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ANAEROBIC DIGESTION STUDY OF DISTILLERY WASTE

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by

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

Distillery wastewater is one of the most significant sources of high strength waste in the alcoholic beverage industry. Attempt was made to treat this kind of waste by low cost of construction and simplicity of operation and maintenance as well as the energy recovery. Anaerobic digestion was found to be primary treatment process for cane molasses distillery wastewater, with high BOD removal efficiency. It has the addition advantage of recovery of methane gas which in turn can be used as fuel in steam generation for distillation process.

9 kg COD per cubic meter of working capacity per day was found to be optimum for semicontinuous anaerobic digestion of MAS at 35°C. The polluting organic matter could achieve 90% BOD removal and methane gas yielded at 23 m^3 per m^3 of MAS treated. By economic analysis, the MAS primary treatment cost by anaerobic digestion was found to be ฿65 per m^3 of MAS treated, but the benefit cost ratio was about 1.7.

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I INTRODUCTION

Distillery wastewater contains highly soluble organics (BOD ranges from 20,000 - 35,000 mg/l). It is low in nutrients and high in temperature. Besides, this waste has an acid reaction and contains from 50,000 to 100,000 mg/l total solids of which 75 per cent is volatile. These parameters are extremely variable depending upon the raw materials used. There are two main types of raw materials used for producing alcohol or alcohol product, starchy materials (rice, wheat, or barley) and materials containing sugars (fruits and molasses). The process of converting these raw materials into alcohol by yeasts is also accompanied by the formation of by-product wastes of highly pollutional character.

The discharge of distillery waste without any treatment into the river, or nearby land imposes a heavy load on the streams and land, creating health hazards to people, killing aquatic organisms, and marring the beauty of nature. Therefore it is peremptory to minimize the adverse effects of the distillery waste by appropriate treatment methods.

In developing countries, simple and inexpensive wastewater treatment has been considered as the first priority of treatment process. Anaerobic digestion is one of the processes which can be used to achieve this objective at relatively low cost, because of energy recovery in the form of methane gas while reducing the pollutional load of waste.

1.1 Purpose of Study

a. To study the optimal conditions of anaerobic digestion process of molasses alcohol slop which give the maximum gas production per unit waste input.

b. To study the economic aspects of anaerobic digestion process by cost analysis of product of the digester.

1.2 Scope of Study

a. Wastewater Sampling and Analysis - Grab samples of molasses alcohol slop (MAS) from Ayudhaya Distillery plant will be taken at the discharge point and the following parameters will be analysed.

- pH, temperature, alkalinity
- Solids - total, suspended, volatile
- Biochemical oxygen demand (BOD_5)
- Chemical oxygen demand (COD)
- Nitrogen - total
- Phosphorus - total
- Chlorides

b. Anaerobic Digester Study - Batch process of mesophilic anaerobic digestion of MAS will be experimented at the temperature of 35 ± 1°C with different proportions of digested seed to find out the approximate detention time of anaerobic digestion for MAS.

The semi-continuous process of anaerobic digestion will be carried out at detention times obtained from the batch process. The performance of the condition as well as the volume and composition of gas produced will be compared from one loading to another. The optimum loading or detention time will be used to carry out the biogas digester in the pilot plant scale experiment to confirm the result of organic removal and gas production.

c. Cost Evaluation - The economic aspects of MAS treatment process by anaerobic digestion will be studied. The cost analysis of treatment system and biogas production will be calculated in terms of benefit cost ratio.

II LITERATURE REVIEW

2.1 Distillery Wastewater

The wastewater discharged from distilleries using cane molasses as raw material is called molasses alcohol slop (MAS). This material contaminated with soluble organics and salt is not suitable to be used as animal feed. But waste from fermenting factory or distillery that use grains as raw material has low concentration of pollutants. It can easily be used as supplements in mixed livestocks and poultry rations.

2.2 Wastewater Source and Characteristics

Alcohol production process is shown in Fig. 2.1 (LOWONGWAT, 1979). Molasses is diluted to 12% sugar, and 5% by volume of yeast mother culture was also added. After the mash has been fermented for 3-4 days, about 12-13% of alcohol was produced. The mature mash was distilled to recover 95^o alcohol. At distillation stage, molasses alcohol slop (MAS) was generated as the main waste.

MAS is dark brown in color and high in temperature (about 80^{o}C). The chemical analysis of parameters from different sources of MAS is shown in Table A.1 in Appendix A.

The annual production of all distilleries in Thailand is about 75 million litres of 95^o alcohol (1976). The alcohol distilleries wastewater or MAS is discharged at the rate of 12-15 m^5/kl of 95^o alcohol production (ASRCT*).

2.3 Treatment Technologies

There are several methods that can be used to treat MAS. The suitability depends upon the amount of waste, availability of land, capital and operating cost of treatment processes. Most of the distilleries in Thailand are of small to moderate size (about 75%) discharging MAS at the rate of 50 m^3/day and 100 m^3/day, respectively (ASRCT, 1979).

The possible treatment process as of MAS are:

a. Ponding System - THIRADEJ (1976) designed the holding pond for MAS treatment at Eastern Chemical Distillery. An area of 24 acres containing 14 ponds capacity of 48,740 m^3 receives loading rate of MAS 100 m^3/day. After leaving the waste for long time in the pond, bagasses which was the by-product from sugar mill nearby the distillery were mixed with stabilized waste and then used as fertilizer. The stabilized pond system could reduce BOD from 30,000 mg/l to 90 mg/l. However suspended solids and color of effluent were still high.

RAO (1972) conducted the study of anaerobic lagoon for treatment of distillery waste with BOD of 35,000 - 45,000 mg/l and reported that the optimum loading of the first lagoon was about 0.604 kg

* APPLIED SCIENCE RESEARCH CORPORATION OF THAILAND.

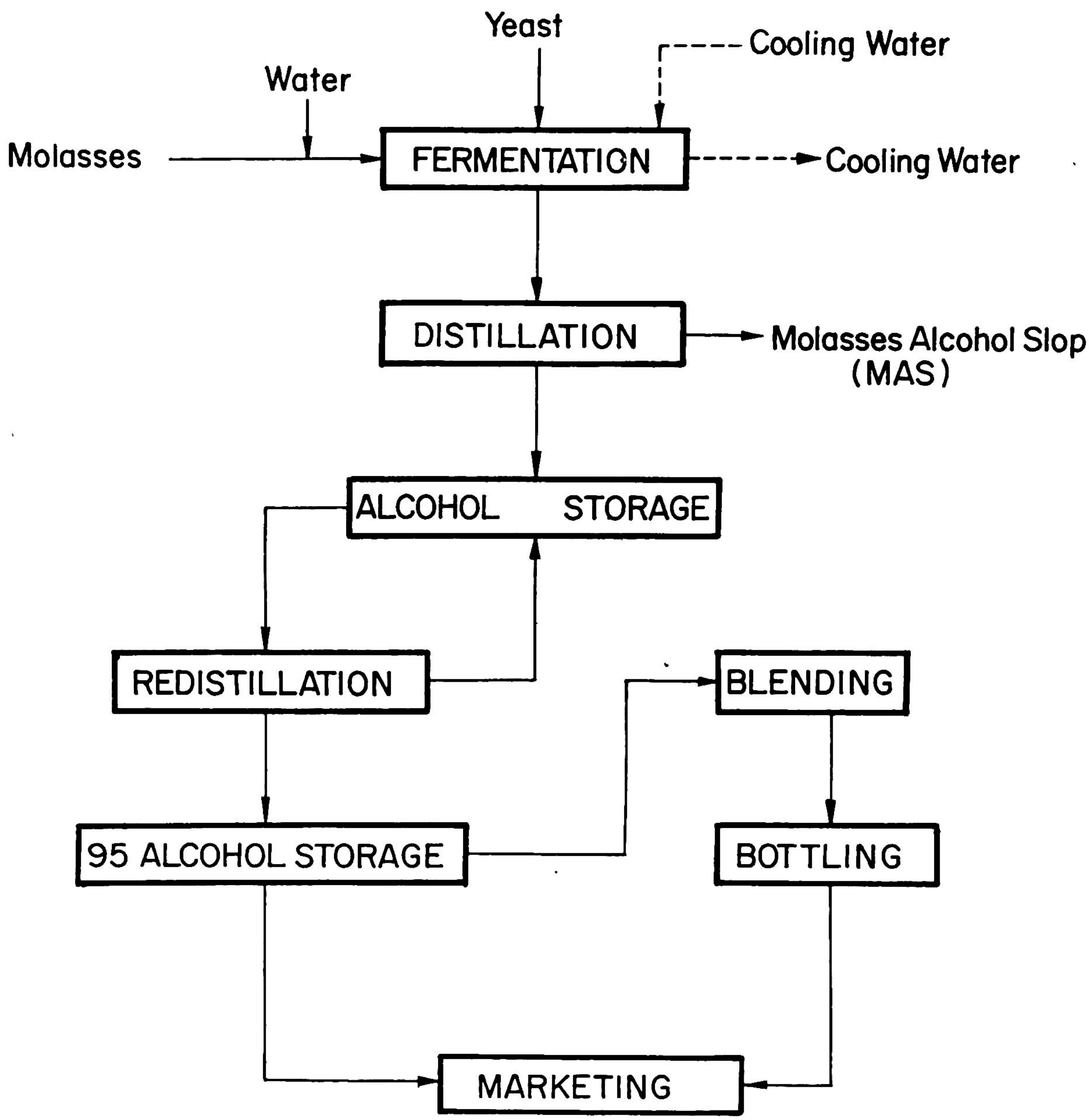


Fig.2.1 - Liquor & Alcohol Distillation Flow Diagram.

BOD/m^3-d and the BOD concentration of first lagoon effluent varied from 2,500 - 3,000 mg/l. With a second lagoon it was possible to reduce the BOD concentration to 600 mg/l at the optimum loading of 0.070 kg BOD/m^3-d. The second lagoon effluent was diluted with fresh water in the ratio of 1:10 and discharged into the crop field. As a result potassium accumulation of 5,000 kg/ha was obtained on 1 year crop. He also estimated that approximately 4,000 m^2 of area was required to treat 100 m^3 of distillery waste.

b. Digestion-Activated Sludge Process - RATASUK (1976) conducted the study of MAS treatment by anaerobic digestion followed by activated sludge process and reported that the mesophillic anaerobic digestion at the loading of 1.84 kg BOD/m^3-d, could remove the BOD and COD about 53% and 50% respectively. The effluent from the digester was then treated by activated sludge process of F/M = 0.39 and MLSS = 1,940 mg/l. The BOD and COD removal efficiency at the secondary treatment stage were 93% and 44% respectively.

Digestion-activated sludge process was applied for distillery wastewater treatment in Japan several years ago by thermophillic methane fermentation of loading about 5.6 kg COD/m^3-d and followed by activated sludge process of F/M = 2.9 and 1.46 kg BOD/m^3-d. The anaerobic digestion could reduce BOD around 80-90% and gas produced at the rate of 1.1 m^3/kg BOD loading or 36.8 m^3/m^3 of MAS feed with 55% methane content. The activated sludge process could reduce the BOD upto 40 mg/l. The total BOD removal efficiency represented about 99% (FERMENTATION RESEARCH INSTITUTE, 1979).

c. Biomass Recovery - HANG et al. (1975) reported that brewery spent grain liquor could be utilized by mold and resulted in BOD reduction from 22,500 mg/l to 900 mg/l, representing 96% BOD removal efficiency. The recovery of this treatment process was the production of citric acid and single cell protein which might be used as a feed supplement.

GRADY (1978) stated that *Penicilium spinulosum* could grow on the soluble residue remaining after distillation of white wine and reduce the COD concentration from 44,000 mg/l to 4,000 mg/l while producing 13,400 mg/l of biomass with 41% of protein content.

d. Organic Acid Production - GRADY (1978) also stated that distillery wastewater after converting sugar to alcohol was suitable for the production of acetic acid by *Acetobacter aceti* and the brewery waste was found to be suitable for the production of citric acid by *Aspergillus foetidus*.

e. Wet Combustion - Due to the difficulty of brown color removal in MAS which tertiary treatment is necessary, wet combustion has been considered as the whole treatment process of MAS.

LUND (1971) recommended the wet combustion of organic waste at high temperature (1,200-1,500^{o}F) or at high pressure furnace (3,000 psia) with low temperature (300-500^{o}F).

NEMEROW (1971) stated another system of combustion which could be burnt by limiting O_2 at the temperature around $1,500^{o}F$ or higher. The recovery of this system was steam which could be utilized in the fermentation process.

f. Anaerobic Digestion - SEN and BHASKARAN (1962) studied the high rate digestion of cane molasses distillery waste at $37^{o}C$ on a laboratory scale using cowdung as seed and reported a BOD removal efficiency of 80-85 per cent, at a maximum BOD possible loading of 3.0 kg/m^3-d. The final effluent BOD was less than 1,000 mg/l from original BOD of 30,000 mg/l. The gas production was about 25 volume for every volume of waste fed with 60% methane content.

SUBRAMANIAN (1978) stated that twelve distilleries in Japan applied the large anaerobic digesters in alcohol distillery wastewater treatment. The range of wastewater treated from 660 to 5,000 m^3/d and the gas yields from 500,000 to 2,000,000 m^3 per year, with a methane content of 50-60%. The gas was used to heat boilers to produce steam for industrial use, and not for heating the digesters because the temperature of those distillery wastes was already high in temperature.

2.4 Anaerobic Waste Treatment Theory

a. Operation - The modes of operation of an anaerobic digester can be divided into two categories according to the methods of raw material feeding, a batch-fed (periodic feeding) and a daily-fed (semi-continuous feeding).

A batch-fed digester can be designed where daily supplies of raw materials are difficult to obtain or ferment coarse wastes such as vegetable wastes and plant stalks, which cannot flow smoothly if fed to a semicontinuously fed digester.

LAWRENCE and McCARTY (1969) described that there are three phases in anaerobic digestion process, i) hydrolysis of complex materials, ii) acid production and iii) methane formation.

