Application of Carrier Anaerobic Baffled Reactor (CABR) for Treatment of Palm Oil Mill Effluent (POME)

by

Witton Yee

Dissertation submitted in partial fulfillment of

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved by,

(Dr. Amirhossein Malakahmad)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

WITTON YEE

ABSTRACT

The focus of this research is to investigate the usage of Carrier Anaerobic Baffled Reactor (CABR) for treatment of raw Palm Oil Mill Effluent (POME). POME is the most polluted organic residues generated from palm oil mills. POME composes of high organic content mainly oil and fatty acids thus contributing to its high chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Anaerobic process is the most suitable approach for such high strength wastewater treatment. In Malaysia, the most popular treatment method for POME which is utilized by more than 85% of the mills is the anaerobic stabilization pond system. Effluent sample will be taken from Nasaruddin Palm Oil Mill situated in the District of Bota, Perak. Untreated POME in general has average values of 25,000 mg/L BOD and 50,000 mg/L of COD and the aim of this research is to obtain the highest COD removal. A laboratory scale CABR system is assembled using flexiglass sheets with dimensions of (0.48 m × 0.20 m × 0.29 m) and divided into 4 baffles. The packing is made of durable and non-degradable polymer having high a specific surface area of 8876 m^2/m^3 and good performance in removing organic pollution and entrapping suspended solids (SS). The CABR system is also equipped with influent and effluent tank of dimensions (0.23 m × 0.31 m × 0.45 m), Cole-Parmer Stir-Pak heavy duty laboratory mixer with an angular velocity of 23 to 2300 revolutions per minute, Masterflex digital peristaltic water pump with a flow rate of 0.6 to 3400 mL/min and a methane gas collection chamber. Collected sludge from the same palm oil treatment facility will be used in the CABR system as seeding material. The CABR system will be operated at 32, 22 and 10 days hydraulic retention time (HRT) which are the optimal HRT's for anaerobic treatment, to find the best performance. Daily analysis will be conducted for produced methane gas, COD and TSS of effluent and pH of every baffle. The performance of the reactor in COD content reduction will be determined.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Anaerobic treatment is a biological process ideally suited for the pretreatment of high strength wastewaters that are typical of many industrial facilities. It has a number of advantages over aerobic treatment such as low energy requirement, low sludge production, low nutrient requirement and biogas production. The anaerobic process utilizes naturally-occurring microorganisms to break down biodegradable material in an industrial waste stream. Hence, purchase of special bacteria and nutrients is not required. (M. Faisal & Hajime Unno, 2001) Because the bacteria are anaerobic they do not require oxygen like the organisms in aerobic processes.

Malaysia is blessed with a suitable climate and geographical factors for the cultivation of oil Palm, scientifically known as *Elaeis guineensis Jacq*. Today, Malaysia is the largest palm oil producer and exporter in the world where an estimated 30 million tons of palm oil mill effluent (POME) are produced annually from more than 300 oil palm mills. (Mohd Ali Hassan et al., 2006) It is also reported that during palm oil extraction, about 1.5 tons of POME is produced per ton of fresh fruit bunch (FFB) processed. POME is a colloidal suspension of 95 - 96% water, 0.6 - 0.7% oil, and 4 – 5% total solids (TS) including 2-4% suspended solid (SS) originating from the mixing of sterilizer condensate, separator sludge and hydro-cyclone wastewater. (Mahmud Ahmed, 2009).

From environmental perspective, fresh POME is a hot and acidic brownish colloidal suspension, characterized by high amounts of total solids (40,500 mg/l), oil and grease

(4000 mg/l), COD (50,000 mg/l) and BOD (25,000 mg/l). POME has been identified as one of the major sources of aquatic pollution in Malaysia. The characteristic of a typical POME is shown in Table 1.1. (Ali Akbar, 2006)

Table 1.1: Typical characteristic of palm oil mill effluent

Parameters	**Range**	**Average value**
Temperature (°C)	75–90	80
pH	4.0–4.8	4.5
Suspended solid, SS (mg/L)	11,500–22,000	17,927
Total solid, TS (mg/L)	36,500–42,600	39,470
Chemical oxygen demand, COD (mg/L)	30,000–50,400	40,200
Oil and grease (mg/L)	1300–4700	2658
Total kjeldahl nitrogen, TKN (mg/L)	660–890	800

(Source: Ali Akbar, 2006; S. Sumathi et al., 2008)

The most common practices for the treatment of POME are the ponding system, open tank digester, extended aeration system and land application system. Considering the highly organic character of POME, anaerobic process is the most suitable approach for its treatment. (Najafpour GD et al., 2005)

1.2 Problem Statement and Project Significance

In Malaysia, various treatments have been proposed to treat POME in order to meet the discharge standard of the Department of Environment (DOE) of Malaysia which is shown in Table 1.2. The ratio of POME produced is approximately 0.6 tonnes per ton of fresh fruit bunch (FFB) processed. (Tokyo Electric Power Environmental Engineering, 2009) For the Nasarudin Palm Oil Mill which uses the ponding wastewater treatment system, their treated POME contains COD and BOD of 1143 mg/L and 618 mg/L respectively which greatly exceed the required Malaysian POME discharge which is 20 mg of BOD/L and 50 mg COD/L as shown in Table 1.2:

Table 1.2: Effluent discharge standards, Environment Quality (Prescribed Premises) (Crude Palm Oil) Regulations, 1977.

Parameter		Parameter Limits	Remarks
Biological Oxygen Demand (BOD; 3-Day, 30°C)	mg/L	100	
Chemical Oxygen Demand (COD)	mg/L	200	
Total Solids	mg/L	1000	
Suspended Solids	mg/L	400	
Oil and Grease	mg/L	50	
Ammoniacal Nitrogen	mg/L	150	Value of filtered sample
Total Nitrogen	mg/L	200	Value of filtered sample
pH	-	5 - 9	
Temperature	°C	45	

(Source: Regulation 12(4) Environment Quality (Prescribed Premises) (Crude Palm Oil) Regulations, 1977)

Hence, there is an urgent need for an efficient treatment of POME to meet the requirements of safe effluent discharge as high COD wastewater will increase the oxygen demand in water bodies and endanger aquatic life.

Over the past decades, several cost-effective treatment technologies comprising anaerobic, aerobic and facultative processes have been developed for the treatment of POME. More than 85% of palm oil mills use solely anaerobic ponding systems due to their low costs. It has been reported that only a few mills are equipped with biogas recovery systems (Najafpour GD et al., 2005). With regard to that the main practice of treating POME is by using ponding, long hydraulic retention time (HRT), low treatment efficiency, high sludge production, extensive land area requirement, emission of large amount of green house gases such as Carbon Dioxide and Methane gas (CO_2 and CH_4) and so on are drawbacks of this conventional POME treatment method (Yacob et al., 2005). Therefore, the application of an efficient, stable and economic high rate anaerobic treatment system such as the Carrier Anaerobic Baffled Reactor (CABR) is required. Further information on the CABR can be found in the literature review section.

1.3 Objective

The aim of this research is to study the application of CABR in different HRT for treatment of raw POME which comprises the following:

1. To investigate the performance of CABR for pollution reduction and biogas production from POME.

1.4 Scope of Study

The main focus of the present study is the design of laboratory scaled CABR to obtain the best COD percentage removal and biogas production rate at varying HRTs of which series of experiments and analysis will be conducted. Real samples of POME will be used without dilution and sludge from the Nasarudin Palm Oil Mill, located at Bota District in Perak will be collected and cultivated as the attached growth seeding material. The COD percentage removal and methane gas production are monitored daily.

CHAPTER 2

LITERATURE REVIEW

2.1 Anaerobic Treatment

Anaerobic digestion may be defined as the engineered methanogenic anaerobic decomposition of organic matter. It involves different species of anaerobic microorganisms that degrade organic matter (Caroline Côté et al., 2006). In the anaerobic process, the decomposition of organic and inorganic substrate is carried out in absence of molecular oxygen. The biological conversion of the organic substrate occur in the mixtures of primary settled and biological sludge under anaerobic condition followed by hydrolysis, acidogenesis and methanogenesis to convert the intermediate compounds into simpler end products as methane (CH_4) and carbon dioxide (CO_2) (Guerrero et al., 1999). Therefore, the anaerobic digestion process offers great potential for rapid disintegration of organic matter to produce biogas that can be used to generate electricity and save fossil energy (Bernd Link, 2006).

Compared to conventional aerobic methods of wastewater treatment, the anaerobic wastewater treatment concept indeed offers fundamental benefits such as low costs, energy production, relatively small space requirement of modern anaerobic wastewater treatment systems, very low sludge production (10-20 % of COD removed) with very high dewaterability, stabilized sludge and high tolerance to unfed conditions (Metcalf and Eddy, 2004). The main advantages of anaerobic treatment are the very high loading rates that can be applied which are 10 to 20 times as high as in conventional activated sludge treatment. Pay-back times of significant investments in anaerobic treatment technologies can be as low as two years. Anaerobic digestion is the most suitable option for the treatment of high strength organic effluents. The presence of biodegradable components in the effluents coupled with the advantages of anaerobic process over other treatment methods makes it an attractive option (K.V. Rajeshwari et al., 1999).

There are few types of anaerobic treatment including Anaerobic Stabilization Pond and Anaerobic digestion which is currently being used to treat POME.

