Application of Anaerobic Baffled Reactor (ABR) for treatment of Raw Palm Oil Mill Effluent (POME)

by

Arizwan B. Abd Aziz

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(CIVIL ENGINEERING)

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CERTIFICATION OF APPROVAL

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Approved by,

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Universiti Teknologi PETRONAS
Tronoh, Perak
JUNE 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 expect as specified in the references and acknowledgements, and that original work contained herein have not been undertaken or done by unspecified sources or persons. I am also already doing the cleaning process in the laboratory and submit all the apparatus that I use for my final year project.

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ABSTRACT

Palm Oil Mill Effluent (POME) is considered to be one of the most polluting wastewater in Malaysia due to its high concentration in chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Discharge of this wastewater will increase the oxygen demand in water bodies and endanger the aquatic life and therefore interrupting the ecosystem in the river. The biogas produced during treatment using conventional stabilization anaerobic pond is released to the atmosphere and not utilized. This project is to study the application of anaerobic baffled reactor (ABR) for treatment of raw POME. Samples were taken from Nasaruddin Palm Oil Mill, located at Bota District in Perak. An ABR was constructed using a flexi glass sheets with the dimension of (0.48m x 0.2m x 0.29) and divided into 6 compartments. The ABR system was equipped with influent, effluent tank, stirrer, water pump and methane gas collection chamber. Collected sludge from the same treatment facility was used in the ABR system as seeding material. The ABR system was initially operated with diluted factor of 1:25 of the samples in order to decrease the high value of COD with 4 days HRT and the dilution factor was continuous decreasing by factor of 19, 15, 8, 5, 2 and lastly without any dilution. The effluent of the system was monitored daily for pH, COD, temperature, TSS, MLSS and biogas production. From the results, the highest percentage of COD removal was found to be at dilution factor of 8 where 34,000 mg/L of COD influent with 98% of COD removal and methane gas production of 941 L/day. The result shows that the ABR system has a high potential of treating POME in short HRT because presence of baffles in the system.

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ABBREVIATIONS & NOMENCLATURES

ABR	Anaerobic Baffled Reactor
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
HRT	Hydraulic Retention Time
OLR	Organic Loading Rate
POME	Palm Oil Mill effluent
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solids

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Anaerobic treatment of wastewater is receiving more attention in recent year throughout the world because the biomethanogenesis process decomposes organic matter to produce methane gas. There are three clear advantages of anaerobic treatment over aerobic degradation, the high product and low biomass yield resulting in a limited generation of waste sludge as an unwanted side product, the in-situ separation of the product as biogas and limiting costs for product separation [1]. Anaerobic processes have wide application in the treatment of sewage sludge and high-strength industrial wastewater treatment.

The Anaerobic Baffled Reactor (ABR) includes a series of vertical baffles to forces the wastewater to flow under and over them as it passes from inlet to outlet, the wastewater comes into contact with a large active biological mass [2]. This type of reactor system has been reported to have many advantages over other well established reactor system. It is simple design and requires no gas separation system. Moreover, the over and underflow of liquid reduces bacterial washout and enables it to retain active biological solids without the use of any fixed media [3]. An anaerobic baffled reactor operates with a combination of several anaerobic process principles, the three basic steps involved are hydrolysis, fermentation and methanogenesis [2].

In Malaysia, palm oil is very productive industry where palm oil mills are operated at least 300 days per year. An estimated 30 million tons of palm oil mill effluent (POME) are produced annually from more than 300 palm oil mills in Malaysia. Based on the process of oil extraction and the properties of Fresh Fruit Bunch (FFB), POME is made up by 95%-96% of water, 0.6%-0.7% oil, and 4%-5% of total solid including 2%-4% suspended solids, which are mainly debris from palm mesocarp [4]. Malaysia is the largest producer and exporter of crude palm oil (CPO). Although the palm oil industry is the major revenue earner for our country but it has also been identified as the single largest sources of water pollution sources due to palm oil mill effluent (POME) characteristic with high organic content and acidic nature [5].