In the first phase, saprophytic bacteria will attack complex organic substances such as proteins, carbohydrates and fats, then convert them into organic compounds by external enzymes. Subsequently, acid forming bacteria, which can be anaerobic or facultative bacteria, will degrade the simple organic compounds to volatile fatty acids and some ammonia. Most of the volatile fatty acids produced are acetic acid and a small proportion of propionic and butyric acids. These acid forming bacteria can grow at a relatively rapid rate because of their ability to buffer against environmental changes. In the third phase, methane forming bacteria utilize these acids as their food to form methane.

For digester start-up, it is common practice to seed it with an adequate population of both bacterial groups from digested sludge, materials from a well rotten manure pit or cow-dung slurry. The seed should be ranging from 50 to 75 per cent by volume of the raw waste feed. The solid concentration should be about 7-9 per cent of the digester contents.

b. Digester Design and Control

Temperature - Temperature plays a very important role in the bacterial metabolism process, high temperature normally results in high metabolism rate with an increase in the amount of gas production. The digestion proceeds best at 30-40^{o}C with a mesophillic flora, and at 50-60^{o}C if a thermophillic flora is developed and adapted. The choice of mesophillic or thermophillic operation will normally be made at the design stage. GARBER et al (1975) reported that thermophillic flora were very sensitive to a sudden temperature changes. So it is common practice in many countries to bury the digester in the ground, taking advantage of the insulating properties of the surrounding soil.

pH, Alkalinity and Volatile Acid

- McCARTY (1964) stated that pH in the anaerobic digester had to be maintained within the neutral ranges preferably between 6.6-7.6 and the volatile acid-alkalinity ratio should be less than or equal to 0.3. With inadequate content of alkalinity in the digester system, the mixed liquor pH could drastically drop with an accumulation of the volatile acids.

FAO (1978) also reviewed the pH range in the anaerobic digester and reported that methane forming bacteria could tolerate at the pH range of 6.5 to 8.0.

Organic Loading and Detention Time

- The size of a digester depends on loading which in turn depends on dilution, detention time and temperature.

The recommended loading rate for standard municipal digesters is from 0.48-1.6 kg of volatile solids per m^3 of digester capacity per day and the detention time can be varied from 30 to 90 days. Optimum loading rates for night-soil digesters in various cities of India were reported as ranging from 1.04 to 2.23 kg volatile solids per m^3 of digester capacity. SEN and BHASKARAN (1962) noted that the optimum loading of high rate anaerobic digester of cane molasses distillery wastewater at 37^{o}C using cow-dung as seed was about 3.0 kg BOD/m^3-d which equivalent to 6.4 kg COD/m^3-d. BARNET (1978) reported that the maximum loading of biogas digester should be 2-3 kg volatile solids per m^3 per day in thermophillic digestion.

Mixing of the Digester

- Mixing is very important both in digestion process and prevention of solid separation for the phase contents in the small scale digester. However, McGARRY and STAINFORTH (1978) found that the installation of mixer was not necessary in the big capacity of biogas digesters (10-20 m^3). SEN and BHASKARAN (1962) reported that mechanical stirrers did not increase the rate of distillery waste digestion.

c. Gas Production The quantity of gas produced and the amount of methane content depend mainly on the nature of raw materials and on the efficiency of the fermentation process.

SEN and BHASKARAN (1962) found that gas production of cane molasses slop by high rate anaerobic digestion at 37^oC was about 25 volume for every volume of waste fed with 60 per cent of methane content.

SUBRAMANIAN and GANESH (1974) reported that the production of gas per kg of daily fed cow-dung varied from 0.1 m^3 in summer and 0.04 m^3 in winter.

The gas yields of some common fermentation material reported by BUREN (1979) are shown in Table A2 in Appendix A.

The composition of biogas produced from different types of raw material is shown in Table A.3 in Appendix A. The important physical and chemical characteristics of methane are presented in Table A.4. The energy of biogas compared with other sources of fuel in term of calorific value are shown in Table A.5.

III EXPERIMENTAL INVESTIGATION

3.1 Wastewater Sampling and Analytical Methods

Grab samples of MAS were collected from Ayudhaya Distillery using 20-litre sampling bottles. Samples were brought back to AIT, Environmental Engineering Division and stored in 5°C room for further analyses.

Samples were analysed for:

a. Temperature (onsite), pH, alkalinity
b. Solids - total, suspended, volatile
c. Biochemical oxygen demand (BOD_5)
d. Chemical oxygen demand (COD)
e. Nitrogen - total
f. Phosphorus - total
g. Chlorides

All parameters were analyzed according to STANDARD METHODS (1975) except the analysis of alkalinity and volatile acids, which follows the method of DILALLO and ALBERTON (1961).

Gas production from anaerobic digestion was measured by water displacement in gas collection bottle. Gas compositions were analysed by using Orsat gas analyzer and gas burette collector (Fig. 3.1).

3.2 Anaerobic Digestion Study

Laboratory scale digestions were run in 35°C control room using 25-litre PVC reactor with 18 litre working capacity. The 230-litre pilot plant digester was half buried in the ground in which temperature at mesophillic range could be controlled. The pilot working capacity was 130 litres. Digested cow-dung was used as seed to start up the anaerobic digester both in experimental and pilot scale digester. The details of operations were summarized in Table 3.1.

3.3 Anaerobic Digestion Unit

Three 25 litre PVC tanks were used as reactors for bench laboratory (Fig. 3.2).

The reactor used for pilot plant experiment was made of ferrocement. The schematic diagram is shown in Fig. 3.3. The pressure in the gas chamber of the reactor can be measured by water pressure gauge (Fig. 3.4).

3.4 Cost and Economic Analysis

The optimum loading which gave the highest gas production and high organic removal efficiency was used to estimate the size and number of digester required for MAS treatment for small distilleries with 50 m^3 of MAS discharged per day.

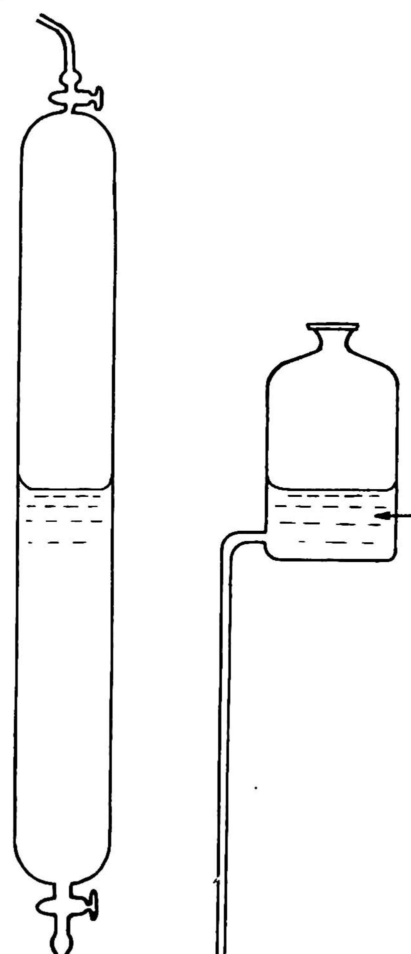
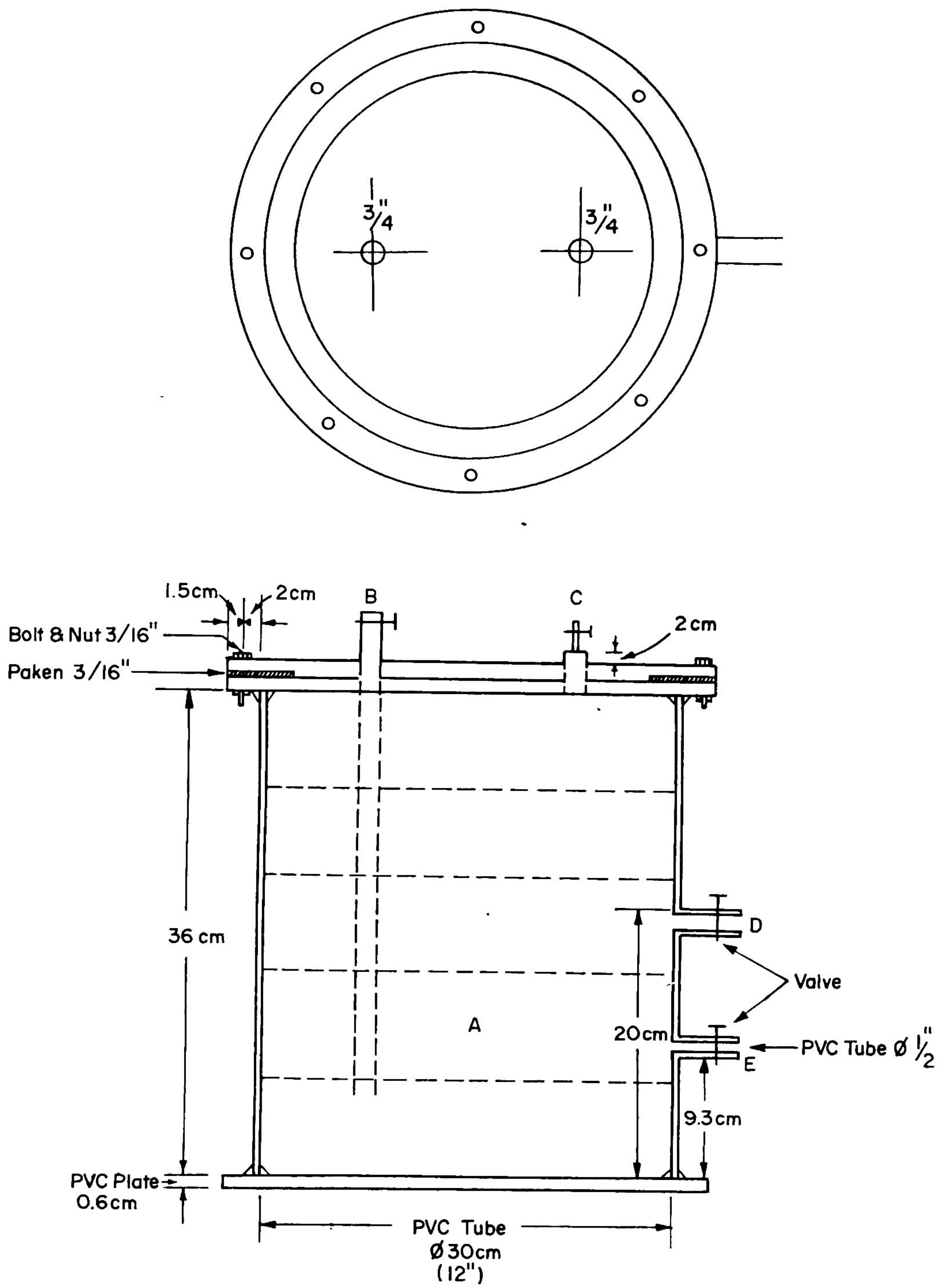


Fig.3.1 - Gas Burette used for Gas Collection.

Table 3.1 Details of MAS Anaerobic Digestion Studies

Step No.	Step Period	Method	Seed:Raw MAS	Operations
I	Acclimatization	Batch fed	*1:1	- Neutralized raw MAS before start-up - pH adjustment by lime when pH drops
		Daily-fed	*1:1	- Dilute and pH adjusted at the beginning - Decreasing the dilution water and pH adjustment until raw wastes were feed without any treatment during the first week - Increasing rate of feed every day
II	Batch	Total Feed at the begining	1:3 1:1 3:1	- pH adjusted by lime or Na HCO_3 to increase bicarbonate alkalinity when pH decreased and low concentration of alkalinity
III	Semi-continuous	Daily-fed (Bench laboratory scale)	-	- At different detention time 10, 12, 15, 20, 25 days
		Daily-fed (Pilot Scale)	-	- At optimum loading

* Digested cowdung from NEA Biogas Digester (NEA = National Energy Administration)



A - Reacter
B - Feed pipe
C - Gas outlet pipe
D - Effluent draw - off pipe
E - Sludge draw - off pipe

FIG. 3.2 - SCHEMETIC DIAGRAM OF ANAEROBIC DIGESTER (25 LITRE CAPACITY) 3 UNITS

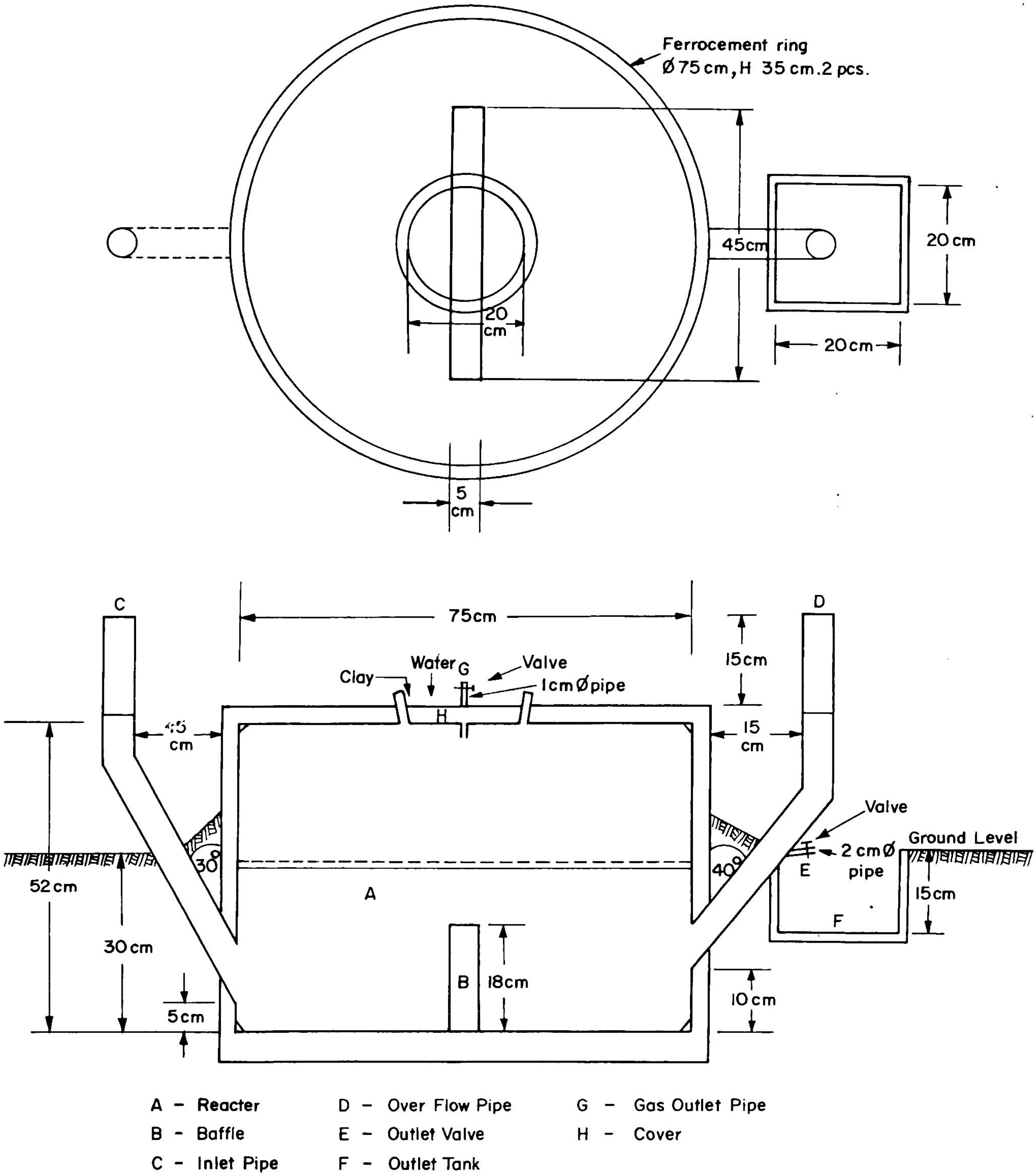


FIG.3.3 - SCHEMATIC DIAGRAM OF BIOGAS DIGESTER (230 LITRE CAPACITY)