2.2 Stabilization Pond

Anaerobic ponds for POME treatment consist of at least two ponds connected in series to other ponds. The raw POME is channeled into the anaerobic pond from the sludge recovery tank. Anaerobic pond system is very effective in the treatment of effluents with high strength, biodegradable organic contents because of long retention time (Yee Shian Wong et al., 2009). However, due to low flow rate in the pond and excessive concentration of nutrients in POME, algal growth is inevitable. In addition, odor from anaerobic ponds disturbs the neighboring community. There is no collection method for the methane gas produced (Noriedah bt Sofian, 2008). The application of the anaerobic stabilization pond is preferred especially in Malaysia is because of its low capital and operational cost (U. Peutpaiboon & J. Chowwattanasak, 2001). Nevertheless, it utilizes a large area to operate.

The Nasaruddin Palm Oil Mill uses the anaerobic stabilization pond treatment system. It consists of 2 cooling ponds, 4 anaerobic ponds, 2 oxidation ponds, a settling pond and a dislodging pond. The influent POME is discharged through the cooling pond No.1 and 2 for 3 days. The wastewater is then kept in the anaerobic ponds No.1, 2, 3 and 4 for a total of 160 days retention time. The oxidized wastewater will be settled in the settling pond for a day before it goes through the oxidation pond No.2 and finally discharged into the stream. The sludge from anaerobic pond No.3 and 4 will be sent into a dislodging pond. The capacity of each cooling ponds, anaerobic ponds, oxidation ponds and settling ponds are 1355m^3, 22000m^3, 4000m^3, 500m^3, and 3, 40, 8 and 1 day. (Farhana bt Abd Lahin, June 2010)

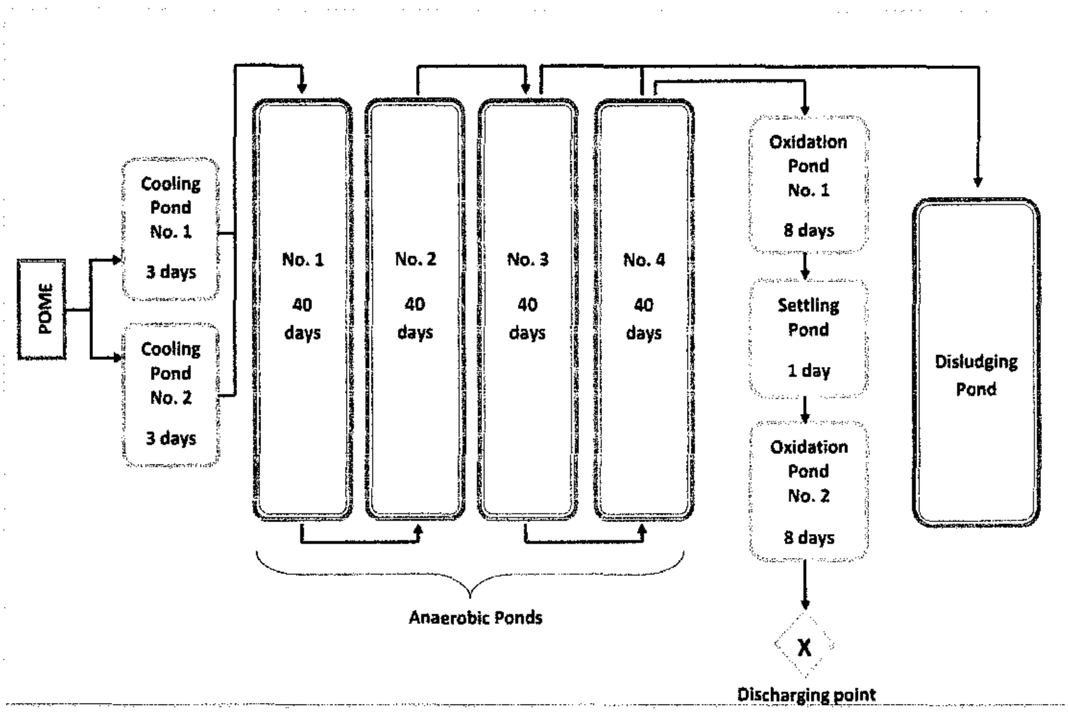

Figure 2.1: Anaerobic Stabilization Pond of Nasarudin Palm Oil Mill.

2.3 Anaerobic Baffled Reactor

The ABR is a high rate anaerobic digester that is internally compartmentalized by a series of hanging and standing baffles. Wastewater enters the reactor and flows under a natural head under and over the hanging and standing baffles. No oxygen or mechanical mixing is applied in the ABR. Treatment is achieved by anaerobic digestion by naturally selected anaerobic microbes or sludge. The ABR is similar in concept to a septic tank in which, passive treatment of wastewater is obtained by the unassisted development of anaerobic microorganisms in a simple digester design. (Barber WP, Stuckey DC, 2000)

Microorganisms within the reactor will gently rise (up flow) and settle (down flow) due to the arrangement of the vertical baffles in each compartment. Hence, the wastewater can come into intimate contact with a large amount of active biomass as it passes through the ABR, while the effluent remains relatively free of biological solids. This configuration has been shown to result in a high degree of COD removal. (Krishna GVT, Kumar P, Kumar P, 2007)

A study on ABR has shown that due to the compartmentalized configuration which keeps the biomass in the reactor for a long period of time independent of the HRT, the ABR has potential to cultivate special microorganisms and retain them in the reactor to obtain efficient operation. (Rongrong Liu et al., 2009) ABRs are suitable for a wide range of wastewater, including high-strength industrial wastewater, but its efficiency increases with higher organic load. Therefore, ABRs are particularly suited for influents with a high percentage of non-settle able suspended solids and a narrow COD/BOD ratio (Ludwig Sasse, 1998).

The most significant advantage of the ABR is the ability to separate acidogenesis and methanogenesis longitudinally down the reactor, allowing different bacterial groups to develop under most favorable conditions (Grobicki et al, 1992). Taking into account the slow growth of many anaerobic microorganisms, particularly methanogenics, the main objective of the efficient reactor design is to achieve high retention time of bacterial cells with very little loss of bacteria from the reactor. The technological challenge in an anaerobic digestion lies in improving the bacterial activity and the mixing, so that a high rate of contact between the microorganism and substrate is ensured. (M. Faisal & Hajime Unno, 2001)

An anaerobic baffled reactor (ABR) was used to treat POME without pH adjustment at various recycle ratios. A COD removal efficiency of 84.6% was achieved at an HRT of 2.5 days, an initial COD concentration of 24,850 mg/l and an effluent recycle ratio of 25:1 (Huajun Fenga et al., 2009).

In another study by Faisal M and Unno Hajime, their modified anaerobic baffled bioreactor (MABR) was studied under steady-state conditions for treating palm oil mill effluent with initial COD concentration of 16,000 mg/l. With a hydraulic retention time (HRT) of 3–10 days, the removal ranges of COD and grease/oil were from 87.4 to 95.3% and from 44.1 to 91.3%, respectively. (M. Faisal & Hajime Unno, 2001)

2.4 Carrier Anaerobic Baffled Reactor

The advantage of The Carrier Anaerobic Baffled Reactor (CABR) over an Anaerobic Baffled Reactor (ABR) is the utilization of packing which is filled in the upcoming and down coming chambers of the reactor. According to (Huajun Fenga et al., 2009), the hollow sphere carrier utilized, which is made of bamboo has high a specific surface area, up to $2100m^2/m^3$ and a high porosity of 95%. It shows good performance in removing organic pollution and entrapping suspended solids (SS). Due to unavailability of environmental friendly packing materials in the lab, a durable and non-degradable carrier made of polymer is used. The carrier is hollow and circular with a diameter of 300mm.

The CABR combines the advantages of an anaerobic baffled reactor and the characteristics of a biofilm reactor and is a new high rate anaerobic reactor for decentralized treatment. The advantages of CABR include:

1. Easier biomass attachment to packing material.
2. Better mixing to ensure a high rate of contact between the biomass and substrate for wastewater treatment.
3. Elimination or minimization of sludge washout.

The biomass in the CABR has two parts, namely the attached growth on the carriers and flocks at the bottom of the reactor. (Huajun Fenga et al., 2009)

Table 2.1: Previous Studies Using CABR

	[1]	[2]	[3]	[4]
Type of Wastewater	Domestic	Domestic	Domestic	Domestic
Type of Media	Hollowsphere bamboo	Hollowsphere bamboo	Hollowsphere bamboo	Hollowsphere bamboo
Temperature (°C)	28	18	28	10
Influent COD (mg/L)	600	300	300	300
Effluent COD (mg/L)	<100	69	88.5	98.43
COD Removal Efficiency (%)	>83.33	77.03	70.48	67.19
F/M Ratio	0.087	0.065	0.087	0.043
HRT (hours)	18	12	9	18

(Source: Huajun Fenga et al., 2009)

CHAPTER 3

METHODOLOGY

3.1 Project Activities

The first phase of this study involves gathering information on anaerobic treatment systems mainly the CABR and its application for treating POME.

The second phase of this study involves the operation of the CABR and analysis of its performance based on its COD removal percentage and methane gas emission.

The parameters of POME such as pH, COD, Total Alkalinity, BOD, Total Kjeldahl Nitrogen, Total Organic Carbon, Total Suspended Solids, and the Mixed Liquor Volatile Suspended Solid (MLVSS) will be determined.