1.2 Problem Statement

In palm oil mills, liquid effluent is mainly generated from sterilization and clarification processes in which large amounts of steam and hot water are used. For every ton of palm oil fresh fruit bunch, it was estimated that 0.5-0.75 tones of POME will be discharged. In general appearance, palm oil effluent (POME) is a yellowish acidic wastewater with fairly high polluting properties, with average of 25,000 mg/l biochemical oxygen demand (BOD), 55,250 mg/l chemical oxygen demand (COD) and 19,610 mg/l suspended solids (SS). This highly polluting wastewater can cause several pollution problems and also create other problems to the neighborhoods of the mills such as a nuisance to the passers-by or local residents and river pollution [5].

A study of high rate anaerobic treatment of palm oil mill effluent (POME) was achieved in a two-stage up-flow anaerobic sludge blanket (UASB) reactor, achieving COD removal efficiency up to 98.4% with the highest operating OLR of 10.63 kg COD/m^3 day (Borja and Banks, 1994c). However, the reactor operated under overload condition with high volatile fatty acid content became unstable after 15 days. This is due to granulation inhibition in the reactor at high volatile fatty acid concentration. The others disadvantages are the reactor performance is depending on the sludge settleability and this reactor might face long start-up period if seeded sludge is not granulated [6].

A study of high rate anaerobic digestion of palm oil mill effluent (POME) was also achieved in an up-flow anaerobic sludge-fixed film bioreactor (Najafpour, 2006). In this study, a UASFF bioreactor with tubular flow behavior was developed in order to shorten the start-up period at low hydraulic retention time (HRT). The reactor was operated at 38℃ and HRT of 1.5 and 3 days achieving COD removals of 89% and 97% respectively. The problem with this reactor is the stability of the reactor is very depending on the internal packing, high ratio of effluent recycling, feed flow rate and the up-flow velocity [13].

1.3 Objectives

This project is to study the application of ABR in different COD influent concentration for raw Palm Oil Mill Effluent (POME) taken from the factory and to investigate the best percentage of COD reduction and biogas production.

1.4 Scope of study

In this study, the application of ABR is to reduce the amount of pollutant content in a POME. A sample of untreated POME and sludge from anaerobic ponds was collected from Nasaruddin Palm Oil Mill located at Bota District in Perak. Laboratory scale of ABR was run with the real sample and sludge as seeding materials. POME samples were collects for a few times and store in a cold room at 4℃ before use. A dilution of POME was prepared using tap water. A sample was analysis for the pH, COD, Total solids and MLSS. A methane gas was collected by gas collection chamber and the volume of gas is measured using water displacement method.

CHAPTER 2

LITERATURE REVIEW

2.1 Anaerobic Treatment

Anaerobic digestion is the degradation of complex organic matters under the absence of oxygen. This process is time consuming as bacterial consortia responsible for the degradation process requires time to adapt to the new environment before they start to consume on organic matters to grow [6]. 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 product as methane (CH_4) and carbon dioxide (CO_2) [5]. Hydrolysis is where complex molecules (i.e. lipids, protein, and carbohydrates) are converted into sugar and amino acid. In the step acidogenesis, acidogenic bacteria will break down these sugars, fatty acid and amino acids into organic acids which mainly consist of acetic acids (from acetogenesis) together with hydrogen and carbon dioxide. Hydrogen and carbon dioxide will be utilized by hydrogenotropic methanogens while acetic acid and carbon dioxide will be utilized by acetoclastic methanogens to give methane as a final product [6].

Probably the most significant advantage of anaerobic treatment is good removal efficiency can be achieved in the system, even at high loading rates and low temperatures. The construction and operation of these reactors is relatively simple. Anaerobic treatment can easily be applied on either a very large or very small scale. Also, when high loading rates are accommodated, the area needed for the reactor is small. In anaerobic treatment, the sludge production is low due to the slow growth rates of anaerobic bacteria [7].

2.2 Application of Anaerobic Treatment on POME

Due to highly polluting properties of POME, with average values of 25 000 mg/L biochemical oxygen demand (BOD) and 50 000 mg/L chemical oxygen demand (COD), the most cost effective technology to treat it is anaerobic treatment [8].

POME can be easily treated using a biological treatment because of its high organic and mineral content which is suitable for microorganism to thrive. The microorganism will consume and break down the pollutant, turning it into harmless byproduct. In some cases, this byproduct can potentially be use as a renewable source of energy and have a high economic value. In order to achieve such goal, a suitable mixed population of microorganism must be introduced and the process should be optimized. The major reduction of POME polluting strength occurs during anaerobic treatment [4]. There are a few type of anaerobic treatment including Anaerobic Stabilization Pond, Anaerobic digestion and ABR. POME is currently using stabilization pond and anaerobic digestion method.