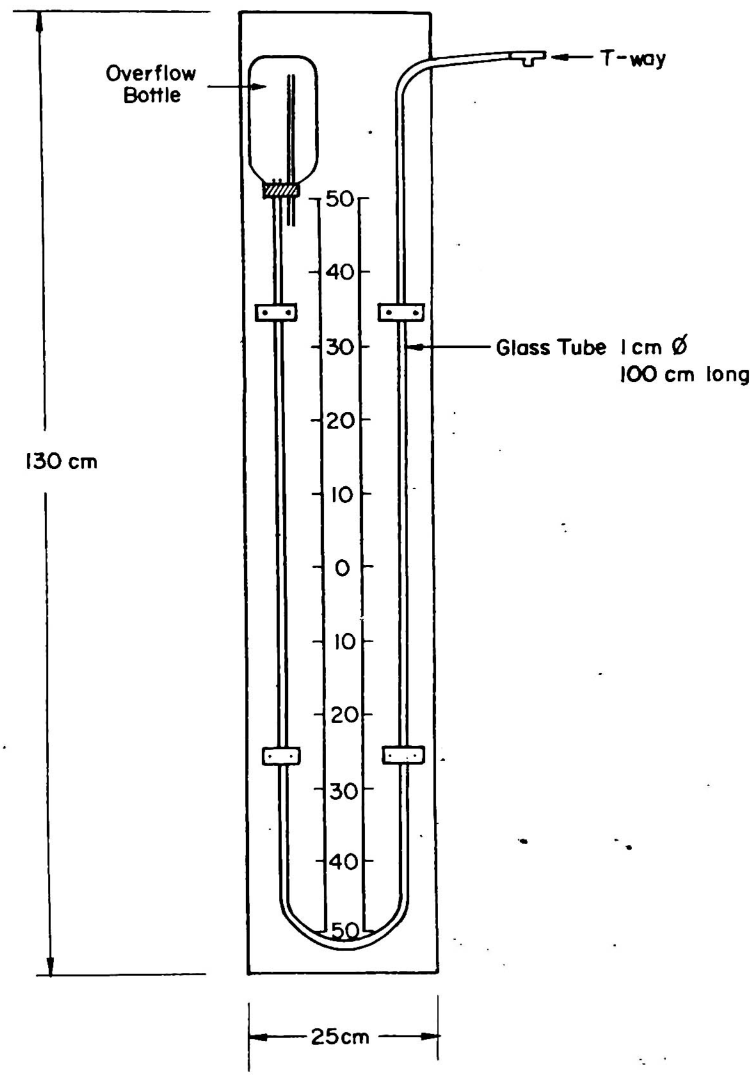


Fig. 3.4 – U – Shape Pressure Gauge

The cost analysis of MAS treatment based on Chinese biogas digester design was calculated to find out the treatment cost per unit volume of MAS treated per year. The economic analysis of methane gas produced was carried out in terms of benefit cost ratio.

The calculation of B/C ratio is based on the following formula: (GRANT and IRESON, 1976)

$$\text{Benefit} = \sum_{t=1}^{T} \frac{B}{(1+i)^t}$$

$$\text{Cost} = \sum_{t=1}^{T} \frac{O}{(1+i)^t} + K$$

$$B/C = \sum_{t=1}^{T} \frac{B}{(1+i)^t} \left[\sum_{t=1}^{T} \frac{O}{(1+i)^t} + K \right]^{-1}$$

where

B = benefits received annually
C = costs per year including the change on capital
K = fixed investment
O = annual operating cost
i = interest rate (assumed to be 18%)
T = investment time span (assume = 10 years)
t = time period

IV RESULTS AND DISCUSSION

4.1 Wastewater Characteristics

The characteristics of MAS grab samples are shown in Table B.1 in Appendix B. The range and average concentration of MAS properties are shown in Table 4.1.

Table 4.1 Properties of Molasses Alcohol Slop from Ayudhaya Distillery

Properties	Concentration	
	Range	Average
Temperature, ^{o}C	95-99	98
pH	4.2-4.5	4.4
Alkalinity, mg/l as $CaCO_3$	1,525-1,900	1,808
Volatile acids, mg/l as CH_3COOH	9,113-10,575	9,985
COD, mg/l	107,016-132,056	112,772
BOD_5, mg/l	30,522-34,318	32,393
BOD/COD	0.29-0.26	0.29
S.S., mg/l	2,740-5,098	4,140
T.S., mg/l	98,500-115,420	108,538
T.V.S., mg/l	73,480-86,128	80,476
T.V.S., % of T.S.	75-74	74
P., mg/l	25.8-32.6	29.2
N, mg/l	562-1,462	973
Cl^-, mg/l	1,834-1,980	1,907

From this table, it can be seen that the average suspended and total solids are 4,140 mg/l and 108,538 mg/l, respectively. The volatile solid content is 80,476 mg/l equivalent to 74% of total solids, indicating that there is a large amount of organic matter in MAS which is biodegradable.

The average COD and BOD_5 were 112,772 mg/l and 32,393 mg/l, respectively. The COD concentration is much higher than that reported by Fermentation Research Institute, Japan (1979) of COD about 47,800 mg/l which was permanganate value or permanganate COD. The values of both COD and BOD_5 from this experiment are quite close to those obtained by ASRCT (1976). The BOD-COD ratio of this waste was around 0.3, showing that this waste is not readily biodegradable. This may due to the presence of high concentrations of complex organic matters.

The BOD/N/P of this waste was found to be 100:3:0.1. This ratio indicates that anaerobic process can be applied for treatment, as it does not require much nutrient as in the case of aerobic treatment. SEN and BHASKARAN (1962) stated that nitrogen content in anaerobic digestion could be limited at BOD/N of 4.2:1.

4.2 Anaerobic Digestion Study

The results of batch anaerobic digestion study are shown in Table B2-B6 in Appendix B and summarized in Table 4.2 and Figs. 4.1 to 4.4. The results of semi-continuous process of both laboratory and pilot digesters are shown in Table B7 to B18 in Appendix B and are summarized in Table 4.2, 4.3 and Figs. 4.5 and 4.6. The result of this experiment compared with other past works are shown in Table 4.4.

Fig. 4.2 - Results of Start-up and Batch Anaerobic Digestion Study of MAS

Step		Start-up Conditions		Stabilized Conditions					D.T
		Seed:MAS	COD_F mg/l	COD_F mg/l	pH	Alk	V.A	VA/Alk	days
Acclimalization Period	Experimental Scale	1:1 (Batch-fed)	67,000	25,000	7.5	7,000	3,000	0.4	40
		1:1 (Daily-fed)	-	25,000	7.7	7,800	2,500	0.3	30
	Pilot Plant Scale	1:1 (Daily-fed)	65,000	30,000	8.0	9,000	2,800	0.3	50
Batch Anaerobic Digestion	Experimental Scale	1:3	90,137	-	-	-	high	high	long
		1:1	67,714	-	-	-	high	high	long
		3:1	43,830	20,000	7.9	8,600	2,500	0.3	20

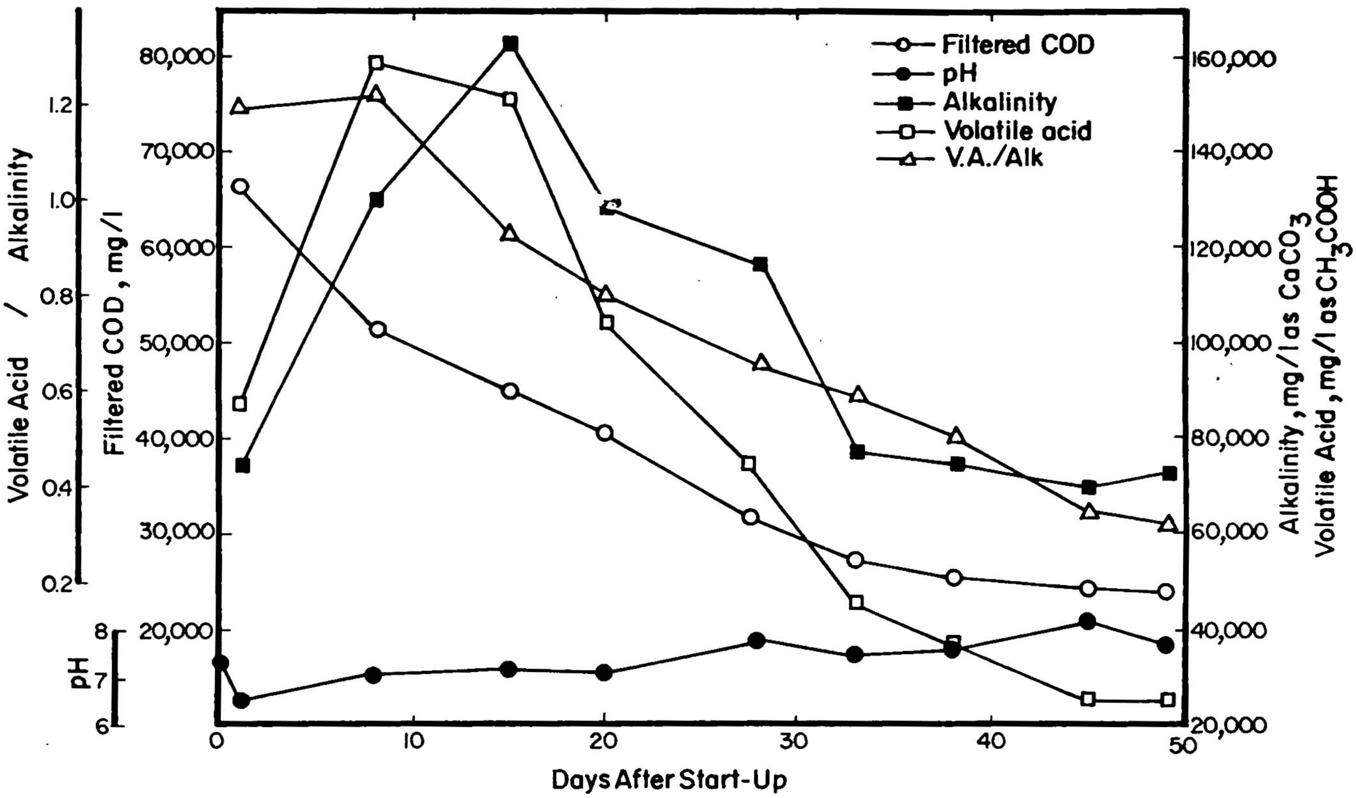


Fig.4.1 – Start-Up of Anaerobic Digestion with Batch-Fed of Digested Cowdung : Neutralized MAS = 1 : 1

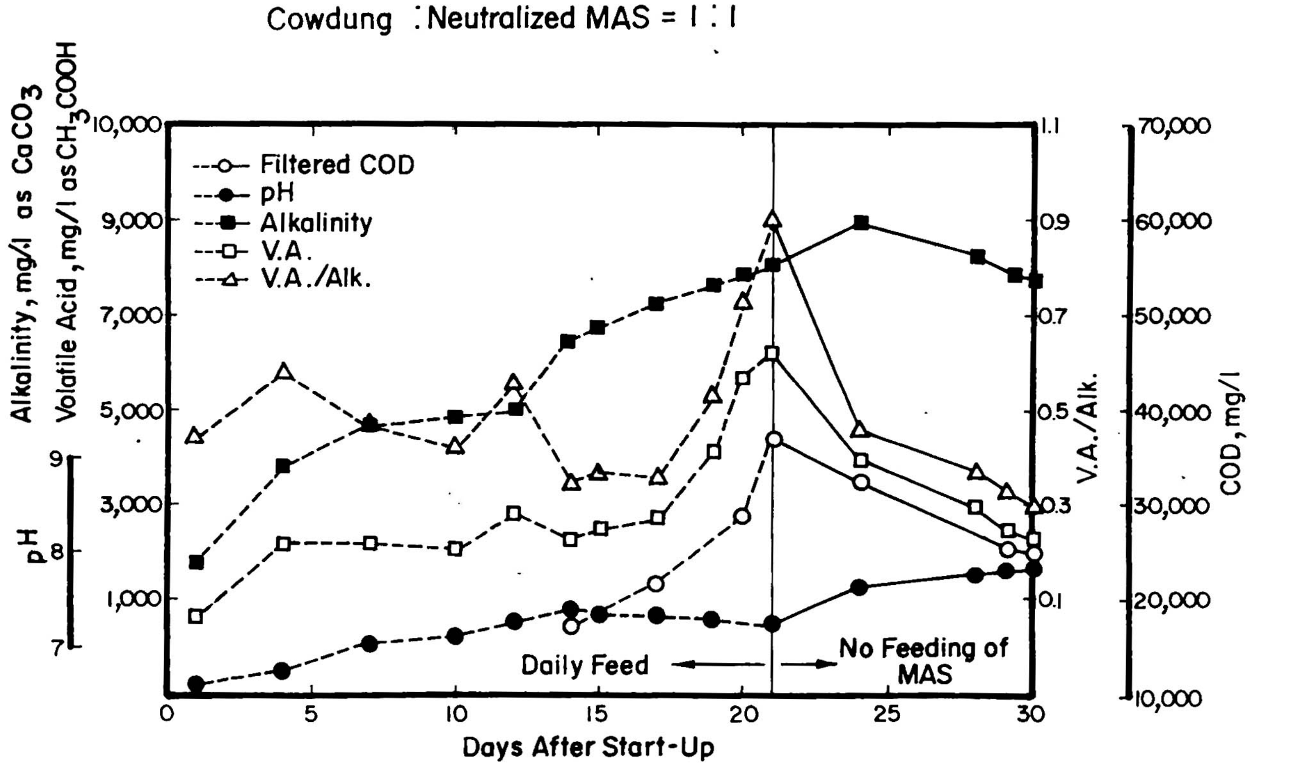


Fig.4.2 – Start-Up Condition in Anaerobic Digestion with Digested Cowdung as Seed and slowly Increasing Rate of Daily Feed of MAS .