When the start-up stage has been completed, the steady-state operation will be conducted which is the seeding and acclimatization of anaerobic mixed culture. The steady-state performance will be evaluated under hydraulic retention time of 32 days. At given loading rate of 1.577 kgCOD/$(m^3 day)^{-1}$, the bioreactor is continuously operated until steady-state condition is achieved, when effluent COD, VSS and gas production rate in bioreactor became constant. After that, the HRT is decreased to 22 and 10 days to test reactor behavior in higher organic loading. The samples were collected and subjected to the daily analysis of the following parameters which are effluent COD, effluent total suspended solids, reactor pH and methane gas production were measured according to standard methods.

3.2 POME Sampling

POME sample will be collected at the wastewater treatment plant of Nasaruddin Palm Oil Mill, Bota, Perak and before the anaerobic pond. The equipment that will be used to collect POME samples are pail, funnel and 18-liter wastewater storage container. Total volume of POME samples to be collected is 18-Liter. The sampling location is ensured to be near the flow channel where the wastewater is well mixed. Using a pail, the sample is collected and transferred to the storage container via a funnel. POME samples will be kept at temperatures of 4°C in a storage room to decrease any microorganism activity so that the composition of the POME remains unaltered.

3.3 Characterization

The POME samples are analyzed to identify its characteristics through conducting experiments. Table 3.1 shows the characteristics of raw POME identified.

Table 3.1: Characteristic of Palm Oil Mill Effluent

Parameter	Concentration range (mg/L)	Mean ± Standard Deviation
pH	4.28 – 4.56	4.44 ± 0.14
COD	49600 – 51300	50466 ± 850
sCOD	20300 – 27620	23842 ± 3665
BOD	21310 – 28390	25230 ± 3602
TSS	10586 – 13520	11933 ± 1481
Temperature	70 – 90 °C	80 ± 10
O&G	1826 - 2251	2086 ±
TKN	714 - 784	742 ± 37
NH_3-N	7.4 – 8.4	7.9 ± 0.5

3.4 pH

The pH of the wastewater sample is determined by using the sens-ion2 pH meter by HACH. The pH meter is calibrated using distilled water. pH of POME sample will be determined in lab. POME sample will be placed in a beaker and three readings are taken down. The average of the readings is taken as the pH of the sample. The POME sample is ensured to be cooled to room temperature before ph measurement is conducted.

3.5 Temperature

The temperature of the POME is taken in-situ in three readings using a thermometer to determine the original operating temperature of the sludge and the wastewater. After storing the POME sample in the incubating room at 4°C, the POME sample is taken from the 18L sampling container into a 1000ml beaker and is left stabilize to lab temperature before temperature measurement is conducted.

3.6 Chemical Oxygen Demand

2ml of POME is measured and poured into high strength vials containing potassium dichromate. The test tube is shaken properly and placed in a reactor at 105°C for 2 hours together with a blank sample. Samples are cooled to room temperature and COD value can be determined using the spectrophotometer. Three readings are taken down and the average of the readings is calculated.

3.7 Biological Oxygen Demand

POME samples are prepared and poured into the BOD bottles according to the volume needed together with blank samples. Samples are diluted to 1:1000 and seed taken from the influent sludge will be added into the bottles that contained these samples. After all the samples are prepared, the initial DO for each sample will be measured by the DO probe that is equipped with a stirring mechanism. The BOD bottles will then be placed in the refrigerator at 20°C temperature and left for 5 days. After 5 days incubation, the final DO is measured by using the DO probe. The value of BOD can be determined using the equation below:

BOD without seed correction:

$$BOD = \frac{(initial\ dissolved\ oxygen) - (final\ dissolved\ oxygen) - (blank\ correction)}{sample\ size/300}$$

BOD with seed correction and blank correction:

$$= \frac{(initial\ dissolved\ oxygen) - (final\ dissolved\ oxygen) - (seed\ \&\ blank\ correction)}{sample\ size/300}$$

BOD with seed correction and blank correction as well as dilution:

$$= \frac{(initial\ dissolved\ oxygen) - (final\ dissolved\ oxygen) - (seed\ \&\ blank\ correction)}{sample\ size/300} \times dilution$$

3.8 Total Kjeldahl Nitrogen

Select an appropriate volume of sample to be placed in the 500 to 800 mL Kjeldahl digestion flask and add 50 mL of digestion reagent. Add several glass beads of boiling chips to the flask. Place flask on digestion apparatus and heat to boiling and continue boiling until the formation of dense white fumes (SO_2) can be seen. Continue to digest the POME sample for 30 minutes. As the digestion continues, colored or turbid samples will turn clear or straw colored. Cool the flask and dilute the sample with 300 mL of ammonia free distilled water. Add 0.5 mL phenolphthalein indicator. Tilt the digestion flask and carefully add a sufficient amount of sodium hydroxide - thiosulfate reagent to form an alkaline layer (pink zone) in the bottom of the flask. Usually 50 mL of reagent is needed for every 50 mL of digestion reagent used. Connect the flask to the distillation apparatus, mix thoroughly and distill 200 mL of distillate into a boric acid absorbing solution. Determine Total Kjeldahl Nitrogen as ammonia.

The Total Kjeldahl Nitrogen (TKN) will be determined by the formula:

$$TKN = \frac{v_1 - v_2}{v_0} \times C \times F \times 1000$$

Where:

v_1 = mL of standard 0.20N H_2SO_4 solution used in titrating sample

v_2 = mL of standard 0.20N H_2SO_4 solution used in titrating sample

N = Normality of sulfuric acid solution

F = miliequivalent weight to nitrogen

v_0 = mL of sample digested

3.9 Total Organic Carbon

Total Organic Carbon (TOC) of the wastewater is determined using differential method where both Total Carbon (TC) and Total Inorganic Carbon (TIC) are determined by separately measuring them. TOC may be calculated by subtracting TIC from TC. The formula for TOC is given by:

$$TOC = TC - TIC$$

3.10 Total Suspended Solids

100ml of wastewater sample will be filtered using a 47mm filter disc through a vacuum flask. The filter disc is then carefully placed in a watch glass dried in the drying oven by using tweezers to handle the discs. The filter discs are dried at 103°C for 1 hour. The watch glass and filter are removed from the oven and carefully placed on a desiccator. Allow the filter disc to be cooled off to room temperature and weight to the nearest 0.1mg using an analytical balance. The formula for TSS calculation is as given:

$$TSS = \frac{(weight\ of\ pan + filter\ paper\ after\ drying) - (weight\ of\ pan + filter\ paper\ before\ drying)}{sample\ size\ (L)}$$

3.11 Mixed Liquor Suspended Solids and Mixed Liquor Volatile Suspended Solids

The Mixed Liquor Volatile Suspended Solid (MLVSS) is determined by filtering the samples using a 47mm fiber glass filter paper, which is used to avoid burning of filter paper when exposed to high temperature of 550°C. The fiber glass is then dried in a drying oven for 105°C for 1 hour and weighed after it is cooled off in a desiccator. The filter paper is then placed in a furnace with the temperature of 550°C for 20 minutes. After being cooled off in a desiccator, the filter paper is weighed to determine the MLVSS of the samples. The MLVSS of the samples can be determined by the formula:

$$MLSS = \frac{(weight\ of\ pan + filter\ paper\ after\ drying) - (weight\ of\ pan + filter\ paper\ before\ drying)}{sample\ size\ (L)}$$

$$MLVSS = \frac{(weight\ of\ pan + filter\ paper\ after\ furnace) - (weight\ of\ pan + filter\ paper\ before\ furnace)}{sample\ size\ (L)}$$

3.12 Total Alkalinity

Total alkalinity of the sample will be determined based on the standard method of analyzing wastewater.

Measure out 100 ml of the wastewater and pour into a clean white porcelain evaporating dish. Add 2 or 3 drops of methyl orange indicator to the sample. Add N/50 sulfuric acid from the burette to the contents of the dish until the faintest pink coloration appears. Titrate to pH 4.5 and record the volume of titrant. Then calculate total alkalinity with the following:

To determine Phenolphthalein Alkalinity (P), as mg $CaCo_3$/l

$$P = \frac{(ml\ H_2SO_4\ titrant\ used) \times Normality of\ H_2SO_4 \times 50000}{Sample\ size\ (ml)}$$

To determine Total Alkalinity (T), as mg $CaCo_3$/l

$$T = \frac{(Total\ H_2SO_4\ titrant\ used) \times Normalityof\ H_2SO_4 \times 50000}{Sample\ size\ (ml)}$$

3.13 Seeding

The sludge will be taken from the wastewater treatment center of Nasaruddin Palm Oil Mill, the anaerobic pond No.2 which is the second pond that the sludge will pass thru after 40 days of retention time in the first pond. In total there are 4 anaerobic ponds with HRT of 40 days each. The sludge is taken from the same treatment facility so that the anaerobic microbes are familiar with the characteristic of the wastewater and environment that will shorten the time for acclimatization of the sludge in the lab. The procedure of collecting sludge will be the same as how the influent is collected. The large particles of the sludge will be removed by passing it through an American Society of Testing Materials (ASTM) sieve No.16 (1.18mm). Then, the sludge will be introduced to all 4 compartments of the CABR. The amount of sludge needed in the system will be calculated using the equation below:

$$\frac{Food}{Microoganism} = \frac{Influent\ BOD\ or\ COD}{HRT\ \times VSS}$$

$$\frac{F}{M} = \frac{S_o}{\theta x}$$

Where:

F = Food

M = Microorganism

So = Influent BOD or COD concentration (mg/l)

θ = Hydraulic retention time (day)

$\theta = \frac{Volume}{Flowrate}$

x = Concentration of volatile suspended solids in tank (mg/l)

3.14 Microorganism observation

Sludge sampling is done at every baffle including the clarifier to identify different types of microorganisms present. 50 ml of sludge is collected from each baffle into centrifuge tubes that are rinsed with distilled water and sterilized at 170 °C for 60 minute in oven. The centrifuge is run at 70,000 rpm for 20 minutes to allow the biomass to settle and be separated from the wastewater. This will increase the density of microorganism being seen under the microscope. The method used to identify microorganisms relied on morphology. Photomicrography was carried out using an optical light microscope equipped with a camera.