2.2.1 Stabilization Ponds

Ponding system is the most current treatment system that is employed in palm oil mills to treat POME with more than 85% of the mills having adopted this method. Ponding system comprises of de-oiling tank, acidification ponds, anaerobic ponds and facultative. Stabilization pond system has high efficiency on removing COD content from POME, because the long retention time [6].

However, the stabilization pond system didn't have facilities to capture the methane gas and the open surface of the pond also contributes to the foul smell that could disturb the surrounding community [6]. One of the palm oil factories that are using this type of wastewater treatment is Nasaruddin Palm Oil Mill. The application of anaerobic stabilization ponds is preferred because of its low capital cost, operating and maintenance cost [6]. However, it consumes a large area to operate and the foul smell generated from the system will disturb the surrounding community.

The ponding system is a series of 12 ponds which consisted of 2 cooling pond, a mixing pond, 4 anaerobic ponds, 2 facultative anaerobic ponds and 4 algae ponds. The influent POME is discharged through the cooling ponds for a 3 days and then kept in the anaerobic ponds for 40 days of retention time. The wastewater will then be oxidized in the oxidation ponds for 8 days retention time. The oxidized wastewater will be settled in the settling ponds for a day and finally discharged into the stream. The sludge from anaerobic pond will be sent into a dislodging pond.