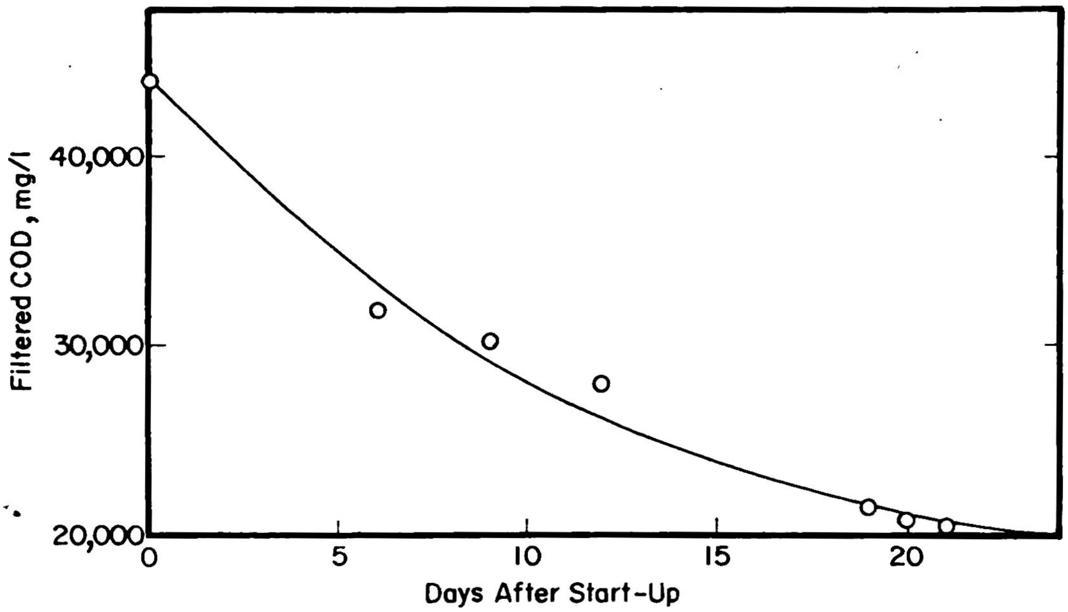


Fig. 4.3 - COD Concentration of the Batch Anaerobic Digestion Anaerobic Digester Liquor : Neutralized MAS = 3 : 1

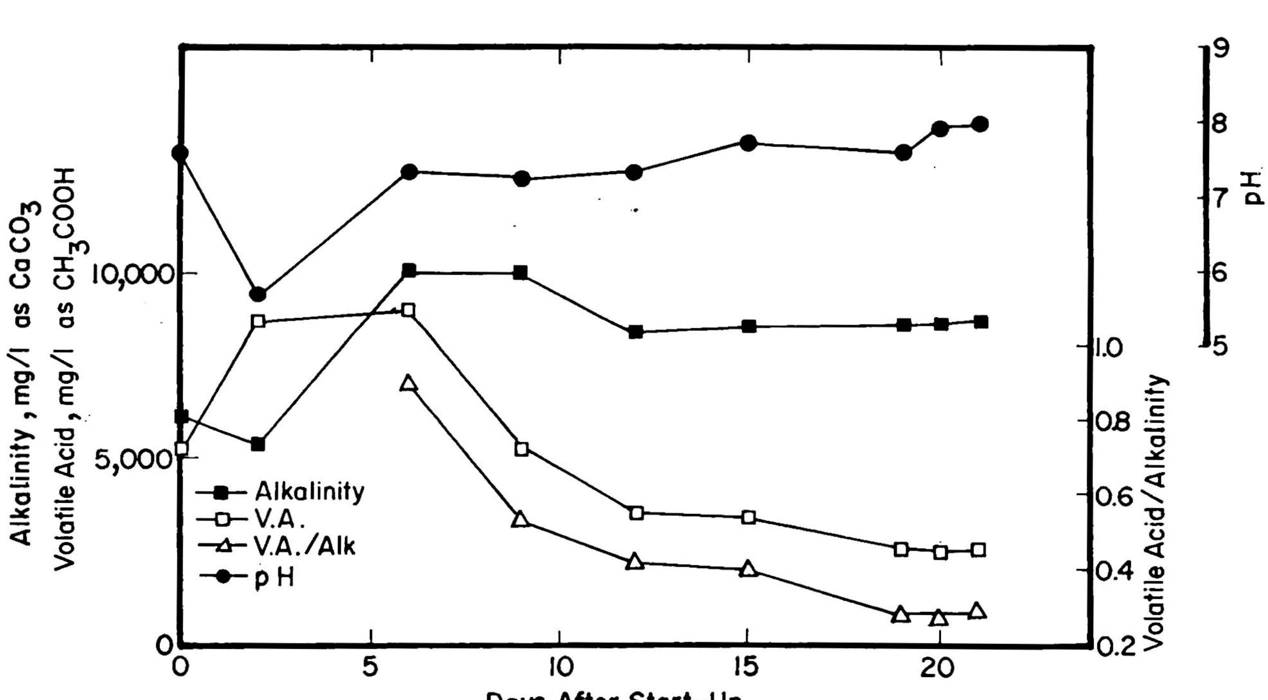


Fig. 4.4 - Performance of Batch Study on the Biodegradabity of the Raw MAS in Anaerobic Digestion with Stabilized Anaerobic Digester Liquor : Neutralized MAS = 3 : 1

Table 4.3 Semi-Continuous Anaerobic Digestion of MAS in Experimental and Pilot Plant Digester

Operation	Laboratory Scale					Pilot Scale
Detention Time (days)	10	12	15	20	25	12
Feeding rate, l/d	1.8	1.5	1.20	0.90	0.72	10.8
Influent COD_T, mg/l	107,500	108,329	107,817	108,200	111,507	107,371
BOD_5, mg/l	30,702	31,977	30,716	31,085	32,029	30,684
Effluent COD_T, mg/l	43,765	35,820	33,445	29,283	26,300	39,417
BOD_5, mg/l	5,070	2,746	2,679	2,327	2,272	4,025
Loading: kg COD_T/m^3-d	10.75	9.03	7.19	5.41	4.46	8.95
kg BOD/m^3-d	3.07	2.66	2.05	1.55	1.28	2.56
Removal Efficiency COD, %	59.3	66.9	69.2	72.4	76.4	63.3
BOD, %	83.5	91.4	91.3	92.5	92.8	86.9
COD removed, kg/m^3-d	6.37	6.04	4.96	3.92	3.41	5.66
Gas Production, l/d	75.3	73.6	56.2	41.9	32.6	-
l/l MAS fed	41.8	49.1	46.8	46.5	45.3	-
l/l of working capacity	4.18	4.09	3.12	2.32	1.81	-
l/kg of COD loading	389	453	474	429	406	-
>l/kg COD removed	656	677	629	592	531	-
% CH_4	43.9	48.3	49.5	50.0	51.3	-
l CH_4/l of MAS fed	18.4	23.7	23.2	23.3	23.2	-
l CH_4/kg COD loading	171	219	215	215	208	-

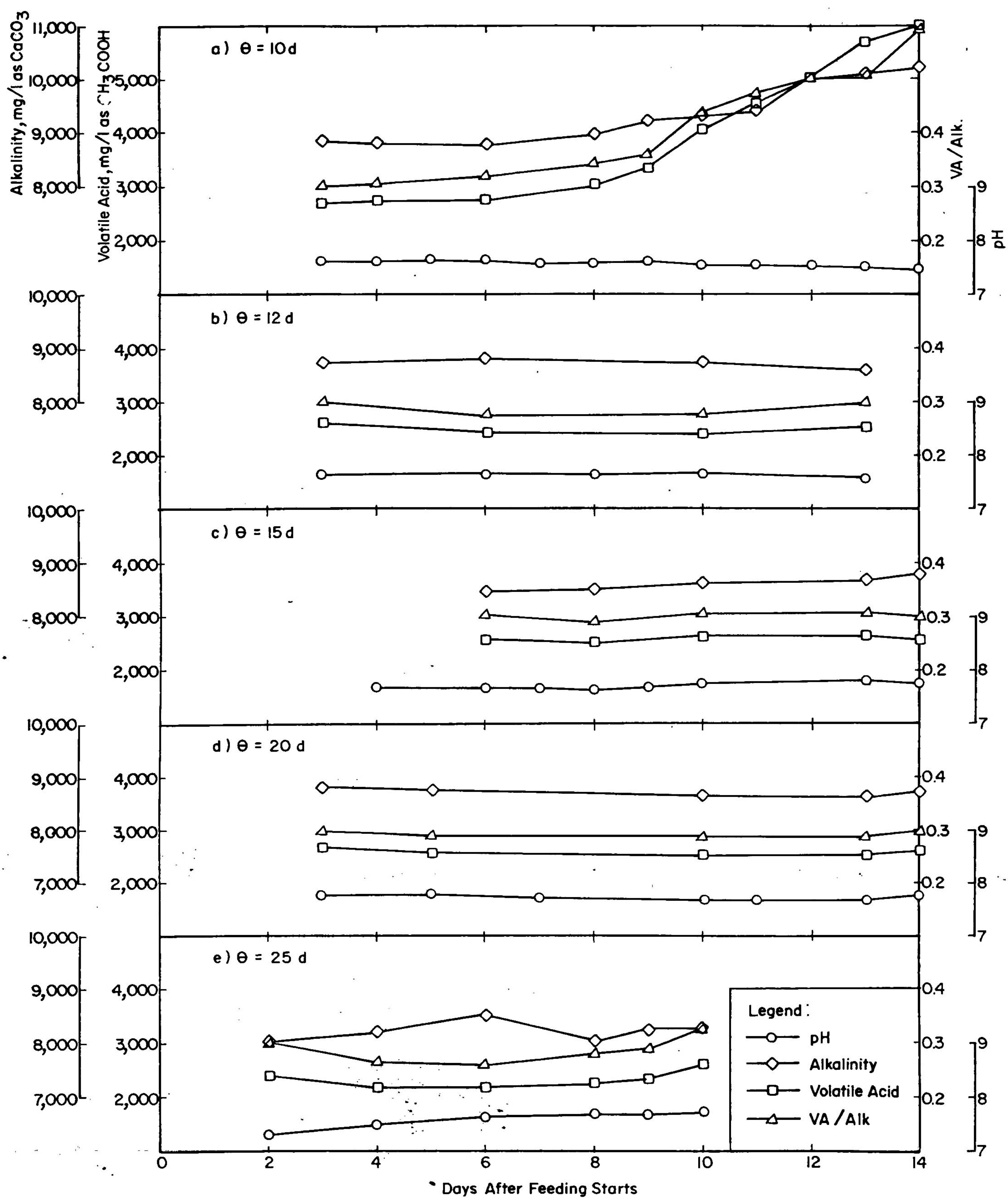


Fig.4.5 - Performance of Anaerobic Digestion of MAS at Various Detention Times.