3.15 Reactor Characteristic and Operation

The reactor used in the experiment is made of flexiglass with a dimension of 0.48m in length, 0.20m in width and 0.28m in height and divided into 4 compartments as biomedia placed in each column will increase the HRT. The volume of the first compartment is $0.0079m^3$ while the next 3 compartments each having $0.0030m^3$ of volume. The first compartment is designed with bigger volume compared to the other 3 compartments to provide longer solid retention time and superior volume compared to reactor with similar sized compartments. The larger compartment acts as a natural filter and provides superior solid retention for the small particles. This configuration will collect more solid materials than having 4 equally divided compartments. (A.Malakahmad et al., 2010)

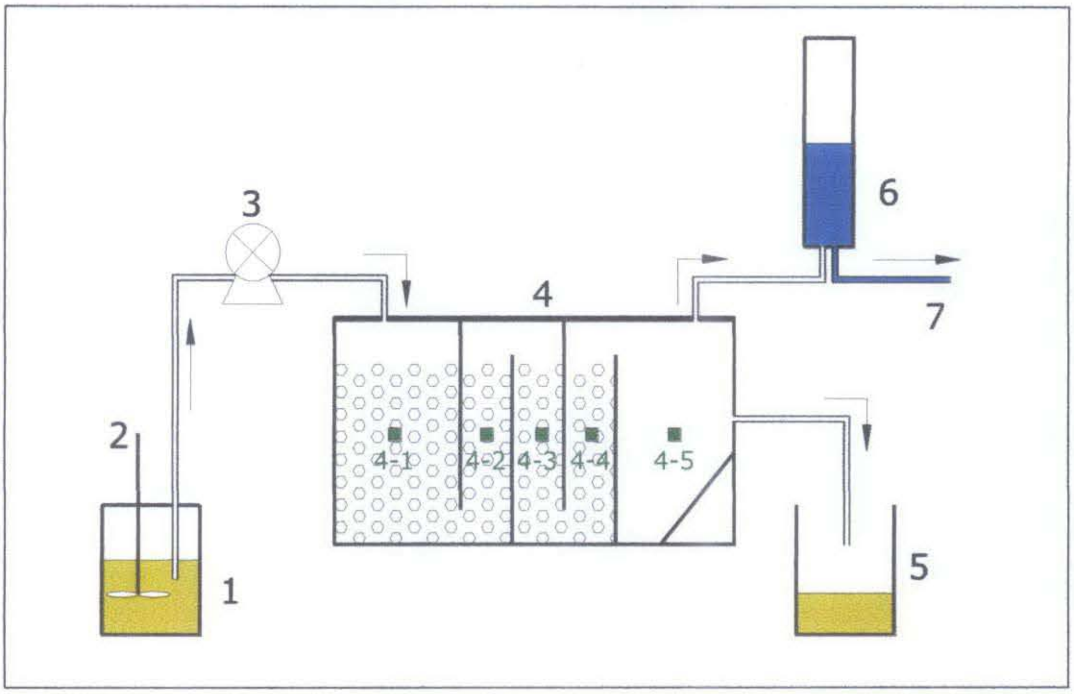

Figure 3.1: Laboratory Scale Carrier Anaerobic Baffled Reactor Schematic Diagram (*1: Influent Tank, 2: Stirrer, 3: Water Pump, 4: CABR System, 4-1 to 4-5 Sampling Points, 5: Effluent Tank, 6: Gas Collection Chamber, 7: NaOH Discharge*)

According to (Feng Huajun et al., 2009), the CABR tended to show a state of plug flow as the number of compartments in the CABR increases. When the effectiveness and capacity of the reactor are considered, a CABR with 6 compartments are found to be optimal. However, our reactor will be based on 4 columns to avoid coagulation and blockage in flow, due to nature of POME which is very high in total solids (40,500 mg/l) and each column will be filled with packing material to the brim.

Table 3.2: Reactor Specification

Details	Baffle No.1	Baffle No.2	Baffle No.3	Baffle No.4
Length (m)	0.14	0.05	0.11	0.05
Width (m)	0.20	0.20	0.20	0.20
Height (m)	0.28	0.28	0.28	0.28
Volume (m^3)	7.84×10^{-3}	2.80×10^{-3}	6.16×10^{-3}	2.80×10^{-3}
Nos of Fillers	225	75	75	75
Height of Fillers(m)	0.23	0.23	0.23	0.23
Specific Surface Area (m^2/m^3)	1.997×10^6	6.657×10^5	6.657×10^5	6.657×10^5

Two tanks both with dimensions of 0.23 m x 0.31 m x 0.45 m and volume of $0.032m^3$ are used for the systems as influent tank and effluent tank. Influent tank will feed the wastewater to the reactor through a mechanical pump. The effluent tank will function to retain the effluent wastewater from the reactor. Stirrer is also added in the influent tank to stir the wastewater in order to prevent sedimentation and for better mixing of influent. The pump is operated at specific flow rate determined based on HRT to feed the influent into the reactor at a constant flow rate.

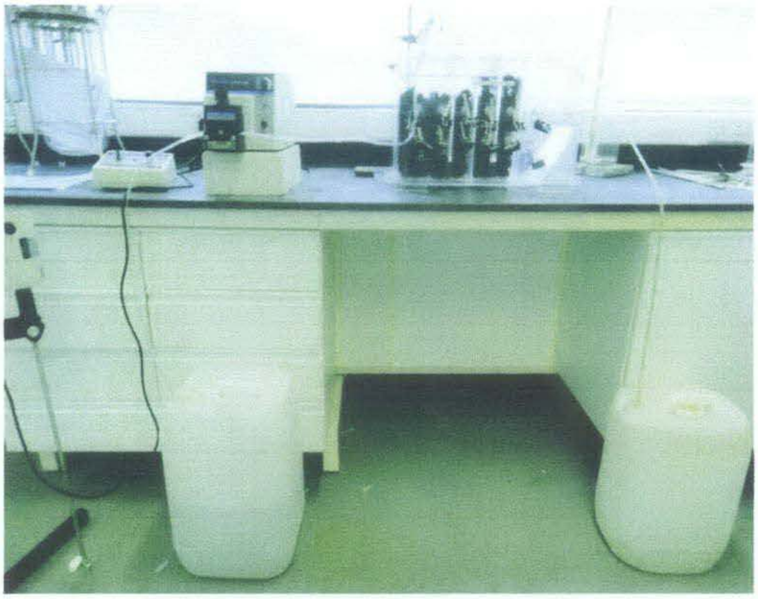

Figure 3.2: Laboratory Scale Carrier Anaerobic Baffled Reactor

The laboratory scale CABR has tubes installed at every compartment for the purpose of taking samples to analyze for ph of POME and also to observe the behavior of the reactor. The influent is pumped into the top of the reactor and is diffused into 3 flow tubes on the middle, left and right as shown in Figure 3.5. This provides even supply of food for microorganism attached to the carriers. A cylindrical gas collection chamber will be used to collect and measure the amount of methane gas produced from the system. The method for collection and measurement of methane gas is the water displacement method where the gas collection chamber is filled with solution of Sodium Hydroxide (NaOH) in order to dissolve and separate the Carbon Dioxide (CO_2) in the biogas, leaving only the methane gas. (G.V.T Gopala Krishna et al., 2008) The NaOH solution is prepared by diluting NaOH of 47% to 2.5%.