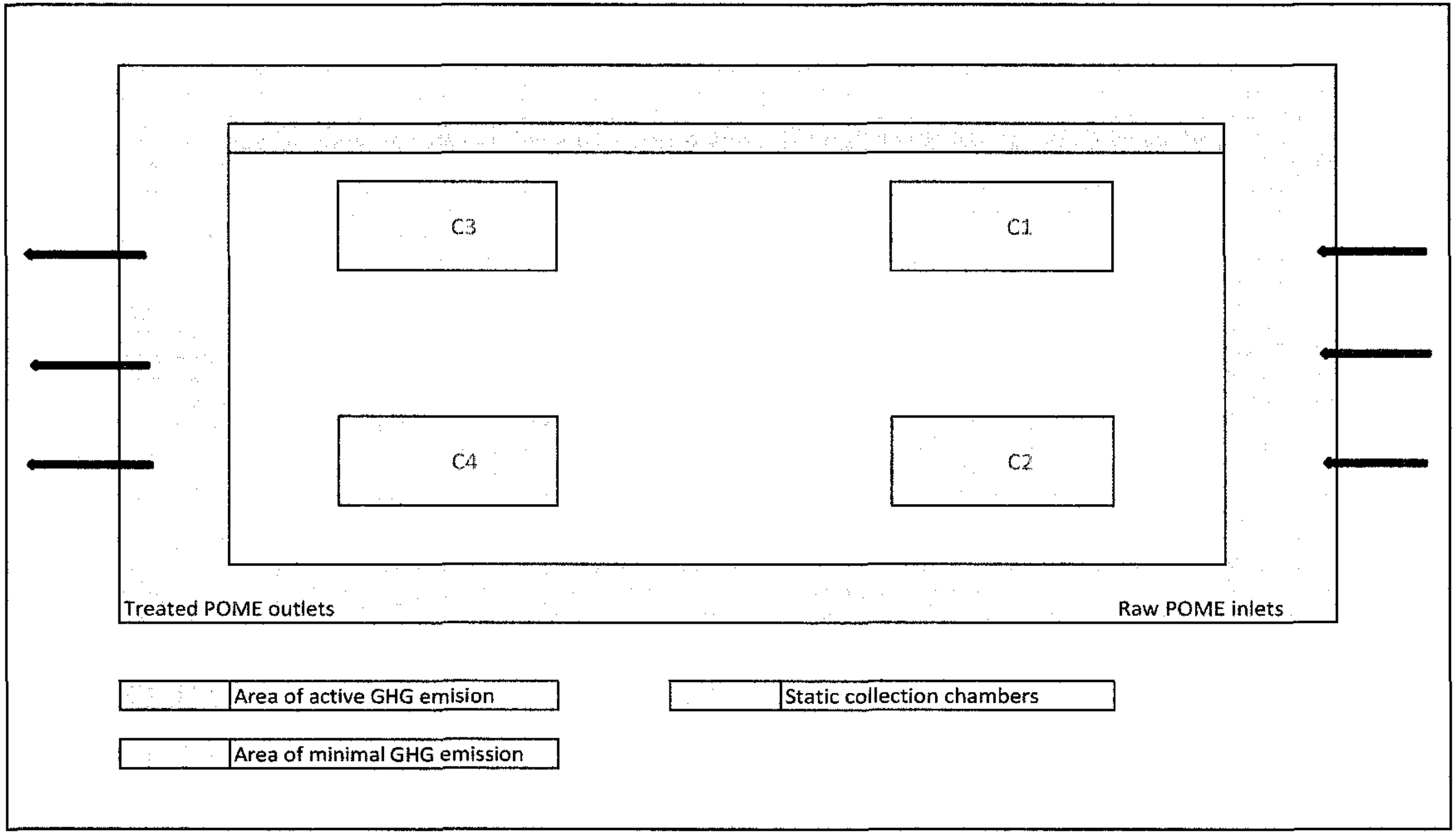
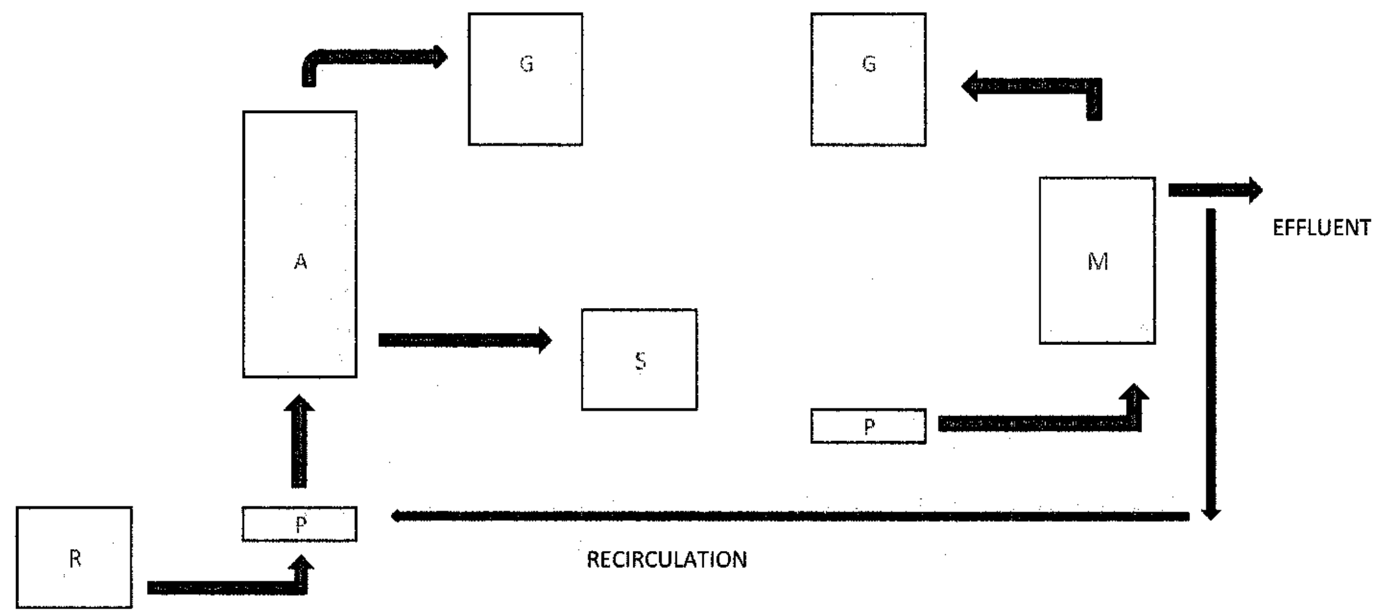


Figure 2.1: Anaerobic Stabilization Ponds System

2.2.2 Application of Two-Stage Up-flow anaerobic Sludge Blanket (UASB) reactor.

The diagram two-stage UASB shown in Figure 2.2. A 12-1 UASB reactor (A) with 13 cm dia. and a 5-1 UASB reactor (M) with 9 cm dia. were used for the acidogenic and methanogenic reaction of a two-stage process. The reactors were separated by a 2.5-1 balancing tank receiving the effluent from reactor (A) and providing the feed reservoir for reactor (M). The reactor and balancing tank were maintained at a constant temperature of 35°C in an insulated cabinet. Each reactor was of a typical UASB design having a gas-biomass-liquid separator at the head of the column and an influent liquid distributor at the base. Each column was connected to a water displacement type gasometer filled with an acidified brine solution to prevent CO_2 dissolution. The reactor content could be sampled at various heights along the column by means of a series of six sampling ports along its length [9].