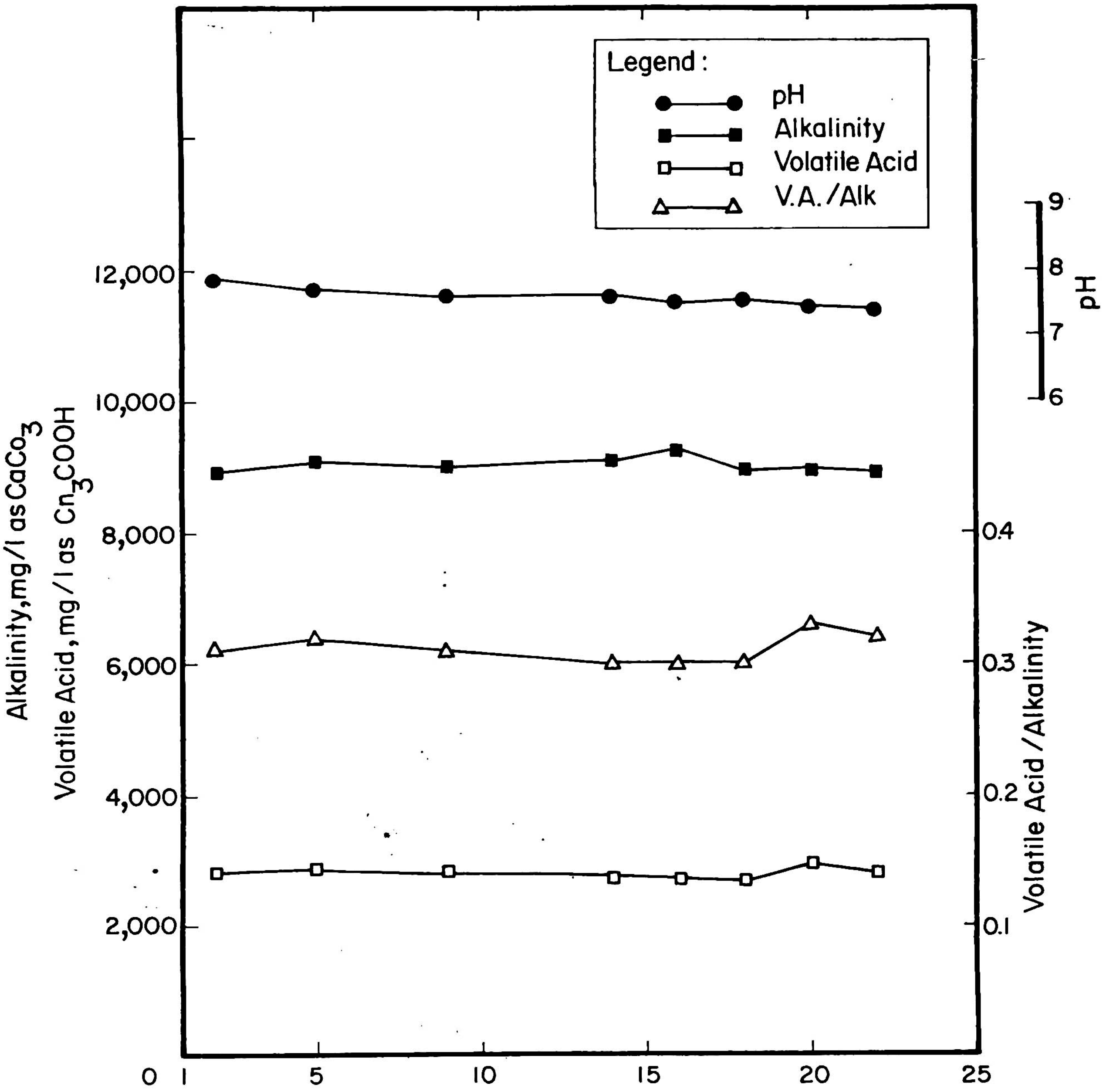


Fig.4.6- Operational Condition of Biogas Digestion of Non Neutralized MAS with Detention Time 12 Days

Table 4.4 - Results of MAS Anaerobic Digestion Compared with Other Past Experiments

Year	1962	1976	1979	1979	1980
After	SEN & BHASKARAN	RATASUK	ASRCT	FRI JAPAN	This Experiment
Anaerobic Condition	H.R.	H.R.	H.R.	H.R.	Conventional
Temperature, ^{o}C	37	34	37	55	35
Influence BOD, mg/ℓ	18,000-37,000	30,000	36,379	33,600	31,977
Influence COD, mg/ℓ	40,000-90,000	109,000	105,038	47,800	108,329
BOD/COD	-	0.28	0.35	0.70	0.30
Detention Time, day	10	5.5	10	10	12
Loading, kg BOD/m^3-d	3.01	1.84	-	6.4	2.66
kg COD/m^3-d	6.4	-	9.0	-	9.0
% Removal, BOD	94.4	53	54.4	84.8	91
COD	-	50	34.2	61.6	67
Gas Produced, ℓ/ℓ of MAS	25	31.7	22.8	36.8	49
% CH_4	60	50	50	55	48

Note: H.R. = High rate

ASRCT = Applied Science Research Coorperation of Thailand

FRI = Fermentation Research Institute

Acclimatization of MAS anaerobic digester (batch-fed and daily-fed) was about 40 and 30 days, respectively. Although the daily-fed system took shorter time for acclimatization, the batch-fed system is preferable as less labour work is required. Therefore, batch-fed acclimatization was applied to start-up the pilot scale digester.

Batch digestion experiments were carried out at three different proportions of digested seed and raw MAS, 1:3, 1:1 and 3:1. The first two proportions were not successful in reducing COD. It was noted that when large amounts of MAS were fed, volatile acids increased immediately, as pH dropped and alkalinity decreased. pH adjustment by lime and sodium bicarbonate was then required to keep the digester in working condition. Under large feed condition, longer time was needed for microflora to stabilize the organic matter.

The ratio of seed:MAS of 3:1 seems to be the best proportion and COD could be removed from 43,830 mg/l to 20,000 mg/l, representing 54% within 20 days. However, it is not recommended to run batch anaerobic digestion for MAS because small quantity of waste could be treated in a certain period of one batch digestion.

Further digestion experiments were carried out on a semi-continuous basis in 25-litre reactors with 18 litre working capacity, at detention times of 10, 12, 15, 20 and 25 days, corresponding to COD loading of 10.75, 9.03, 7.19, 5.41, 4.46 kg per m^3 of working capacity per day, respectively. It appears that the COD removal efficiencies of these five loadings were in the range of 67-76% while BOD removal efficiencies were around 92% (Fig. 4.7).

Loading rate of 9.03 kg COD/m^3-d gave the highest gas production rate (Fig. 4.8), representing 23.7 litre of methane gas per litre of MAS feed or 219 litres per kg of COD loading.

The digester showed signs of deterioration at the COD loading of 10.75 kg/m^3-d, corresponding to 10 days detention time of original feeding COD at 107,000 mg/l. The volatile acid tended to increase from stabilized condition of 8,600-8,900 mg/l as CH_3COOH up to 11,925 mg/l as CH_3COOH. The sludge was slightly bulky and the suspended solids in the effluent increased. The gas yields also decreased with low methane content.

The choice of design organic loading depends not only on COD or BOD removal efficiency, but also on the gas production rate. Therefore, it can be stated that, for raw MAS with COD concentration of 107,000 mg/l, 12 days detention time or about 9 kg/m^3-d of COD loading should be the maximum loading for MAS digestion.

Further semi-continuous anaerobic digestion of MAS was carried out in pilot digester of 130 litre working capacity 12 days detention time, corresponding to COD loading of 8.95 kg/m^3-d. The COD and BOD removal efficiency were relatively lower than obtained from laboratory digestion (about 5%). This may be due to the shock load during the time of feeding in the pilot digester.

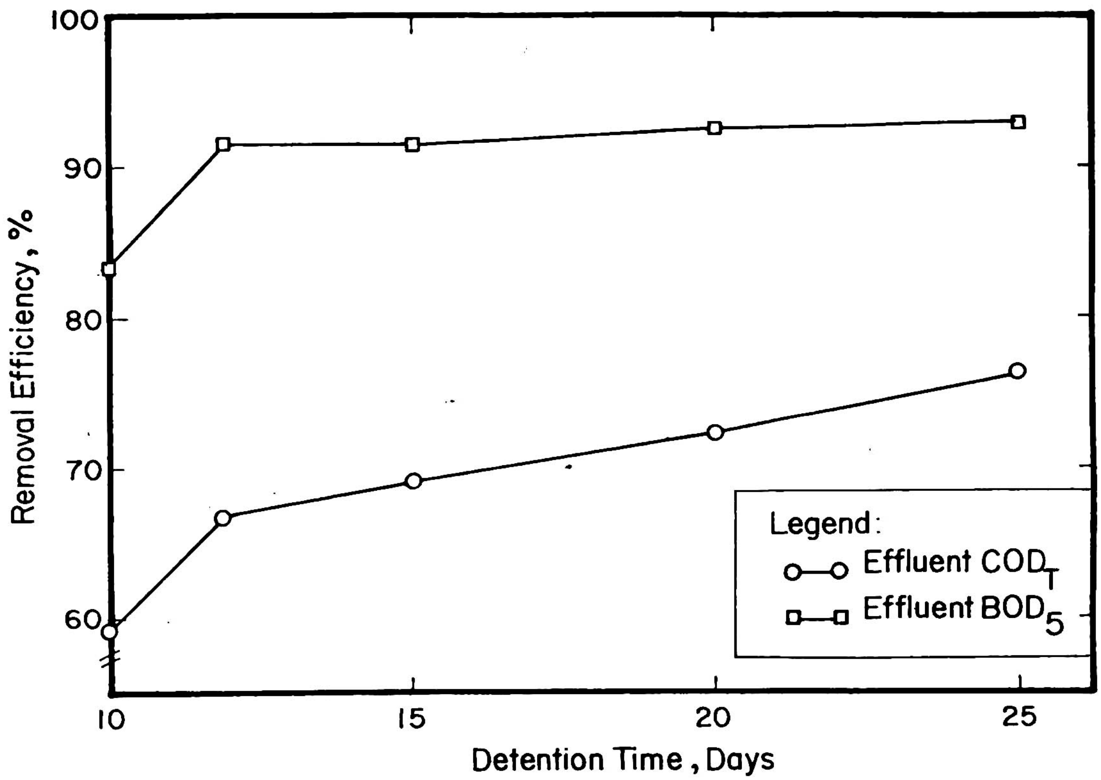


Fig.4.7 - Effect of Detention Time on Removal Efficiency of Anaerobic Digestion of Non-Neutralized MAS

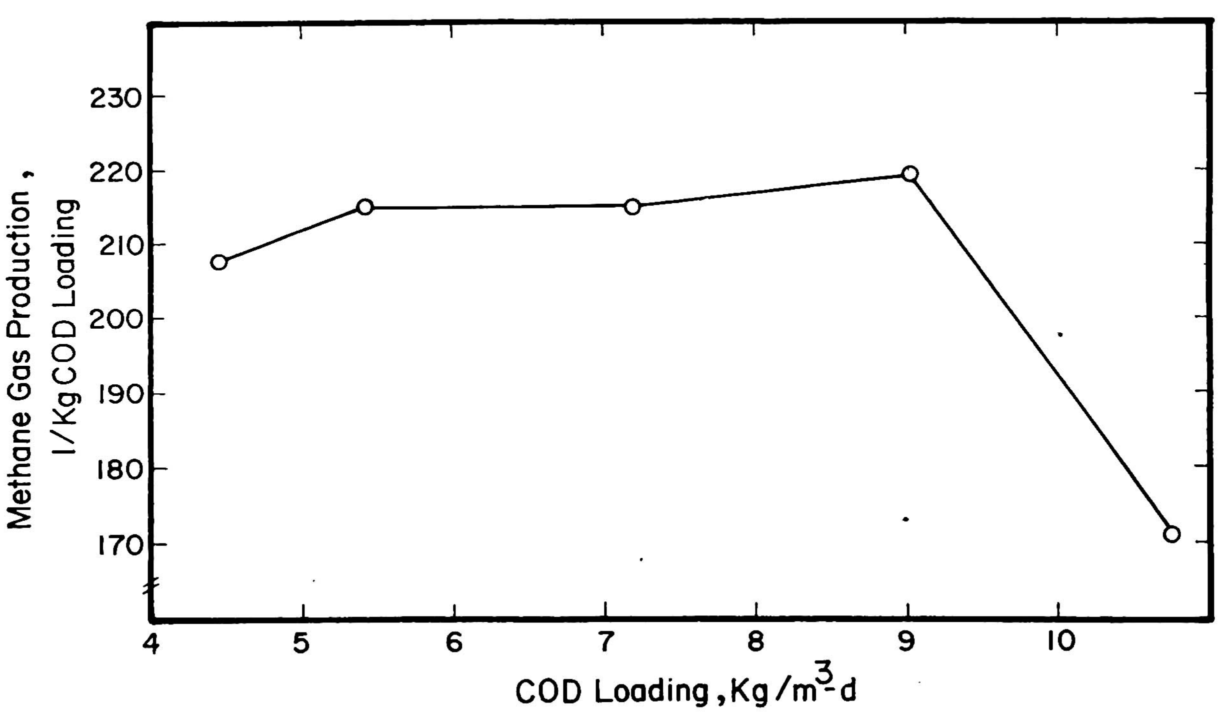


Fig.4.8 - Effect of Loading on Methane Production

In the pilot plant digestion, gas produced could not be collected and measured because of gas leaking through the pores of ferrocement ring. This should be one of the demerit of ferrocement applying in biogas digester construction.

4.3 Cost Analysis

Cost and economic analysis of MAS primary treatment by anaerobic digestion was calculated with following basis:

a. MAS discharge rate of 50 m^3/d (small distillery)

b. Size and type of digester: 100 m^3 Chinese Biogas digester (SOUTH WEST ARCHITECTURAL DESIGN INSTITUTE, 1979).

c. Material and construction cost of digester estimated at 2,000 ฿/m^3 of digester volume (Table C2 in Appendix C).

d. Personal wage (1981) with 10% inflation rate

   - General rate for engineer and assistant salary
   - Average wage rate of unskillful labour in Bangkok in 1981 which is not less than 45฿/day
   - Statistic of working after LIEWTANAMONKOL, 1977 (Table C1 in Appendix C).

e. Equipment cost: market price (1981)

f. 10 years loan at 18% interest rate

g. Approximate land cost

   land buying: ฿125/m^2 (฿20,000/rai)
   land leasing: ฿12.5/m^2/yr (฿20,000/rai/yr)

h. Maintenance cost = 5% construction and equipment cost

i. Methane gas produced from 10% deviation of the gas produced in experimented scale digester at loading of 9 kg/m^3-d

j. Fuel oil price at Bangkok in March, 1981

On the basis of this information, the annual treatment cost for MAS anaerobic treatment was estimated to be ฿65.68 and 65.18/m^3 of MAS treated for land buying of ฿125/m^2 and land leasing of ฿12.5/m /yr, respectively. (Table 4.5).

The benefit gained from methane gas production was about 2,012,245฿ per year and the B/C ratios of both types of lands investment were around 1.7 (Table 4.6) showing that the pay back period was found about one and a half year (Fig. 4.9), it is attractive for investment of anaerobic digestion process for MAS treatment. Under these figures, a return of about 65฿ per m^3 of MAS treated is possible. However, this cost and economic analysis excluded the installation of methane gas utilization instead of fuel oil and secondary treatment processes are necessary to reduce the rest organic matter in the digester effluent.