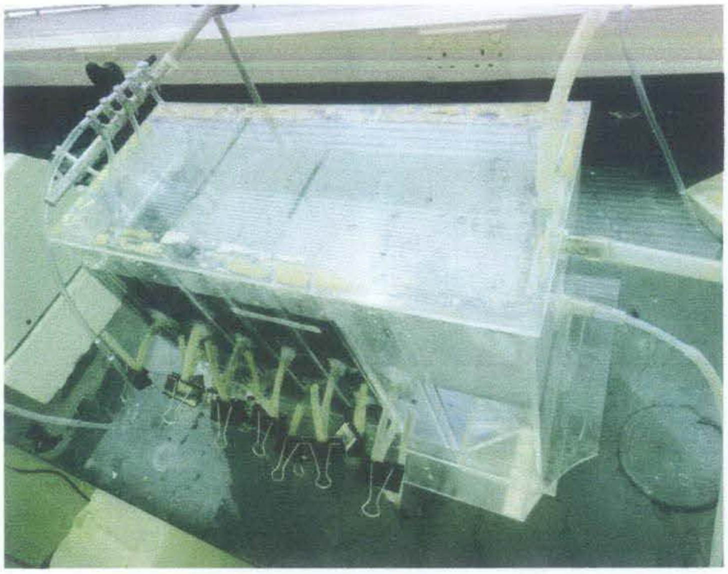

Figure 3.3: Close-up view of CABR

Figure 3.4: Influent diffuser

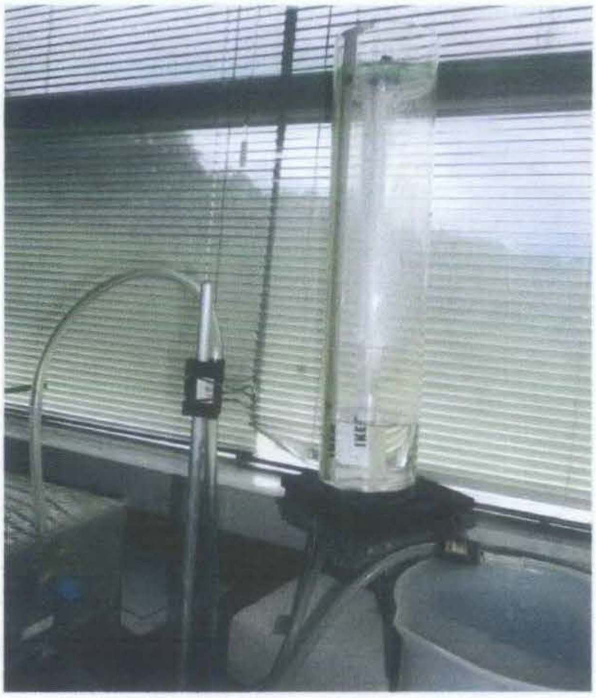

Figure 3.5: Methane Gas Collection Column

The Carrier Anaerobic Baffled Reactor is packed with carriers (bio-balls) made of polymers which are non-degradable and high in specific surface area of 8876 m^2/m^3. The carriers have a diameter of 300 mm and a volume of 3.333×10^{-6} m^3. A 19 Liter box of 1125 bio-balls contains 9.98 m^2 of surface area. The carriers are ordered from Armfield Limited, which is the producer of engineering education laboratory equipments in England. Figure below shows the type of carriers to be used.

Figure 3.6: CABR Biomedia

3.16 Hydraulic Retention Time

The calculation of HRT based on pack column is shown below:

Reactor characteristic:

- Length = 0.48m
- Width = 0.20m
- Height = 0.29m
- Volume = $0.027m^3$
- COD = 40,000mg/L = 40 kg/m^3
- HRT = 3 days

$$Flowrate, Q = \frac{Reactor\ volume\ (m^3)}{HRT}$$

$$Flowrate, Q = \frac{0.027}{3} = 0.009\ m^3/d\ or\ 9\text{L/d}$$

$$Organic\ Loading\ Rate = \frac{Flowrate\ \times COD}{Volume\ of\ Reactor}$$

$$Organic\ Loading\ Rate = \frac{9\frac{L}{d} \times 40g/L}{27\ L} = 13.33\ gCOD\ (Lday)^{-1}$$

3.17 Sampling and Analysis

The effluent in the system is monitored daily for pH, COD, TSS, MLSS, MLVSS and biogas production. Samples are taken from the effluent tank and also from each compartment of the reactor to monitor behavior of the treatment system. The sampling will be done by starting from the last compartment toward the first to prevent air intrusion and to maintain the anaerobic condition in the reactor. (G.V.T Gopala Krishna et al., 2008)

3.18 Tools Required

Equipments that will be used are 1 unit of Masterflex digital peristaltic pumps, 3 meters of Masterflex tube size 16, 1 unit of Tube diffuser, 5 units of 32 liters sample containers and 1 unit of Stir-Pak laboratory mixer.

CHAPTER 4

RESULT AND DISCUSSION

The CABR system is monitored daily by taking samples of the POME from each baffle and also the effluent of the system. Figure 4.1 shows the COD content of the effluent and percentage COD reduction of the system. The TSS results of the effluent samples are depicted in Figure 4.2. The methane gas produced by the CABR system is illustrated in Figure 4.3.

4.1 Chemical Oxygen Demand

The CABR performance in terms of COD removal was consistent throughout the experiment, reaching a steady state around the 26th day. It is in agreement with (Huajun Fenga et al., 2009) which reported COD removal efficiency was consistent throughout the experiment and reaching a steady state around the 21st day. The CABR system achieved reasonable performance in terms of COD removal with highest 74.7% COD removal at HRT of 22 days. The graph of COD below shows that in the early operation of the CABR system, there are major fluctuations of COD content in the effluent. This is due to the adaptation of the microorganism with the new environment of the CABR system especially under lower temperature in the laboratory which ranges from 22 – 25 °C compared to its original treatment facility which has higher temperature. Based on the Arrhenius relationship, a decrease in temperature results in a decreased reaction rate and for a 10 °C drop, biological reaction rates are expected to drop by half. It is in agreement with (K.V. Rajeshwari .,et al, 1999) which reported that COD removal efficiency of cheese whey with a COD of 75,000 mg/L dropped from 15.6% to 8.7% without pH control. After 26 days, the COD content has stabilized and reached a steady-state condition at day 32 onwards. After reaching steady-state condition, the HRT has been reduced from 32 days to 22 days. Due to sudden increase in organic loading rate from 1.577 $kgCOD/m^3d$ to 2.294 $kgCOD/m^3d$, a reduction in COD removal efficiency of 4.3% is observed on day 37 until day 44 where COD removal efficiency increases till a steady state is achieved . After steady state has been achieved, the HRT is reduced to 10 days which observed a decrease in COD removal efficiency of 4.9%. The result of COD content in the effluent is depicted in Appendix 3.

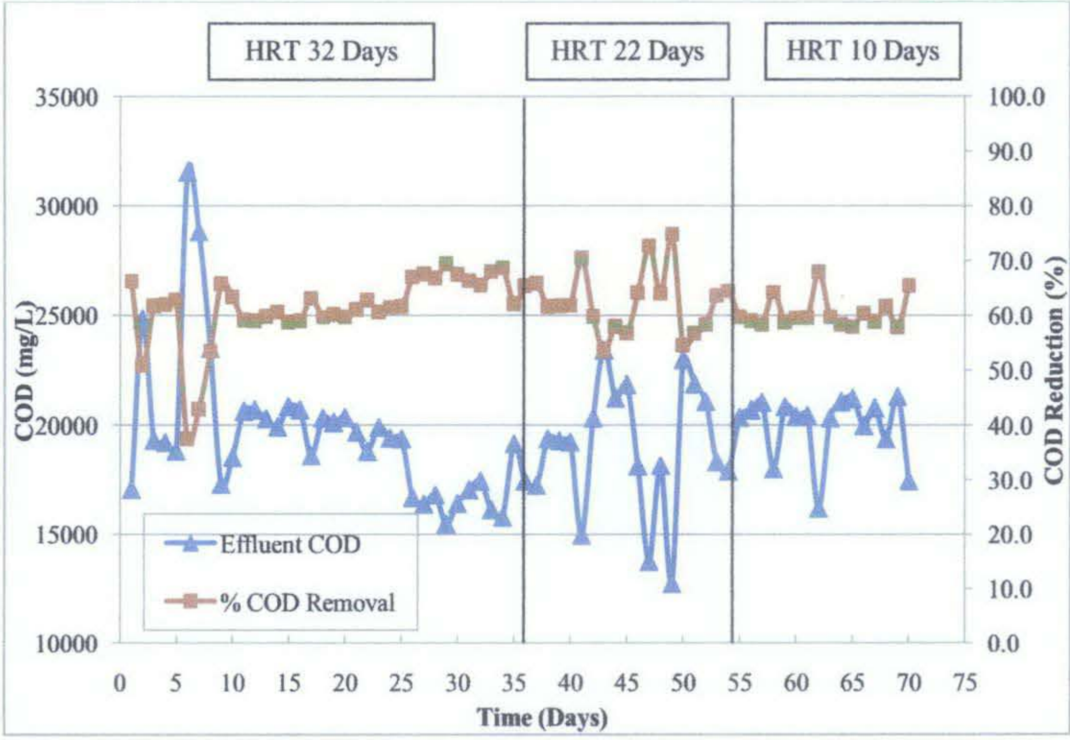

Figure 4.1: COD Removal Efficiency in the CABR System

4.2 Total Suspended Solids

Superior performance of the reactor in terms of SS removal is observed as shown in Figure 4.2.1. The average total SS removal efficiency was 95.65%, resulting in an effluent with 518.74 mg/L TSS. The lowest TSS recorded was 30 mg/L at HRT 32 days. The TSS of effluent sample is observed to be fluctuating in the beginning of the CABR system operation. This is due to the adaptation period of the microorganism to the new environment. By the passing of time, the TSS concentration in the wastewater is found to be decreasing and the fluctuation of TSS is reduced. The TSS of the influent is depicted in appendix 4. (Huajun Fenga et al., 2009)