The acidogenic reactor acclimated rapidly to the wastewater and was tolerant to the suspended solids (SS) concentration of 5.4 g/l in the effluent wastewater. Loading was gradually increased over a period of 100 days resulting in a satisfactory hydrolysis and acidification giving a maximum rate of acid production of 4.1 g/ld acetic acid at a loading rate of 16.6 g/ld COD at a hydraulic retention time of 0.9 days. An increase in alkalinity throughout the acclimatization maintained the effluent from the reactor at around pH 5.8. The methanogenic reactor was initially fed on dilution of the effluent from the first stage reactor after pH adjustment. The loading was gradually increased, and then stepwise, to 60g/ld at which point COD removal efficiency had declined significantly and an accumulation of long-chain volatile fatty acids was observed. It was concluded that the reactor could work efficiently up to loading of 30 g/ld COD, which producing a good methane yield and a COD reduction of greater than 90%. Effluent recirculation alleviated the need for alkali additions to the feed of the methanogenic reactor and a direct coupling of the two reactors was achieved towards the end of the experimental run of 175 days.



A	Acidogenic UASB reator		S	Separation tank
M	Methanogenic UASB reactor		P	Peristaltic pump
R	Refrigerated feed tank		G	Gas collector

Figure 2.2: Two-stage UASB system

2.2.3 Anaerobic Baffled Reactor (ABR)

The ABR is a reactor design which uses a series of vertical baffles to force a wastewater containing organic pollutants to flow under and over (or through) the baffles as it passes from the inlet to outlet. Bacteria within the reactor gently rise and settle due to flow characteristics and gas production, but move down the reactor at a slow rate [10].

Probably the most significant advantages of the ABR is its ability to separate acidogenesis and methanogenesis longitudinally down the reactor, allowing the reactor to behave as a two-phase system without the associated controls problems and high costs. Two-phase operation can increase acidogenic and methanogenic activity by a factor of up to four as acidogenic bacteria accumulate within the first stage and different group can develop under more favorable condition [10].

The main problems associated with the treatment of high strength material in a baffled reactor is the inability to produce a floating sludge layer which would enhance solids retention and the high velocities associated with the baffles causes a significant washout of solid material [2].

A study on performance of a modified anaerobic baffled reactor to treat high strength wastewater was conducted by Malakahmad, [2009]. A modified ABR with a working volume 50 liter was designed to determine the treatment efficiency and methane production rate of high strength wastewater at different hydraulic retention time and organic loading rate (OLR). A mixture of 62% kitchen waste and 38% sewage sludge was used as substrate. A rectangular reactor of 75 cm in length, 27 cm width and 25 cm height was used. The baffled reactor was modified to reduce up-flow liquid velocities and to accept the whole substrate [2].

Initially the characteristics of kitchen waste were measured. Next the effect of different HRT and OLR were evaluated in the reactor. The continuous operation of ABR was started using an initial COD concentration of 25g/L at HRT 5 days. The ABR was run continuously and observations were made for 20 days at a particular HRT. Result show that the highest COD removals (74.5% and 75.4%) were observed at 3 days HRT and

OLR of 2 kg/m^{3}d, respectively. While the best production of biogas (7.4 and 9.10 L/d) was observed at 5 days HRT and OLR of 6 kg/m^{3}d respectively [2].

The comparison of advantages and disadvantages between these three types of treatment are summarized in the Table 2.1 and the performance of an anaerobic treatment to treat raw POME which done in previous works are summarized in the Table 2.2.

Table 2.1: Adantages and disadvanteges of the Stabilization ponds, UASB and ABR [11].