Table 4.5 - Cost Analysis of MAS Treatment by Using 100 m^3 Chinese Biogas Digester

Item	Unit	Amount	Cost in ฿	
			Unit	Total
Capital Cost				
Construction cost :[1/]	Original	10	200,000	2,000,000
Pump		1	40,000	40,000
Land buying cost	m^2	600	125	75,000
Total: (Land buying method)	m^2/yr	600	12.5	2,115,000
(Land leasing method)				2,040,000
Annual: (10 year loan, 18% interest, Capital Recovery for = 0.22251)				
(Land buying method)				470,609
(Land leasing method)				453,920
Annual Operation Cost :				
Personnel: Engineers	Cap/yr	2	96,000	192,000
Assistants	Cap/yr	4	57,600	230,400
Labours	Cap/yr	6	31,200	187,200
Maintenance (5% constuction & P				102,000
Land leasing cost	m^2/yr	600	12.5	7,500
Total: Land buying method				711,600
Land leasing method				719,100
Annual Treatment Cost:				
Land buying method	m^3	18,000	65.68	1,182,205
Land leasing method	m^3	18,000	65.18	1,173,020

[1/] From Table C2

Table 4.6 - Economic Analysis of Methane Gas Produced for 50 m^3 MAS/d

		Quantity m^3	Unit Price ฿/Unit	Value ฿
Benefits (B)	Methane gas product rate/d	1,067		
	Equivalent to fuel oil*	1,173	4,700	5,513
	Gas benefit			2,012,245
Cost (C)	Fixed Investment Cost (K)			
	Land Buying Method : (฿125/m^2)			2,115,000
	Land Leasing Method: (฿12.5/m^2/yr)			2,040,000
	Operating Cost (0)			
	Land Buying Method (฿125/m^2)			711,600
	Land Leasing Method (฿12.5/m^2/yr)			719,100
Benefit Cost Ratio	B/C+ (= BF/OF + K)			
	Land Buying Method (฿125/m^2)			1.70
	Land Leasing Method (฿12.5/m^2/yr)			1.72
Net return per year	Total Annual Cost			
	Land Buying Method			1,182,250
	Land Leasing Method			1,173,020
	Yearly Benefit			2,012,245
	Net Return Per Year			
	Land Buying Method			829,995
	Land Leasing Method			839,225

*Redwood I 600 seconds

+Sumation of present worth factor, 18% interest rate

$$\left(\sum_{n=1}^{10} \frac{1}{(1+18)^n} \right) = 4.4941$$

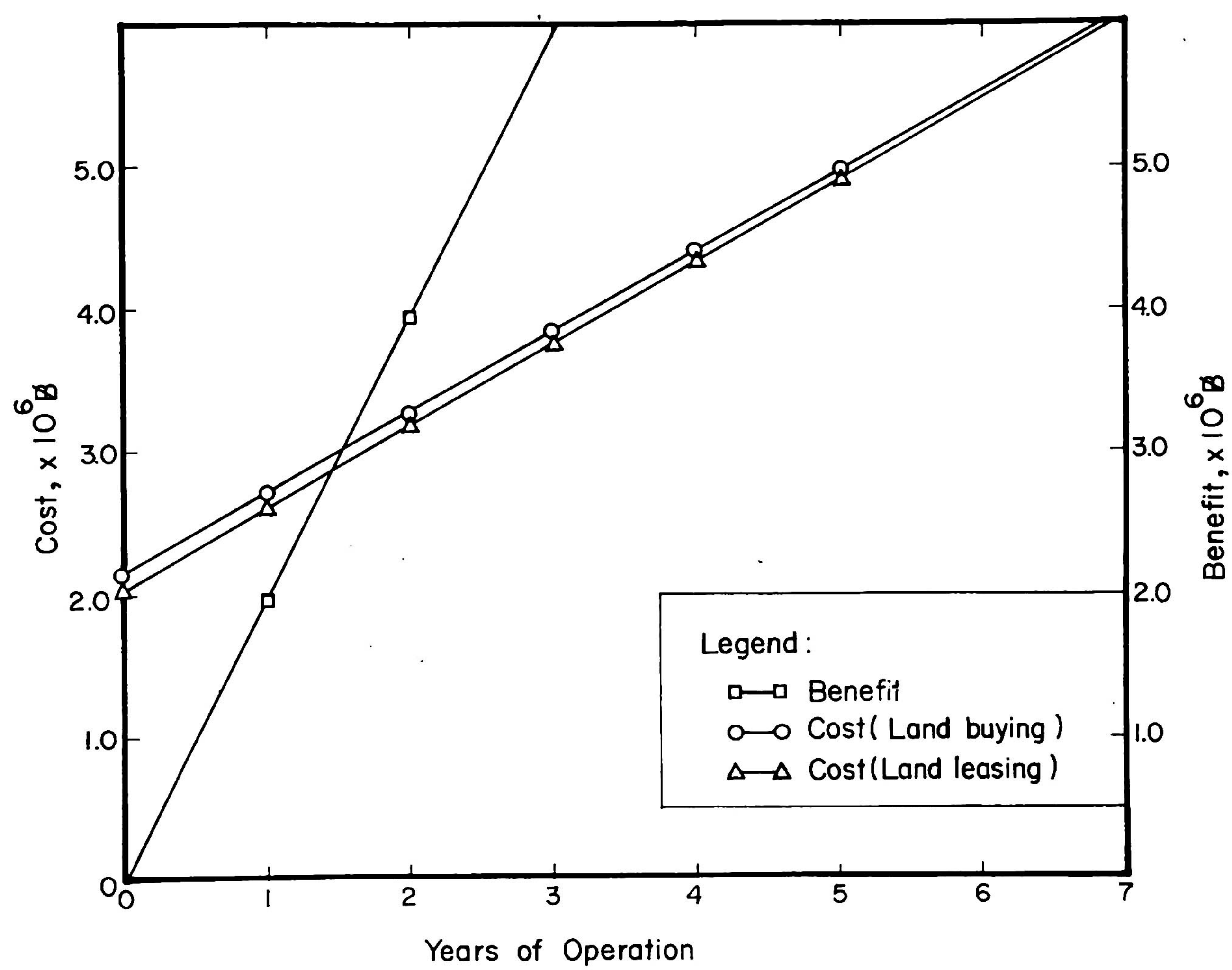


Fig. 4.9 – Pay-Back Period of MAS Treatment by Anaerobic Digestion for Small Distillations.

V CONCLUSIONS

The following conclusions may be drawn from the study.

1. Start-up of anaerobic digester of MAS could be done by batch-feeding of neutralized MAS in 50% by volume of digested cowdung. The solids content should be about 7-9% and pH is adjusted by lime. The acclimalization period was around 45 days. The stabilized conditions were achieved at the alkalinity concentration of 7,000-9,000 mg/l as $CaCO_3$ and at the volatile acid concentration of 2,500-3,000 mg/l as CH_3COOH.

2. Batch anaerobic digestion of raw MAS could be carried out at the 75% seed of digested anaerobic liquor within 20 days. When less than 75% of seeds were used, the digester showed signs of deterioration or longer time may be needed in organic removal. Therefore it may be stated that it is unfavourable to run the MAS treatment by batch anaerobic digestion.

3. With an average influent COD and BOD of around 110,000 mg/l and 31,000 mg/l, the semi-continuous digestion at $35^{o}C$ could be successfully operated at 12 days detention time, corresponding to COD and BOD loading of 9 kg COD/m -d and 2.7 kg BOD/m -d. Under this condition, the COD and BOD removal efficiencies averaged 67 and 91%, corresponding to effluent COD and BOD of 35,000 mg/l and 2,700 mg/l, respectively. The gas production yield was about 49 litres per litre of MAS fed with 48% of methane content.

4. The efficiency of organic matter removal in pilot scale digester was relatively lower than what obtained from experimental scale (about 5%). But gas production rate could not compared because of gas leaking through the pores of ferrocement ring. So it may be noted that ferrocement is not a suitable material for anaerobic digester construction.

5. Under the economic analysis of MAS primary treatment by anaerobic digestion process for the small distillery with 50 m^3 of MAS discharged per day, the benefit-cost ratio of both land buying and land leasing method were about 1.7. The pay-back periods were around one and a half year of treatment operation.

VI RECOMMENDATION FOR FURTHER WORK

The following studies are recommended, as a continuation of this investigation.

1. MAS anaerobic digestion should be carried out in the full scale to find out the real organic removal and gas production rate.

2. Ferrocement ring should be tried to use in biogas digester building with proper design and construction to prevent the gas leaking.

3. Volatile acid concentration in the MAS digester content may be decrease by any other ways which may result in increasing organic loading.

4. Other alternative of secondary treatment process should be studied out and further stage treatment should be worked out then economic analysis would be analysed in the whole treatment system.

5. Two stages of digestion should be tried with and without sludge recycle.

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APPENDIX A

Table A-1 Characteristics of Molasses Alcohol Slop

Parameters	Thaitham Distillery (RATASUK, 1976)	Eastern Chemical Distillery (McGARRY, 1972)	JAPAN (FRI, 1979)	INDIA (SEN & BHASKARAN, 1962)	BELGIUM (BASU, 1975)
Temperature, ^{o}C	95		780		98-9[illegible]
PH	4.8		5.0	4.2-4.5	5.1-5.7
COD, mg/l	109,721	56,017	47,800	40,000- 90,000	115,200-176,344
BOD_5, mg/l	30,496	26,800	33,600	18,000- 37,000	61,250- 95,750
T.N., mg/l	802		850	600- 900	1,050- 8,900
S.S., mg/l	15,564	9,153	2,650	1,030- 7,000	3,590- 8,120
T.S., mg/l	95,426	63,168	71,780	70,000-120,000	109,275-145,200
T.V.S., mg/l	76,242		55,600	-	70,260-100,875
T.V.S., % T.S.	79.9		77.5	-	-
PO_4 as P, mg/l	85			-	355- 1,030 (PO_4)
K mg/l	5,711			5,000-20,000 (K_2O)	9,300- 18,750
Na	2,020				1,070- 1,920
Ca	1,355				900- 2,100
Mg	494				400- 700
SO_4	1,485				5,440- 6,600

Table A-2 Gas Yield of some Common Fermentation Material (BUREN, 1979)

Materials	Gas production m^3/tone of dried matter	% CH_4
General stable manure from livestock	260-280	50-60
Pig manure	561	-
Horse manure	200-300	-
Rice husks	615	-
Fresh grass	630	70
Flex stalks or hemp	359	59
Straw	342	59
Leaves from trees	210-294	58
Potato plant leaves & vive etc.	260-280	-
Sunflower leaves & stalks	300	50
Sludge	640	50
Waste water from wine or spirit making factories	300-600	58

Table A-3 Composition of Biogas (FLORIDA, 1973)

		% gas from Dung	% gas from Feces
Methane	(CH_4)	50-55	60-65
Carbon dioxide	(CO_2)	40-45	30-32
Nitrogen	(N_2)	2-5	2-5
Hydrogen	(H_2)	1-2	0.6-1.0
Oxygen	(O_2)	0.1-0.4	0.1-0.4
Hydrogen sulfide	(N_2S)	< 1	< 1

Table A-4 Phisical and Chemical Properties of Methane

Sources: Katz, et al. (1959); Johnson and Auth (1951) and Weast, et al. (1964)

Chemical formula:	CH_4
Molecular weight:	16.042
Boiling point at 14.696 psia (760 mm)	-258.68°F (-161.49°C)
Freezing point at 14.696 psia (760 mm)	-296.46°F (-1824°C)
Critical pressure:	673.1 psia (47.363 Kg/cm^2)
Critical temperature:	-116.5°F (-82.5 C)
Specific gravity:	
Liquid (at -263.2°F (-164°C))	0.415
Gas (at 77°F (25°C)) and 14.686 psia (760 mm))	0.000658
Specific volume at 60°F (15.5°C) & 14.696 psia (760 mm)	23.61 ft^3/lb (1.47 l/gm)
Calorific value at 60°F (15.5°C) & 14.696 psia (760 mm)	1.012 Btu/ft^3 (38,130.71 KJ/m^3)
Air required for combustion ft^3/ft^3	9.53
Flammability Limits:	5 to 15% by volume
Octane Rating:	130
Ignition temperature:	1202 °F (650 °C)
Combustion equation	$CH_4 + 2O_2$ -- $CO_2 + 2H_2O$
O_2/CN_4 for complete combustion:	3.98 by weight
O_2/CN_4 for complete combustion:	2.0 by volume
CO_2/CN_4 from complete combustion:	2.74 by weight
CO_2/CN_4 from complete combustion:	1.00 by volume

Table A-5 Comparison of the Colorific Value of Biogas and Other Source of Energy

Source	Fuel	Carorific Value			
		J/cm^3	KJ/Kg	BTU/lb	Kcal/l
Meynell (1975)	Coal gas	16.7-18.5			
	Biogas	20-26			
	Methane	33.2-39.6			
	Natural gas	38.9-81.4			
	Propane	81.4-96.2			
	Butane	107.3-125.8			
FAO (1979)	Biogas		15,600		
	Wood		2,400		
	Charcoal		7,000		
	Kerozene		18,000		
	Methane *	38.13		23,893	9
	Fuel oil +			18,000	8,185

* Specific volume at 15.5^{o}C, 760 mm = 1.47 l/gm.