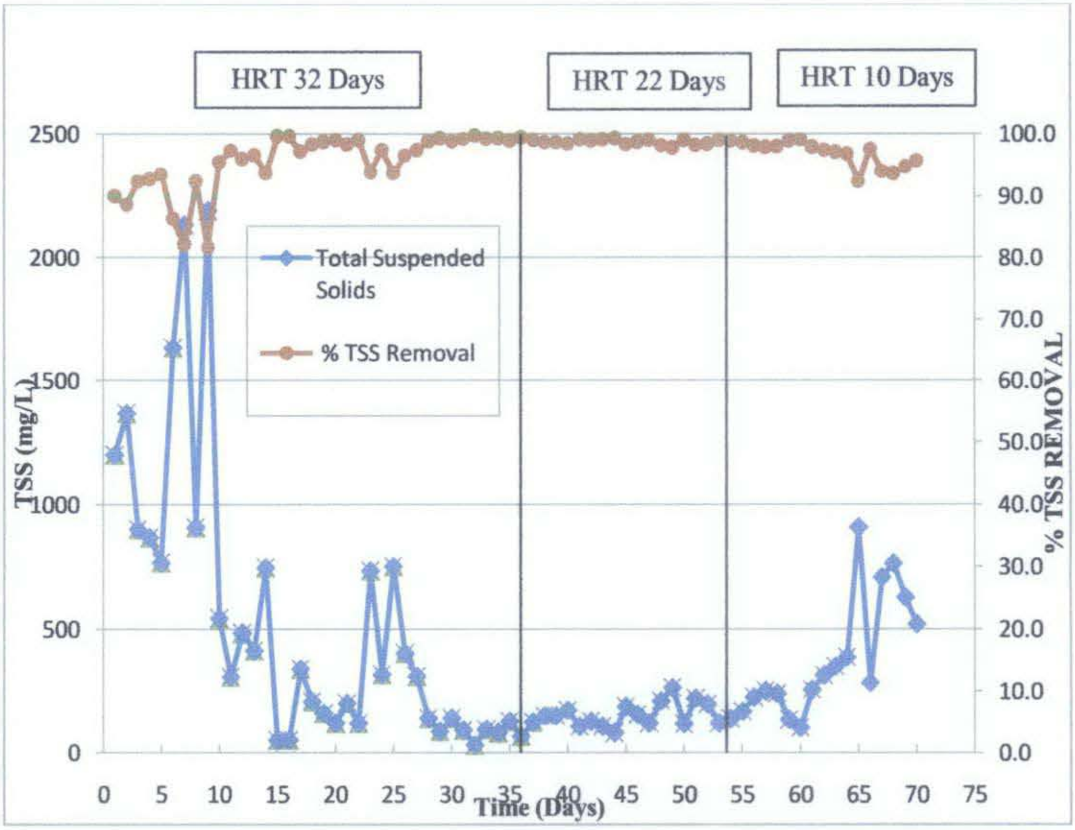

Figure 4.2: TSS removal efficiency in the CABR system

4.3 pH Profile

The difference of pH in every compartment of the reactor demonstrates the behavior of anaerobic digestion in the CABR system. Overtime, the pH profile of the baffle is becoming more stable. A decrease in pH in baffle 3 signifies the formation of acid in acidogenesis phase while an increase in baffle 4 illustrates the methanogenesis phase where methane is formed. After a period of 65 days, the growth of microorganism inside the different baffles served its different purposes. The pH of the effluent was some-what higher than that of the influent under steady state operation of an anaerobic system. Therefore, pH can indicate whether the anaerobic system is working normally because it is determined by VFA concentration and alkalinity. An increase in pH is observed in successive chambers due to the VFA concentration decreasing with increasing alkalinity. (Huajun Fenga et al., 2009) Results of pH are shown in Appendix 5.

4.4 Methane Gas

In the beginning stages of the operation, methane gas produced was very high because of the aggressive consumption of organic matter by the microorganism after being stored in the storage area for several days. By time, the methane gas production is stabilized as the microorganism adapts to the wastewater content and reactor condition. The maximum production of methane gas observed at 32 HRT is 134.05 cm^3/d with an average of 57.58 cm^3/d methane gas production. From an OLR of 1.577 $kgCOD/m^3d$ to 2.294 $kgCOD/m^3d$, methane gas production is lower due to insufficient time for microorganisms to breakdown organic matter to produce biogas although there in an increase in OLR. At the final OLR of 5.047 $kgCOD/m^3d$, methane gas production is stabilized at an average of 25.97 cm^3/d. Results of methane production are shown is appendix 6.

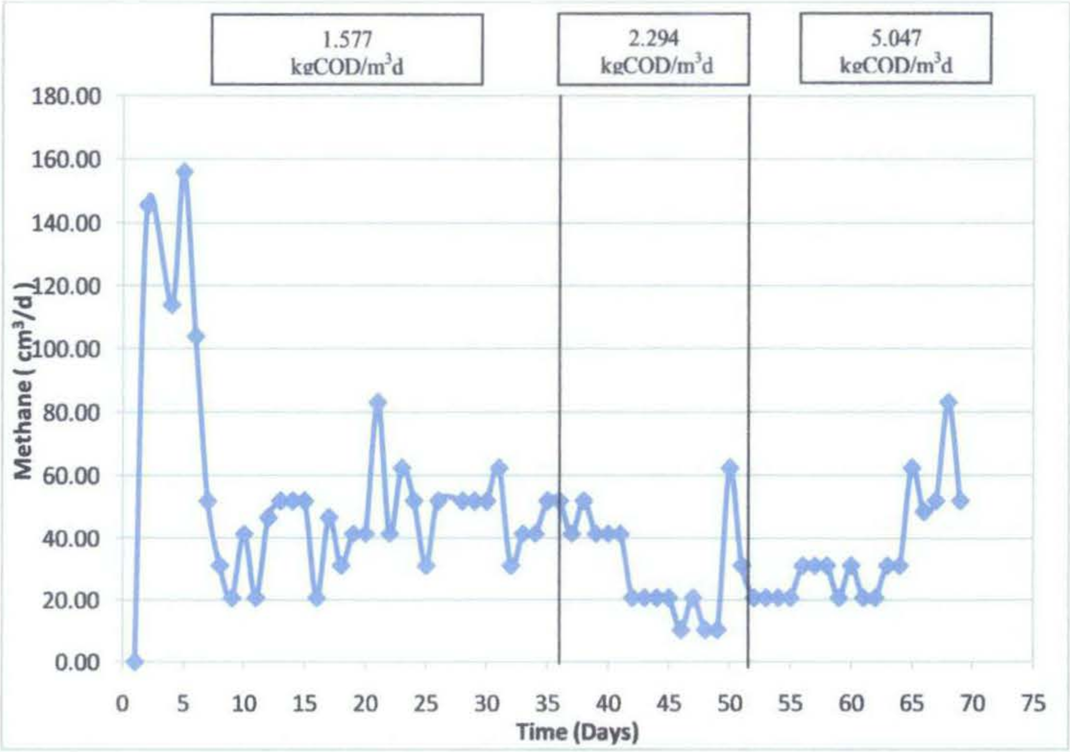

Figure 4.3: Graph of methane produced

4.5 Microscopic Observation

Figure 4.4 illustrated the microorganism identification in the CABR. The microbiological observations indicated the presence of *Arcella*-like cells in the CABR system. *Arcella* sp are found in both aerobic and anaerobic biological systems. *Arcella* is one of the most frequently encountered of the testate amoebae species, especially in highly organically polluted waters, and in the sediments on the pond's bottom, where plant materials rot under conditions of low oxygen concentration. They nourish on diatoms, unicellular green algae or animal protozoa such as flagellates and ciliates. (A. C. Tomasini Ortiz et al., 2007) This finding proves that the presence of *Arcella* sp could have contributed to pollution removal in the anaerobic system.

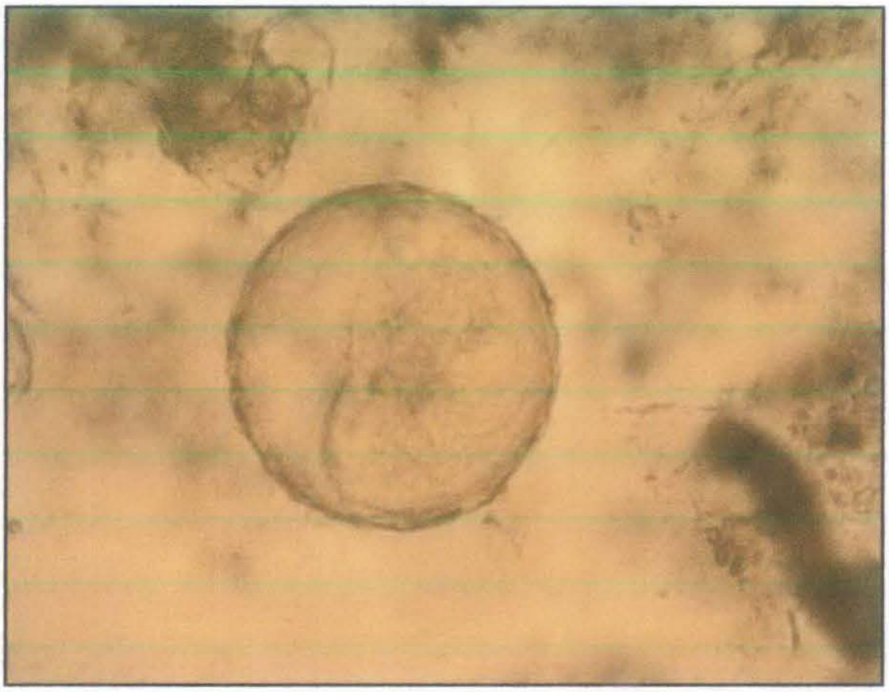

Figure 4.4: *Arcella*-like amoeba

According to (M. Priya et al., 2010), anaerobic degradation using laboratory reactors have showed direct influence of anaerobic ciliates on the higher performance of anaerobic reactors irrespective of loading rates and retention time. This includes high sludge activity, increased removal of COD (chemical oxygen demand) and MLSS (mixed liquor suspended solids) and higher biogas production with the presence of anaerobic ciliates. In the batch experiments overall biodegradation efficiency was more than 90% with anaerobic ciliates compared to 60% without ciliates. Anaerobic protozoa, especially ciliates are indicator organisms for the best performance of anaerobic degradation or treatment systems.