Treatment processes	Advantages	Disadvantages	References
Stabilization Ponds	Reliable and stable. Anerobically digested POME from the ponds could be used to culture algae. Cheap, simple to construct and has low maintenance costs. The energy needed to operate a ponding system is minimal. Recovered sludge cake from pond can be sold as fertilizer.	Large areas of land required,making it unsuitable for factories located in the near urban and other developed areas. The removal of nitrogen and solids are usually unsatisfactory. Dead spots or short circulation with island of floating solids can be found in anaerobic ponds due to an inadequate mixing by the envolved biogas. Difficult to control and monitor in view of sizes and configuration. Sludge accumulation is usually high.	Ta Yeong Wu(2010) Abdul Wahab Mohammad(2010) Jamaliah Md. jahim (2010); Nurina Anuar
UASB	High organic loading, short HRT and has a low energy demand. High removal of COD for POME treatment. High concentration of boimass as granular sludge retained in the	Perfomance depending on the sludge settleability. Longer development times for anaerobic sludge granular. Foaming and flotation of granular sludge at high organic loading rate.	Ta Yeong Wu(2010) Abdul Wahab Mohammad (2010) Jamaliah Md. Jahim (2010); Nurina Anuar
ABR	Simple and inexpensive to construct. Stability to shock loading and a capability of achieving high volumetric rate. With proper modification of ABR, high retentation times of the cells and efficient treatment of POME could be maintened.	Sufficient recycling needed to maintain the reactor stability when treating POME. Occurrence of fouling due to the long solid retention time of the system, which allow the decomposition of the suspended solids on the membrane.	Ta Yeong Wu(2010) Abdul Wahab Mohammad(2010) Jamaliah Md. Jahim (2010); Nurina Anuar

Table 2.2: The perfomance of an anaerobic treatment of raw POME [11].

Treatment processes	Operational condition			Parameters						Reference
	Retention time (day)	Temperature (°C)	Organic loading rate (g COD/l day)	COD Influent (mg/l)	COD Overall reduction (%)	TSS Influent (mg/l)	TSS Overall reduction (%)	Oil and grease Influent (mg/l)	Oil and grease Overall reduction (%)	
Upflow anaerobic filter	6	35	11.4	69000	91	-	-	-	-	Borja and Banks (1994c)
Complex mixed reactors	35	55	-	67000	95.6	31800	81.8	-	-	Chin and Wong (1983)
Membrane anaerobic system	3.15	35	21.7	68310	92.1	-	-	-	-	Fakhru'l Razi and Noor (1999)
Anaerobic hybrid digester	3.5	-	16.2	56700	92.3	-	-	-	-	Borja et al. (1996a)
Modified anaerobic baffled reactor	10	-	1.6	16000	95.3	-	-	410	91.3	Faisal and Unno (2001)

CHAPTER 3

METHODOLOGY

3.1 Project Activities

The project is dividing into two phases, which are FYP I that was conducted in the first semester and FYP II that was carried out in the second semester. In FYP I, activities done basically are research and information collection on the anaerobic treatment system and its application in POME, especially the performance of ABR to treat high strength wastewater. The sample of POME was being taken from Nasaruddin Palm Oil Mill and the sample was analyzed to identify the characteristic of the POME before it can be used in the second phase of the project. Design and fabrication of the ABR was done based on the literature and the installment and troubleshooting was done to ensure the system is operating without any defect that will lead to further complication.

The operation of the anaerobic baffled reactor system was conducted in FYP II. The efficiency of the anaerobic treatment was measured based on the COD removal efficiency and biogas production by taking the best HRT of 4 days or 6.74 L/d that gives the maximum COD content reduction and methane gas production based on the previous work that was done by UTP student on the application of ABR for polishing of treated POME [12]. The project process flow is shown in Figure 3.1.