\+ Redwood I at 100^{o}F, 600 seconds, lb. per gal. at 15.5^{o}C, 750 mm = 6.83 (818.5 gm/l)

Table A-6 Properties of Fuel Oil (Redwood I at 100°F 600 seconds)
Sources: CALTEX (THAILAND) CO. (1981) &
ADKINS (1958)

Kenematic Viscosity at 122°F (50°C)	78 centistoke
Specific gravity 60°/60°F	0.82
API Viscosity	41. °A.P.I.
Specific Volume at 60°F (15.5°C)	6.83 lb/gal (818.5 gm/l)
C/H	5.57
Mean average boiling point	490 °C
Calorific value at 15.5°C, 760 mm.	18,000 Btu/lb

APPENDIX B

Table B-1 Characteristic of Molasses Alcohol Slop of Ayudhaya Distillery

Parameters \ Date	14-10-80	14-11-80	16-12-80	23-1-81
Temperature, ^{o}C	98	95	99	98
pH	4.2	4.5	4.4	4.4
Alkalinity, mg/l as $CaCO_3$	1,625	1,850	1,525	1,900
Volatile acid, mg/l as CH_3COOH	10,575	10,313	5,938	9,113
COD, mg/l	107,744	132,056	104,272	107,016
BOD_5, mg/l	32,735	34,318	31,996	30,522
BOD/COD	0.30	0.26	0.31	0.29
S.S, mg/l	2,740	5,098	4,480	4,242
T.S, mg/l	107,980	115,420	98,500	112,250
T.V.S, mg/l	79,640	86,128	73,480	82,656
T.V.S, % T.S	74	75	75	74
P, mg/l	25.8	32.6	-	-
N, mg/l	1,462	-	891	562
Cl^- mg/l	-	-	1,834	1,980

Table B-2 Start-Up Condition in An-Anaerobic Digestion Fed with Didested Cow Dung and Neutralized MAS (1:1)

Date	Days After started	Filtered COD mg/1	pH	Alkalinity mg/1 as $CaCO_3$	Volatile Acid mg/1 as CH_3COOH	$\frac{V.A.}{Alk.}$
15-10-80	0	-	7.40	-	-	-
16-10-80	1	66,955	6.50*	7,400	8,755	1.19
23-10-80	8	51,746	7.10	13,000	15,900	1.22
30-10-80	15	44,966	7.20	16,250	15,075	0.93
4-11-80	20	40,858	7.10	12,850	10,313	0.80
12-11-80	28	31,584	7.90	11,650	7,500	0.64
17-11-80	33	27,744	7.50	7,700	4,550	0.59
22-11-80	38	25,560	7.70	7,500	3,825	0.51
29-11-80	45	24,108	8.10	6,950	2,438	0.35
3-12-80	49	24,031	7.65	7,300	2,250	0.31

* pH adjustment up to 8.6 by adding lime 6.3 g/l

Table B-3 Start-Up Condition in An-Anaerobic Digestion Using Digested Cow Dung as Seed and Dairy Increasing Feeding Rate of MAS

	Days After started	Filtered COD, mg/l	pH	Alkalinity mg/l as $CaCO_3$	Volatile Acid mg/l as CH_3COOH	$\frac{V.A.}{Alk.}$
16-10-80	1	-	6.60	1,850	825	0.45
19-10-80	4	-	6.75	3,875	2,288	0.59
22-10-80	7	-	7.05	4,750	2,250	0.47
25-10-80	10	-	7.10	4,800	2,025	0.42
27-10-80	12	-	7.20	5,000	2,850	0.57
29-10-80	14	18,346	7.40	6,500	2,325	0.36
30-10-80	15	-	7.35	6,750	2,550	0.38
1-11-80	17	21,950	7.35	7,350	2,700	0.37
3-11-80	19	-	7.30	7,750	4,125	0.53
4-11-80	20*	29,491	7.25	7,925	5,725	0.73
5-11-80	21	37,093	7.20	8,050	6,245	0.90
8-11-80	24	33,008	7.60	8,950	3,938	0.44
12-11-80	28	-	7.70	8,350	3,075	0.37
13-11-80	29	25,674	7.75	7,850	2,475	0.32
14-11-80	30	25,376	7.80	7,750	2,325	0.30

Table B-4 Batch Study on the Biodedradability of the Raw MAS in Anaerobic Digestion (Digested Slurry : Raw MAS = 1:3)

Date	Day After started	Filtered COD, mg/l	pH	Alkalinity	V.A.	V.A./Alk
2-12-80	0	90,137	7.70	-	-	-
3-12-80	1	82,048	6.10*	-	-	-
4-12-80	2	82,048	6.40	11,200	13,763	1.23
5-12-80	3	-	6.20	-	-	-
6-12-80	4	84,744	6.00	12,550	16,988	1.35
7-12-80	5	-	5.90	-	-	-
8-12-80	6	-	5.90*	13,375	21,675	1.62
9-12-80	7	82,005	5.95	-	-	-
10-12-80	8	-	5.90*	-	-	-
11-12-80	9	82,533	5.90	12,890	22,853	1.77
12-12-80	10	-	5.90*	-	-	-
13-12-80	11	-	6.00	-	-	-
14-12-80	12	82,493	6.00	12,950	24,675	1.90

* pH Adjustment by Lime Addition

Table B-5 Batch Study on the Biodegradability of the Raw MAS in Anerobic Digestion (Digested Slurry : Raw MAS = 1:1)

Date	Day	Filtered COD	pH	Alkalinity	V.A.	V.A./Alk
2-12-90	0	67,714	7.40	-	-	-
3-12-80	1	67,196	6.80*	11,235	10,335	0.92
4-12-80	2	66,768	6.50	11,850	13,500	1.14
5-12-80	3	-	6.20	-	-	-
6-12-80	4	66,538	6.00*	12,800	15,225	1.19
7-12-80	5	-	6.10	-	-	-
8-12-80	6	-	5.90*	-	-	-
9-12-80	7	65,834	6.50	15,350	18,675	1.22
10-12-80	8	-	6.20*	-	-	-
11-12-80	9	-	6.80	-	-	-
12-12-80	10	65,035	6.80	15,925	17,520	1.10
13-12-80	11	-	6.00*	-	-	-
14-12-80	12	65,000	6.50	15,150	16,075	1.06

* pH Adjustment by Lime Addition

Table B-6 Batch Study on the Biodegradability of the Raw MAS in Anaerobic Digestion (Stabilized Anaerobic Digester Liquor : Raw MAS = 3:1)

Date	Day After started	Filtered COD, mg/l	pH	Alkalinity mg/l as $CaCO_3$	Volatile Acid mg/l as CH_3COOH	$\frac{V.A.}{Alk}$
15-11-80	0	43,830	7.60	6,200	5,275	0.85
17-11-80	2	-	5.70*	5,400	8,700	1.61
21-11-80	6	31,834	7.35	10,000	9,000	0.90
24-11-80	9	30,250	7.25	9,950	5,250	0.53
27-11-80	12	28,034	7.30	8,375	3,525	0.42
30-11-80	15	-	7.70	8,550	3,375	0.40
4-11-80	19	21,362	7.60	8,600	2,475	0.29
5-12-80	20	20,875	7.90	8,650	2,425	0.28
6-12-80	21	20,684	7.80	8,625	2,550	0.30

* pH Adjustment by Lime Addition

Table B-7 Performance of Anaerobic Digestion of Non-Neutralized MAS with Detention Time 25 days

Influent			Effluent		COD Removed	% Removal Efficiency		Gas Production					
COD_T	BOD_5	Organic loading Kg COD/m^3-d	COD_T	BOD_5	Kg/m^3-d	COD_T	BOD_5	1/d	1/1 MAS	1/1 of content	1/Kg COD loading	1/kg COD destroyed	% CH_4
115,505	-	4.62	26,964	-	3.54	76.7	-	34.6	47.9	1.92	416	542	56
110,828	-	4.43	26,441	-	3.38	76.1	-	30.4	42.4	1.69	381	500	-
107,514	-	4.30	25,674	-	3.27	76.1	-	30.0	41.4	1.66	386	508	-
113,832	-	4.55	24,653	2,352	3.57	78.3	92.7	35.6	49.6	1.98	435	555	50
113,016	32,318	4.52	25,768	-	3.49	77.2	-	35.1	48.7	1.95	431	559	-
106,022	-	4.24	26,893	2,212	3.17	74.6	93.0	32.0	44.4	1.78	420	562	-
113,832	32,372	4.55	27,710	2,352	3.44	75.7	92.7	30.4	42.4	1.69	371	491	48
Average		4.46	26,300	2,272	3.41	76.4	92.8	32.6	45.3	1.81	406	531	51.3

Table B-8 Performance of Anaerobic Digester of Non-Neutralized MAS with Detention Time 20 days

Influent			Effluent		COD Removed	% Removal Efficiency		Gas Production					
COD_T	BOD_5	Organ loading Kg COD/m^3-d	COD_T	BOD_5	Kg COD / m^3-d	COD_T	BOD_5	1/d	1/1 MAS	1/1 of content	1/Kg COD loading	1/kg COD destroyed	% CH_4
108,528	31,183	5.43	29,317	2,380	3.96	73.0	92.4	39.8	44.2	2.21	407	558	--
108,893	-	5.44	29,880	-	3.95	72.6	-	41.6	46.1	2.31	425	585	50
109,328	-	5.47	30,673	-	3.93	72.9	-	43.9	48.9	2.44	446	621	49
109,934	31,245	5.40	30;079	2,324	3.89	72.1	92.6	-	-	-	-	-	52
107,625	-	5.38	29,482	-	3.91	72.6	-	43.6	48.4	2.42	450	619	48
107,841	-	5.39	30,278	-	3.88	71.9	-	40.2	44.7	2.23	414	575	-
107,252	30,826	5.36	19,118	2,278	3.91	72.9	92.6	42.0	46.7	2.33	435	596	-
Average		5.41	29,832	2,327	3.92	72.4	92.5	41.9	46.5	2.32	429	592	50

Table B-9 Performance of Anaerobic Digestion of Detention Time 15 days Without Neutralization of MAS

Influent			Effluent		COD Removed	% Removal Efficiency		Gas Production					
COD_T	BOD_5	COD loading Kg/m³-d	COD_T	BOD_5	Kg/m³-d	COD_T	BOD_5	1/d	1/1 MAS	1/1 of content	1/Kg COD loading	1/kg COD destroyed	% CH_4
107,789	31,680	7.19	32,144	2,842	5.04	70.2	91.0	56.4	47.0	3.13	435	621	48.5
-	-	-	-	-	-	-	-	-	-	-	-	-	-
107,529	-	7.17	33,320	-	4.96	69.0	-	55.2	46.0	3.07	428	619	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-
108,015	30,464	7.20	34,179	2,575	4.92	68.4	91.5	55.9	46.6	3.11	432	632	49.0
107,937	-	7.20	33,597	-	4.96	68.9	-	57.5	47.9	3.19	443	643	50.5
107,816	30,005	7.19	33,985	2,620	4.92	69.4	91.3	55.8	46.5	3.10	431	630	50.0
Average		7.19	33,445	2,679	4.96	69.2	91.3	56.2	46.8	3.12	434	629	49.5

Table B-10 Performance of Anaerobic Digestion of Detention Time 12 days Without Neutralization of MAS

Influent			Effluent		COD Removed	% Removal Efficiency		Gas Production					
COD_T	BOD_5	COD loading kg/m^3-d	COD_T	BOD_5	Kg/m^3-d	COD_T	BOD_5	1/d	1/1 MAS	1/1 of content	1/Kg COD loading	1/kg COD destroyed	% CH_4
108,796	32,058	9.07	35,877	2,736	6.08	67.0	91.5	72.9	48.6	4.05	447	666	-
108,933	-	9.08	36,496	-	6.04	66.5	-	74.0	49.3	4.11	453	680	47.5
-	-	-	-	-	-	-	-	-	-	-	-	-	-
108,092	31,763	9.01	35,824	2,880	6.02	66.9	90.9	73.5	49.0	4.08	453	678	49.0
107,988	-	9.00	36,443	-	5.96	66.3	-	72.5	48.3	4.03	448	676	48.5
107,988	31,802	9.00	34,535	2,726	6.12	68.0	91.4	75.2	50.3	4.18	464	683	48.0
108,167	32,284	9.01	35,750	2,640	6.03	66.9	91.8	-	-	-	-	-	-
108,327	31,977	9.03	35,820	2,746	6.04	66.9	91.4	73.6	49.1	4.09	453	677	48.3

Table B-11 Performance of Anaerobic Digester of Detention Time 10 days Without Neutralized of MAS

Influent			Effluent		COD Removed	% Removal Efficiency		Gas Production					
COD_T	BOD_5	COD loading kg/m^3-d	COD_T	BOD_5	Kg/m^3-d	COD_T	BOD_5	1/d	1/1 MAS	1/1 of content	1/Kg COD loading	1/kg COD destroyed	% CH_4
107,832	31,040	10.8	38,171	4,080	6.97	64.6	86.9	80.4	44.7	4.47	414	641	-
107,945	-	10.8	39,877	-	6.81	63.1	-	79.8	44.3	4.43	410	651	46
107,842	-	10.8	41,037	-	6.68	61.9	-	75.2	41.8	4.18	387	626	-
107,842	30,720	10.8	42,869	5,088	6.50	60.2	83.4	-	-	-	-	-	-
107,384	-	10.7	43,198	-	6.42	59.8	-	80.8	44.9	4.49	420	699	44.5
107,368	-	10.7	43,757	-	6.36	59.2	-	75.2	41.8	4.18	391	657	-
107,622	30,080	10.8	44,382	5,472	6.32	58.8	81.8	74.1	41.2	4.12	381	652	45.0
107,028	-	10.7	45,067	-	6.20	57.9	-	-	-	-	-	-	-
107,028	-	10.7	48,365	-	5.87	54.8	-	70.0	38.9	3.89	364	663	-
107,112	30,968	10.7	50,930	5,640	5.62	52.5	81.8	67.2	37.3	3.73	349	664	40.0
107,500	30,702	10.75	43,765	5,070	6.37	59.3	83.5	75.3	41.8	4.18	389	656	43.9

Table B-12 Operational Conditions of Anaerobic Digestion of Non-Neutralized MAS, Detention time = 25 days

Date	Days after started	pH	Alkalinity mg/l as $CaCO_3$	Volatile Acid mg/l as CH_3COOH	VA/Alk
8-12-80	2	7.35	8,000	2,400	0.30
10-12-80	4	7.50	8,200	2,175	0.27
12-12-80	6	7.65	8,550	2,250	0.26
14-12-80	8	7.70	8,000	2,200	0.28
15-12-80	9	7.70	8,225	2,425	0.29
16-12-80	10	7.80	8,250	2,625	0.32

Table B-13 Operational Conditions of Anaerobic Digestion of Non-Neutralized MAS, Detention time = 20 days

Date	Days after started	pH	Alkalinity mg/l as $CaCO_3$	Volatile Acid mg/l as CH_3COOH	VA/Alk
19-12-80	3	7.80	8,900	2,700	0.30
21-12-80	5	7.80	8,850	2,588	0.29
23-12-80	7	7.75	-	-	-
26-12-80	10	7.70	8,725	2,513	0.29
27-12-80	11	7.70	-	-	-
29-12-80	13	7.65	8,650	2,513	0.29
30-12-80	14	7.70	8,750	2,625	0.30

Table B-14 Operational of Anaerobic Digestion of Non-Neutralized MAS, Detention time = 15 days

