.4.8 Gas containers: quantity = 12 2.4.9 Support frame and case for portable model. 2.4.10 Reagents (a) Disorbent: quantity 1 (b) Lusorbent: quantity 1 (c) Oxsorbent: quantity 1 (d) Cosorbent: Quantity 1 2.4.11 Rubber tube 2.4.12 Applied for 220 VAC, 50 Hz.	153,000	153,000

Attachment A2

Item No.	Quantity	Description	Unit Baht	Total Baht
		2.4.13 The other necessary accessories for complete operation and 2 set of instruction, manuals are supplied. 2.4.14 The unit is guaranteed for 1 year against the manufacturing defects. Manufacturer: Burell Corporation U.S.A.		
		Total CIF/Bangkok		153,000

INDUSTRIAL BIOGAS COMPONENT

FINANCIAL PLAN

FY 84 (OCTOBER 1983 - SEPTEMBER 1984)

ITEM	QUARTER I OCT. 1983 - DEC. 1983				QUARTER II JAN 1984 - MAR. 1984				QUARTER III APR. 1984 - JUN. 1984				QUARTER IV JULY 1984 - SEPT. 1984				TOTAL FOR EACH AGENCY			
	AID	DTEC	NEA	OTHER	AID	DTEC	NEA	OTHER	AID	DTEC	NEA	OTHER	AID	DTEC	NEA	OTHER	AID	DTEC	NEA	OTHER
1. Technical Assistance																				
1.1 Foreign Consultant																				
- Salary																				
- Perdium/lodging																				
- International Travel																				
- Local Travel																				
1.2 Local Consultant																				
- Salary																				
- Pedium/lodging																				
- Local Travel																				
1.3 Researcher																				
- Salary(20 m/m)	816				816				816								2448			
- Pedium/lodging	500				500				700								1700			
- Local Travel																				

ITEMS	QUARTER I OCT. 1983 - DEC. 1983				QUARTER II JAN 1984 - MAR. 1984				QUARTER III APR. 1984 - JUN. 1984				QUARTER IV JULY 1984 - SEPT. 1984				TOTAL FOR EACH AGENCY			
	AID	DTEC	NEA	OTHER	AID	DTEC	NEA	OTHER	AID	DTEC	NEA	OTHER	AID	DTEC	NEA	OTHER	AID	DTEC	NEA	OTHER
1.4 Service of FERS & other institute																				
2. Procurement																				
2.1 Material																				
2.2 Equipment	(7166)																(7166)			
2.3 Construction					(59536)		(30000)										(59536)		(30000)	
3. Administrative Support																				
- Salaries			8100				8100				8100								24300	
- Wages																				
- Perdium/Lodging			300				300				300								900	
- Local Travel																				
- Office supplies			1875				1875				1875								5625	
4. Others (please specify)																				
TOTAL for FY 84	1316		10275		1,316		10275		1,516		10275						4148		30825	
TOTAL for FY 83	7166				59536		30000										66702		30000	
Total for FY 83 - 84	8482		10275		60852		40275		1,516		10275						70850		60825	

REMARK

means the grant requested in FY 83 and is transferred to FY 84

INDUSTRIAL BIOGAS COMPONENT

OPERATIONAL PLAN

FY 84 (Oct. 1983-Sept. 1984)

TASKS/ACTIVITIES.	OCT. 83	NOV. 83	DEC. 83	JAN. 84	FES. 84	MAR. 84	APR. 84	MAY. 84	JUN. 84	JULY. 84	AUG. 84	SEP. 84	RESPONSIBLE AGENCY
I. OBJECTIVE AND TARGET (FY 83-84)													
1. To strengthen the officials capabi -lity to provide technical service.													
2. To demonstrate and evaluate techno -economic feasibility of in ustrial biogas plant with the capacity of 50 cubic meters.													
3. To disseminate the technique and economic aspects.													NEA PROCUREMENT
I. TASK													
II-1 FY 83 TASKS REMAINING													NEA
1. Construction bidding.													
2. Tender selection and contract signed.													NEA/COMMITTEE
3. Construction of demonstration plant.													NEA/CONTRACTOR NEA/CONTRACTOR

INDUSTRIAL BIOGAS COMPONENT

OPERATIONAL PLAN

FY 84 (Oct. 1983-Sept. 1984)

TASKS/ACTIVIBIES	OCT. 83	NOV. 83	DEC. 83	JAN. 84	FEB. 84	MAR. 84	APR. 84	MAY. 84	JUN. 84	JUL. 84	AUG. 84	SEP. 84	RESPONSIBLE AGENCY
II-2 NEW FY 84 TASKS													
1. Acceptance.						—							NEA/NEA ACCEPTANT COMMITTEE
2. Plant start-up and test run.							—						FERS/NEA
3. Technoeconomic feasibility study								—	—				NEA
4. Dissemination (routinely carried out by NEA)										—	—	—	NEA

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9. Wise, D.L., *Anaerobic Fermentation of Whey/Manure to Fuel Gas*. Whey Products Conference co-sponsored by the Whey Product Institute and the U.S. Department of Agriculture, October, 1980.

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