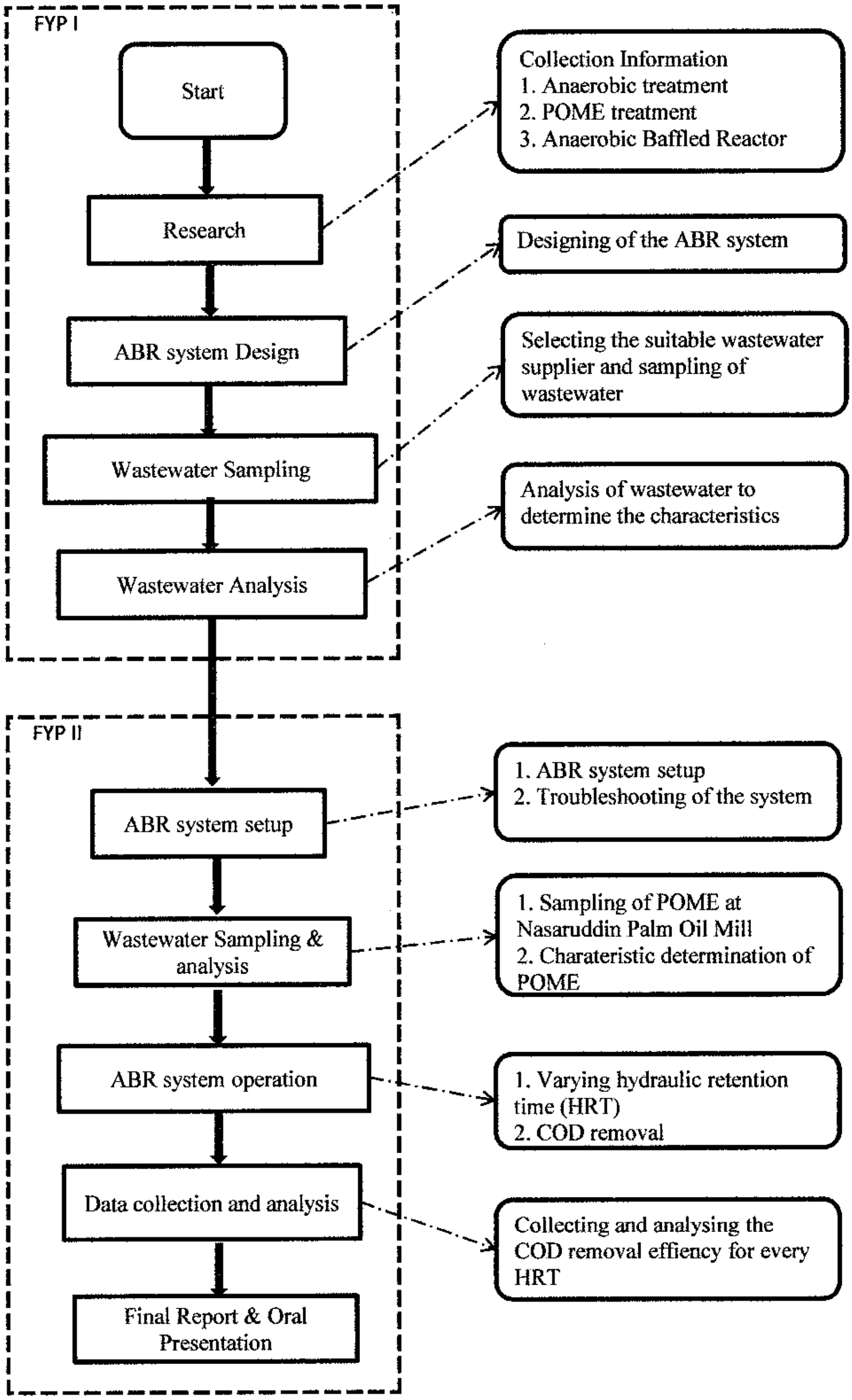


Figure 3.1: Project Process Flow

3.2 Wastewater samples

The wastewater samples used in the project was the raw Palm Oil Mill Effluent (POME) taken from one of the palm oil mill that practices anaerobic pond system to treat its wastewater, which is Nasaruddin Palm Oil Mill located in Bota District, in Perak.

After sampling, the wastewater sample were directly placed in the cool storage at temperature of 4 ℃ to stop any microorganism reaction therefore no composition changes will happen in the samples. The pH was never adjusted and no chemicals were added to the wastewater.

The characteristics of the wastewater were determined before it was used in the ABR system. The wastewater was analyzed for the parameters of pH, BOD, COD, TSS and TKN.

3.2.1 pH determination

For the reactor, the pH measurement was done for each compartment, influent sample that coming from 1st compartment and finally samples from the effluent tank. pH of the wastewater sample was determined using a digital pH meter based on the HACH method. In order to getting the more accurate results, a digital pH meter was calibrated and washes by distilled water before using it.

3.2.2 COD determination

The palm oil mill effluent (POME) sample was being diluted before proceeding with the COD test to make sure it's not will given a negative or over range result for the COD. The high range of the vial COD was used for this test and the COD was measured using the spectrophotometer based on the APHA method.

3.2.3 TKN determination

The TKN value is measure based on the formula;

TKN

$$= \frac{V1 - V2}{Vo} \; x \; C \; x \; F \; x \; 1000 \qquad (Eq. 1)$$

Where:

V_1 = mL of standard 0.2N H_2SO_4 solution used in titrating sample.