Date	Days after started	pH	Alkalinity mg/l as $CaCO_3$	Volatile Acid mg/l as CH_3COOH	VA/Alk
3-1-81	4	7.70	-	-	-
5-1-81	6	7.70	8,475	2,599	0.31
6-1-81	7	7.70	-	-	-
7-1-81	8	7.65	8,550	2,513	0.29
8-1-81	9	7.70	-	-	-
9-1-81	10	7.80	8,600	2,625	0.31
12-1-81	13	7.80	8,700	2,666	0.31
13-1-81	14	7.75	8,500	2,513	0.30

Table B-15 Operational of Anaerobic Digestion of Non-Neutralized MAS, Detention time = 12 days

Date	Days after started	pH	Alkalinity mg/l as $CaCO_3$	Volatile Acid mg/l as CH_3COOH	VA/Alk
16-1-81	3	7.70	8,700	2,625	0.30
19-1-81	6	7.70	8,825	2,438	0.28
21-1-81	8	7.65	-	-	-
23-1-81	10	7.70	8,775	2,475	0.28
26-1-81	13	7.60	8,600	2,550	0.30
28-1-81	15	7.60	8,675	2,438	0.28
30-1-81	17	7.70	8,650	2,588	0.30

Table B-16 Operational of Anaerobic Digestion of Non-Neutralized MAS, Detention time = 10 days

Date	Days after started	pH	Alkalinity mg/l as $CaCO_3$	Volatile Acid mg/l as CH_3COOH	VA/Alk
2-2-81	3	7.70	8,900	2,700	0.30
3-2-81	4	7.70	8,850	2,650	0.30
4-2-81	5	7.75	-	-	-
5-2-81	6	7.70	8,800	2,775	0.32
6-2-81	7	7.65	-	-	-
7-2-81	8	7.65	9,000	3,050	0.34
8-2-81	9	7.70	9,250	3,375	0.36
9-2-81	10	7.60	9,275	4,050	0.44
10-2-81	11	7.60	9,400	4,425	0.47
11-2-81	12	7.55	10,225	5,063	0.50
12-2-81	13	7.5	11,025	5,625	0.51
13-2-81	14	7.5	11,925	7,025	0.59

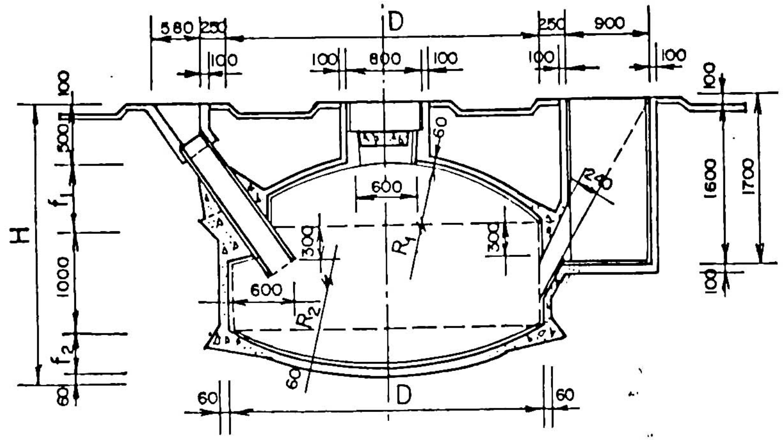
Table B-17 Performance of Anaerobic Digestion of Pilot Plant Biogas Digester, 230 litre capacity, with Detention time of 12 days

Influent		COD loading kg/m^3-d	Effluent		COD Removed Kg/m^3-d	% Removal	
COD_T	BOD_5		COD_T	BOD_5		COD_T	BOD_5
107,842	-	8.99	39,256	-	5.72	63.6	-
107,842	30,720	8.99	39,498	4,032	5.70	63.4	86.9
107,384	-	8.95	39,132	-	5.69	63.6	-
107,367	-	8.95	39,622	-	5.65	63.1	-
107,622	30,080	8.97	40,197	4,118	5.62	62.6	86.3
107,028	-	8.92	38,313	-	5.73	64.2	-
107,028	-	8.92	39,495	-	5.63	63.1	-
107,112	30,968	8.93	39,988	3,987	5.59	62.7	87.1
107,112	30,968	8.93	39,249	3,963	5.66	63.3	87.2
Average		8.95	39,417	4,025	5.66	63.3	86.9

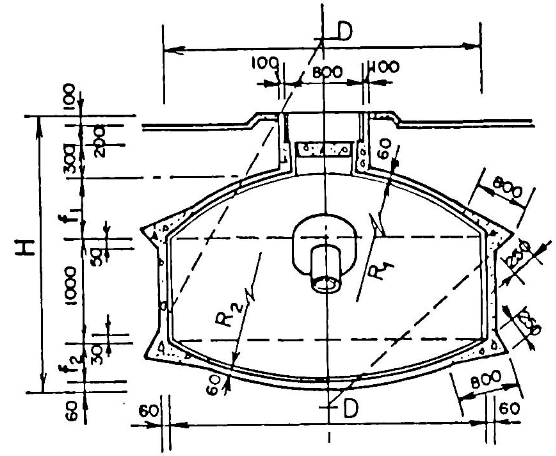
Table B-18 Operational Conditions of Biogas Disester with Detention time of 12 days

Date	Days after start-up	pH	Alkalinity mg/l as $CaCO_3$	Volatile Acid mg/l as CH_3COOH	VA/
26-1-81	2	7.90	8,925	2,813	0.31
29-1-81	5	7.75	9,125	2,888	0.32
2-2-81	9	7.60	9,000	2,813	0.31
7-2-81	14	7.60	9,075	2,738	0.30
9-2-81	16	7.50	9,250	2,775	0.30
11-2-81	18	7.55	8,900	2,700	0.30
13-2-81	20	7.45	8,950	2,925	0.33
15-2-81	22	7.40	8,925	2,813	0.32

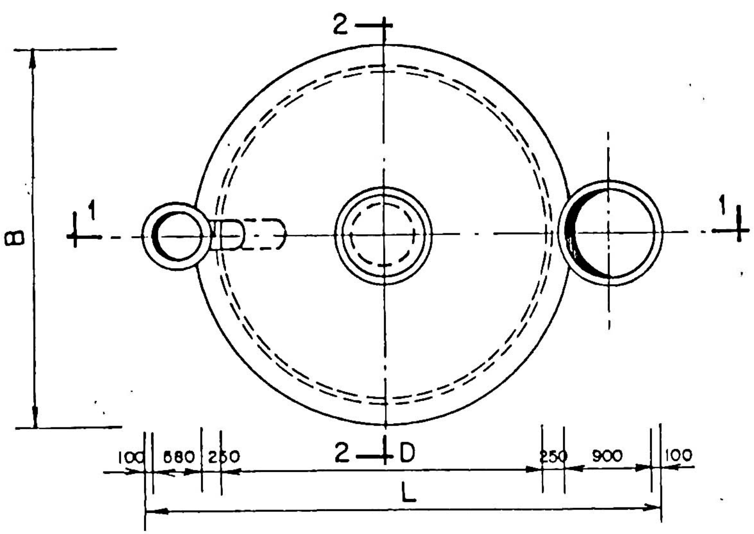
APPENDIX C



1 - 1 Section



2-2 Section



PLAN

CAPACITY	L	B	H	D	R_1	f_1	R_2	f_2	Area (m^2) = BC
6	4580	2880	2440	2400	1740	480	2550	300	13.19
8	4880	3180	2540	2700	1960	540	2860	340	15.52
10	5180	3480	2640	3000	2180	600	3180	380	18.03
12	5380	3680	2700	3200	-	640	-	400	19.80
50	7180	5480	3990	5000	-	1000	-	630	39.35
100.	8480	6780	4910	6300	-	1260	-	750	54.49
m^3									

Fig. C-1 Chinese design biogas unit with a cast concrete dome (SOUTH-WEST ARCHITECTURAL DESIGN INSTITUTE, 1979)

Table C.1 - Statistic of Working (LIEWTANAMONKOL, 1977)

Item	Person	Quantity of Working per day	Wage Rate[1/] (฿/d)
Soil excavation	1	2.2 m^3	45
Soil embankment	1	3.0 m^3	45
Wooden pile driving	3	15-18 pieces	45
Steel bar preparing	2	40-60 kg	80
Slab concrete pouring	1	1-1.5 m^3	100
Column concrete pouring	1	1.1 m^3	100
Concrete mixing	3	4-5 m^3	100
Formwork preparing	2	6-8 m^2	150
Brick laying (1/2 piece)	1	1,100 pieces	150
Wall plastering	1	8-10 m^2	150
Painting	1	15-20 m^2	100

[1/] Average wage rate of unskilled labour in Bangkok in 1980 is not less than 45 Baht/d.

Table C.2 - Capital Costs of 100 m^3 Chinese Biogas Digester

	Material	Unit	Unit Price	Quantity	Cost (฿)
1.	Wooden Pile (10 cm x 4.0 m)	piece	70	110	7,700
2.	Cement	sack	60	380	22,800
3.	Sand	m	200	80	16,000
4.	Crushed stone	m	220	60	13,200
5.	Lime	sack	7	300	2,100
6.	Timber (Kabark 2.5 x 15 cm)	m	180	310	55,800
7.	Nail (6.25 cm)	kg	14	75	1,050
	(7.50 cm)	kg	14	75	1,050
8.	Asbestos cement pipe (Ø200 mm 3.0 m)	piece	60	1	60
9.	Gate valve (Ø2.5 cm)	"	250	1	250
10.	PVC pipe (Ø2.5 cm)	"	80	1	80
11.	Bend PVC (Ø2.5 cm)	"	12	1	12
12.	Plange (Ø2.5 cm)	"	6	1	6
13.	Seepage potection additive	gallon	60	3	180
14.	Gas pipeline	m	10	50	500
	Total Material Costs				131,588
	Labour Cost[1/] and Contingencies (50% of M.C.)				65,794
	Total Capital Costs			197,382 ≈	200,000

[1/] Labour cost is calculated from Table C1.

APPENDIX D

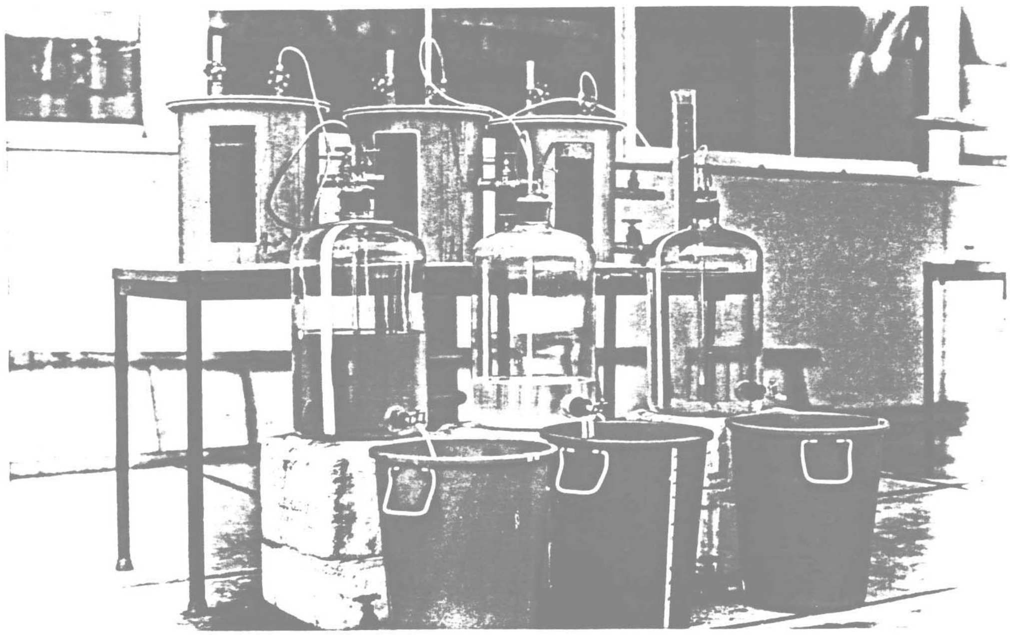


Fig. D1 - Anaerobic Digester with Gas Measuring by Water Replacement

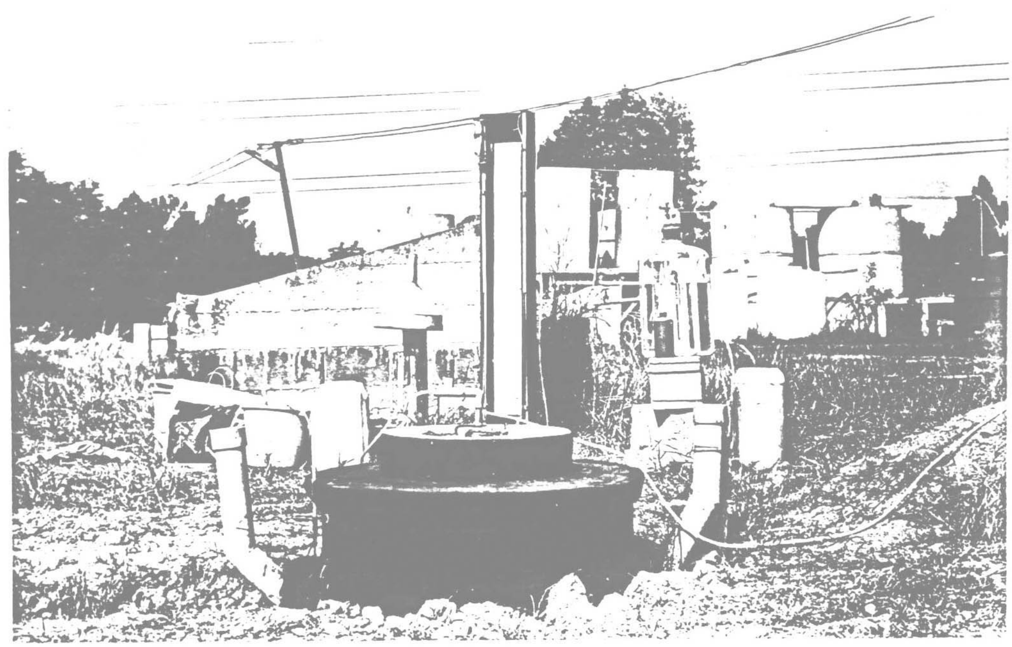


Fig. D2 - Biogas Digester