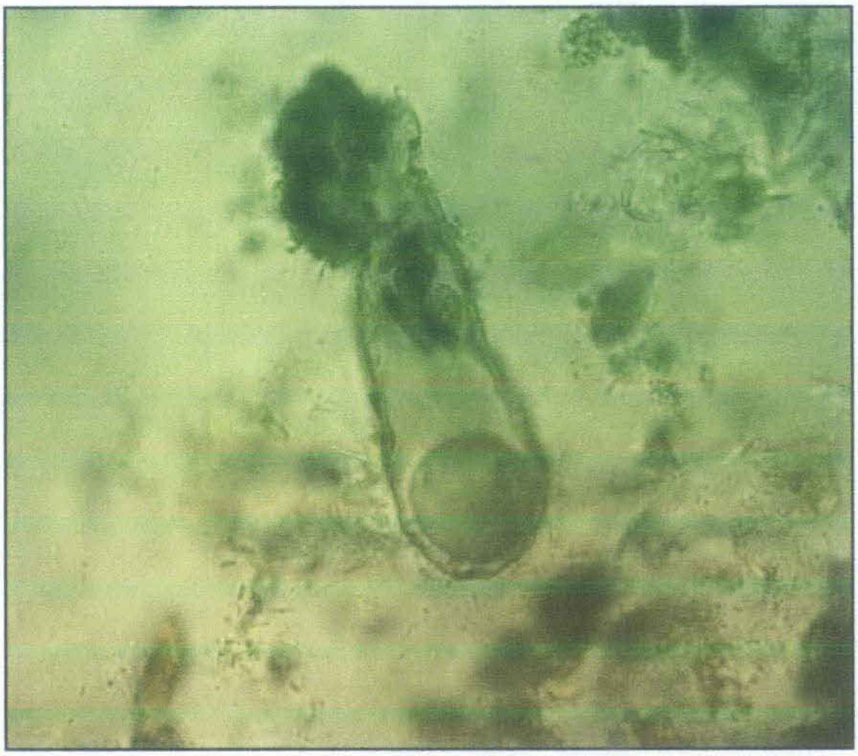

Figure 4.5: *Metopus*-like cilliate

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

From this experiment, the best condition for the Carrier Anaerobic Baffled Reactor is at 22 days HRT which resulted in COD removal efficiency of 74 % and TSS removal efficiency of 90 – 95 %. On the other hand, methane gas production averaged at 30.6 cm^3/d.

5.2 Recommendation

The following are recommended for the future works:

1) Study on the variation of number of baffles in the CABR, its configuration and the type of packing material.
2) Study on other treatment system such as aerobic or physicochemical treatments for further treatment of the treated effluent from the CABR in order to meet the Malaysian wastewater discharge standards.

CHAPTER 6

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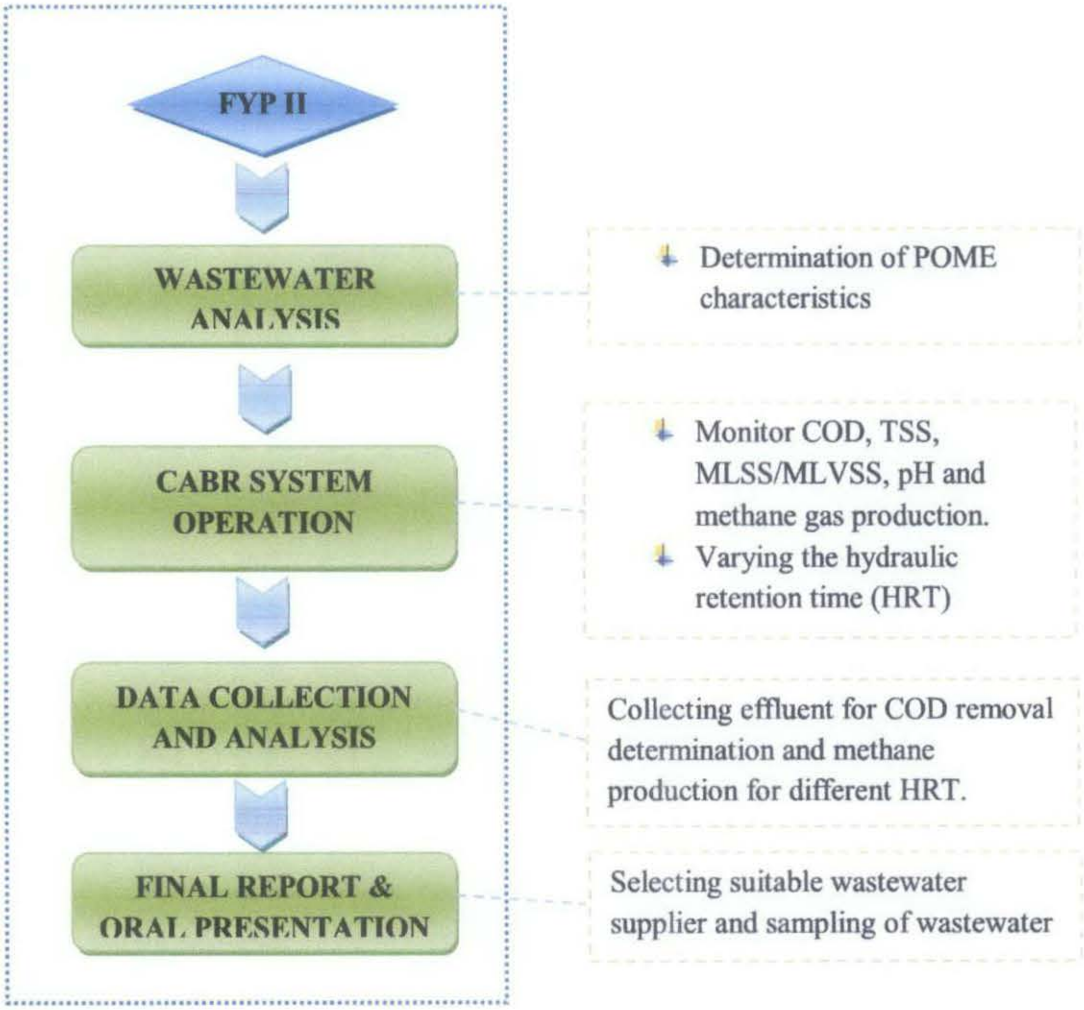
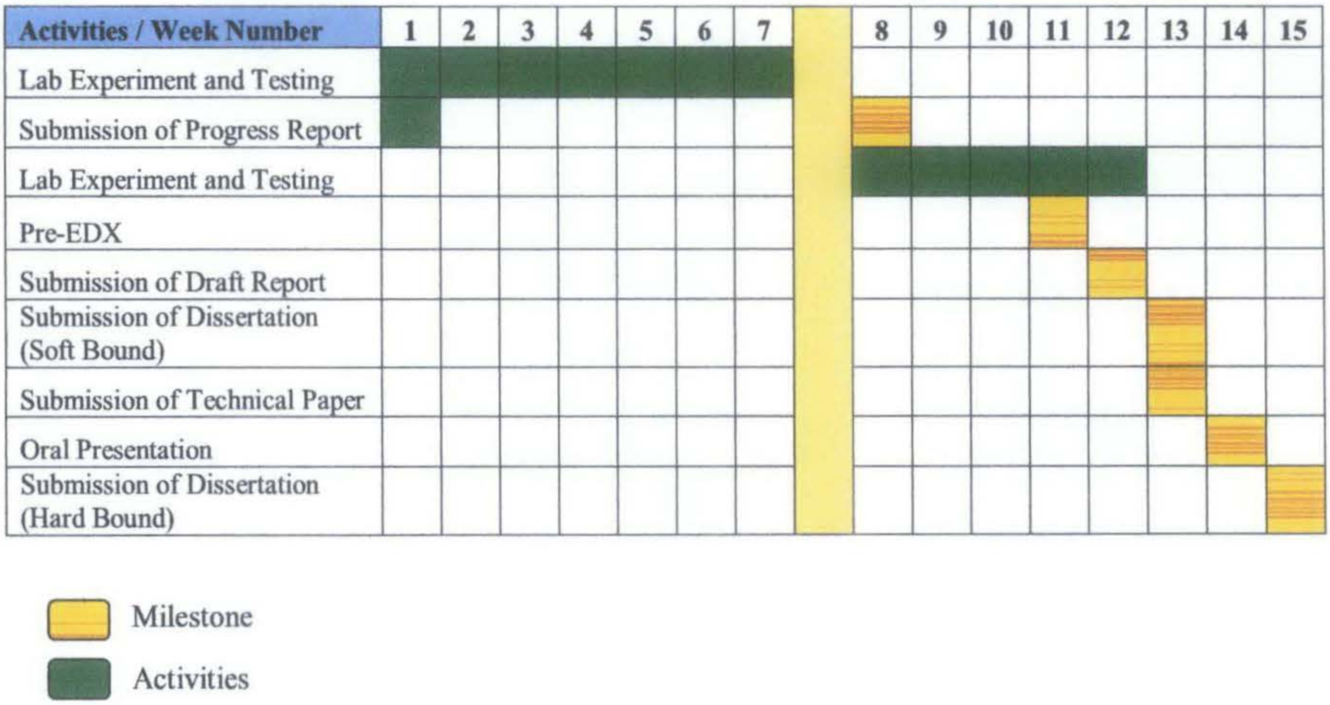
APPENDIX 1 - Project Process Flow



APPENDIX 2 - Gantt chart for Final Year Project II



APPENDIX 3 – COD CONTENT

Table A3-1: COD content

HRT	DAY	Effluent (mg/L)	COD REMOVAL (%)
32	1	17067	66.2
32	2	24850	50.8
32	3	19333	61.7
32	4	19233	61.9
32	5	18833	62.7
32	6	31567	37.5
32	7	28833	42.9
32	8	23500	53.4
32	9	17300	65.7
32	10	18533	63.3
32	11	20650	59.1
32	12	20733	58.9
32	13	20333	59.7
32	14	19933	60.5
32	15	20867	58.7
32	16	20733	58.9
32	17	18633	63.1
32	18	20350	59.7
32	19	20133	60.1
32	20	20383	59.6
32	21	19708	60.9
32	22	18817	62.7
32	23	19920	60.5
32	24	19427	61.5
32	25	19400	61.6
32	26	16693	66.9
32	27	16400	67.5
32	28	16813	66.7
32	29	15467	69.4
32	30	16427	67.5
32	31	17040	66.2
32	32	17440	65.4
32	33	16133	68.0
22	34	15787	68.7

Table A3-1(cont): COD content

HRT	DAY	Effluent (mg/L)	COD REMOVAL (%)
32	35	19187	62.0
32	36	17467	65.4
32	37	17253	65.8
22	38	19413	61.5
22	39	19320	61.7
22	40	19253	61.8
22	41	14960	70.4
22	42	20347	59.7
22	43	23427	53.6
22	44	21253	57.9
22	45	21853	56.7
22	46	18147	64.0
22	47	13760	72.7
22	48	18160	64.0
22	49	12760	74.7
22	50	22987	54.5
22	51	21907	56.6
22	52	21093	58.2
22	53	18333	63.7
22	54	17920	64.5
10	55	20373	59.6
10	56	20707	59.0
10	57	21067	58.3
10	58	18040	64.3
10	59	20867	58.7
10	60	20413	59.6
10	61	20453	59.5
10	62	16200	67.9
10	63	20360	59.7
10	64	21080	58.2
10	65	21227	57.9

APPENDIX 4 – TSS CONTENT

Table A4-1: TSS content

HRT	DAY	Effluent (mg/L)	TSS REMOVAL (%)
32	1	1200	89.94
32	2	1367	88.55
32	3	900	92.46
32	4	867	92.74
32	5	767	93.58
32	6	1633	86.31
32	7	2133	82.12
32	8	907	92.40
32	9	2190	81.65
32	10	543	95.45
32	11	307	97.43
32	12	483	95.95
32	13	413	96.54
32	14	747	93.74
32	15	50	99.58
32	16	50	99.58
32	17	340	97.15
32	18	207	98.27
32	19	160	98.66
32	20	120	98.99
32	21	200	98.32
32	22	120	98.99
32	23	733	93.85
32	24	317	97.35
32	25	750	93.71
32	26	403	96.62
32	27	310	97.40
32	28	140	98.83
32	29	87	99.27
32	30	140	98.83
32	31	90	99.25
32	32	30	99.75
32	33	93	99.22
32	34	80	99.33
32	35	126	98.94

Table A4-1(cont): TSS content

HRT	DAY	Effluent (mg/L)	TSS REMOVAL (%)
32	36	67	99.44
32	37	123	98.97
22	38	150	98.7
22	39	150	98.7
22	40	173	98.5
22	41	107	99.1
22	42	127	98.9
22	43	107	99.1
22	44	80	99.3
22	45	187	98.4
22	46	153	98.7
22	47	120	99.0
22	48	210	98.2
22	49	263	97.8
22	50	116	99.0
22	51	220	98.2
22	52	197	98.4
22	53	120	99.0
22	54	137	98.9
10	55	167	98.6
10	56	227	98.1
10	57	250	97.9
10	58	240	98.0
10	59	133	98.9
10	60	101	99.2
10	61	257	97.8
10	62	313	97.4
10	63	350	97.1
10	64	389	96.7
10	65	909	92.4

APPENDIX 5 – pH

Table A5-1: pH

HRT	DAY	Effluent	Baffle 1	Baffle 2	Baffle 3	Baffle 4	Clarifier
32	15	4.88	4.54	4.83	4.61	4.62	4.6
32	16	4.85	4.78	4.96	4.8	4.77	4.81
32	17	4.75	4.54	4.78	4.63	4.64	4.68
32	18	4.56	4.8	4.92	4.84	4.86	4.86
32	19	4.6	4.61	4.72	4.63	4.68	4.67
32	20	4.56	4.78	4.8	4.85	4.73	4.91
32	21	4.56	4.62	4.63	4.63	4.62	4.66
32	22	4.56	4.61	4.74	4.67	4.65	4.66
32	23	4.52	4.67	4.62	4.52	4.49	4.48
32	24	4.6	4.95	4.89	4.9	4.81	4.81
32	25	4.58	4.81	4.81	4.84	4.79	4.76
32	26	4.63	4.49	4.75	4.98	4.59	4.72
32	27	4.65	4.67	4.74	5.03	4.78	4.77
32	28	4.71	4.57	4.64	4.66	4.65	4.64
32	29	4.63	4.42	4.6	4.62	4.76	4.61
32	30	4.64	4.48	4.57	4.54	4.59	4.64
32	31	4.83	4.66	4.75	4.71	4.78	4.72
32	32	4.67	4.56	4.59	4.58	4.59	4.62
32	33	4.78	4.56	4.62	4.62	4.65	4.78
32	34	4.59	4.51	4.52	4.54	4.59	4.59
32	35	4.44	4.5	4.52	4.54	4.61	4.67
32	36	4.79	4.5	4.5	4.57	4.6	4.62
32	37	4.63	4.55	4.58	4.55	4.58	4.61
22	38	4.71	4.55	4.61	4.53	4.6	4.69
22	39	4.66	4.55	4.59	4.54	4.59	4.65
22	40	4.69	4.58	4.62	4.56	4.61	4.67
22	41	4.63	4.56	4.61	4.64	4.69	4.61
22	42	4.71	4.53	4.62	4.62	4.61	4.63
22	43	4.63	4.62	4.58	4.56	4.58	4.57
22	44	4.61	4.57	4.62	4.61	4.58	4.62
22	45	4.62	4.54	4.56	4.73	4.67	4.66
22	46	4.66	4.54	4.53	4.62	4.61	4.63
22	47	4.61	4.54	4.66	4.64	4.62	4.63
22	48	4.67	4.56	4.65	4.6	4.64	4.61

Table A5-1(cont): pH

HRT	DAY	Effluent	Baffle 1	Baffle 2	Baffle 3	Baffle 4	Clarifier
22	49	4.58	4.57	4.65	4.57	4.6	4.56
22	50	4.64	4.55	4.58	4.57	4.58	4.57
22	51	4.61	4.51	4.57	4.52	4.55	4.59
22	52	4.77	4.52	4.56	4.52	4.55	4.55
22	53	4.65	4.52	4.55	4.51	4.57	4.51
22	54	4.49	4.53	4.56	4.49	4.54	4.46
10	52	4.77	4.52	4.56	4.52	4.55	4.55
10	53	4.65	4.52	4.55	4.51	4.57	4.51
10	54	4.49	4.53	4.56	4.49	4.54	4.46
10	55	4.62	4.54	4.57	4.5	4.53	4.54
10	56	4.58	4.55	4.55	4.6	4.72	4.58
10	57	4.62	4.52	4.58	4.51	4.6	4.6
10	58	4.6	4.49	4.56	4.5	4.59	4.63
10	59	4.63	4.58	4.64	4.58	4.57	4.59
10	60	4.58	4.53	4.56	4.61	4.7	4.66
10	61	4.62	4.55	4.57	4.53	4.59	4.61

APPENDIX 6 – METHANE GAS PRODUCED

Table A6-1: Methane Gas Produced

HRT	DAY	VOLUME (cm^3)
32	1	0.00
32	2	145.44
32	3	0
32	4	114.27
32	5	155.82
32	6	103.88
32	7	51.94
32	8	31.16
32	9	20.78
32	10	41.55
32	11	20.78
32	12	46.75
32	13	51.94
32	14	51.94
32	15	51.94
32	16	20.78
32	17	46.75
32	18	31.16
32	19	41.55
32	20	41.55
32	21	83.11
32	22	103.88
32	23	103.88
32	24	51.94
32	25	31.16
32	26	51.94
32	27	135.05
32	28	51.94
32	29	51.94
32	30	51.94
32	31	62.33
32	32	31.16
32	33	41.55
32	34	41.55
32	35	51.94
32	36	51.94
32	37	41.55

Table A6-1 (cont): Methane Gas Produced

HRT	DAY	VOLUME (cm^3)
22	38	51.94
22	39	41.55
22	40	41.55
22	41	41.55
22	42	20.78
22	43	20.78
22	44	20.78
22	45	20.78
22	46	10.39
22	47	20.78
22	48	10.39
22	49	10.39
22	50	62.33
22	51	31.16
22	52	20.78
22	53	20.78
22	54	20.78
10	55	20.78
10	56	31.16
10	57	31.16
10	58	31.16
10	59	20.78
10	60	31.16
10	61	20.78
10	62	20.78
10	63	31.16
10	64	31.16