V_2 = mL of standard 0.2N H_2SO_4 solution used in titrating blank.

N = normality of sulfuric acid solution.

F = milliequivalent weight to nitrogen (14mg)

V_o = mL of sample digested.

3.2.4 Total Suspended Solid determination

Total suspended solid (TSS) is measure by filtering the 40 ml of wastewater samples using a 47 mm filter disc. The filter paper then dries in a drying oven 105 °C for 1 hour. After the filter paper is cool off in desiccators, the filter paper is weighed to determine the suspended solids of the wastewater. The TSS is measure by the following formula:

Total suspended solid (TSS)

$$= \frac{(Weight\ of\ pan + filter\ paper\ after\ drying) - (Weight\ of\ pan + filter\ paper\ before\ drying)}{(Sample\ size\ (L))} \qquad (Eq. 2)$$

3.2.5 BOD determination

The value of BOD is measure using the equation of;

To determine the BOD value without seed correction:

$$= \frac{(\textit{Initial dissolved oxygen}) - (\textit{Final dissolved oxygen}) - (\textit{Blank correction})}{\textit{Sample size / 300}} \qquad (Eq.\ 3)$$

To determine the BOD value with seed correction and blank correction:

$$= \frac{(\textit{Initial dissolved oxygen}) - (\textit{Final dissolved oxygen}) - (\text{Seed } \& \textit{ blank correction})}{\textit{Sample size / 300}} \qquad (Eq.\ 4)$$

To determine the BOD value with seed correction and blank correction

as well as dilution:

$$= \frac{(\textit{Initial dissolved oxygen}) - (\textit{Final dissolved oxygen}) - (\text{Seed } \& \textit{ blank correction})}{\textit{Sample size / 300}} \qquad (Eq.\ 5)$$

3.3 Seeding

Sludge was taken from the Anaerobic Pond No.3 from Nasaruddin Palm Oil Mill. The sludge is taken from the same source of treatment facility to ensure that the microorganisms are familiar with the environment and characteristic of wastewater that it will encounter to shorten the duration for acclimatization of the system. The large particles and debris from the sludge were removed by passing it through American Society of Testing Materials (ASTM) sieve. The sludge then introduce equally to all 6 compartments of the ABR. Amount of sludge needed in the system is calculate using Eq. 6. The calculations of amount of sludge are shown in the Appendix 1.

$$\frac{F}{M} = \frac{So}{\emptyset x} \qquad (Eq. 6)$$

Where:

F = Food

M = Microorganism

S_o = Influent BOD and COD concentration, mg/L (g/m^3)

Θ = hydraulic detention time (day)

$$\Theta = \frac{\text{Volume}}{\text{Flow rate}}$$

X = concentration of volatile suspended solids in tank, mg/L (g/m^3)

3.4 Reactor Characteristic and Operation

The reactor use in the experiment is a flexi glass cubic tank with 0.48 m in length, 0.2 m in depth and 0.29 m in height and divided into 6 compartments. The volume of the first compartment is 0.0048 m^3, the next 4 compartments each having 0.0044 m^3 of volume and the last compartment with volume 0.0054 m^3. The last compartment is designed with bigger volume compared to other 5 compartments to provide longer solid retention time and superior performance as 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 6 equally divided compartments [1].

Two tanks both with the volume of 0.027 m^3 were designed for the system, which is the influent tank has the function of feeding wastewater to the reactor and effluent tank for the purpose of retaining the wastewater from the reactor. Stirrer is adding in the effluent tank to stir the wastewater in order to prevent sedimentation of particulate. Pump is use to keep a constant flow rate of feeding to the system. The design of the laboratory scale reactor is depicted in Figure 3.2.

A tube is installing at the middle elevation of the reactor in each compartment. The installation of the tube is for the purpose of taking the samples in every compartment. The ABR system that used in the laboratory is shown in Appendix 7.

A cylinder shaped gas collection camber was design to collect and measure the volume of methane gas produce from the system. Water displacement method is use to collect and determine the volume of methane gas produce by the system. The collection chamber will be filling with solution of Sodium Hydroxide (NaOH) in order to dissolve and separate the CO_2 in the biogas produce, leaving only the methane gas. The design of the gas collection chamber is depicted in Appendix 8.

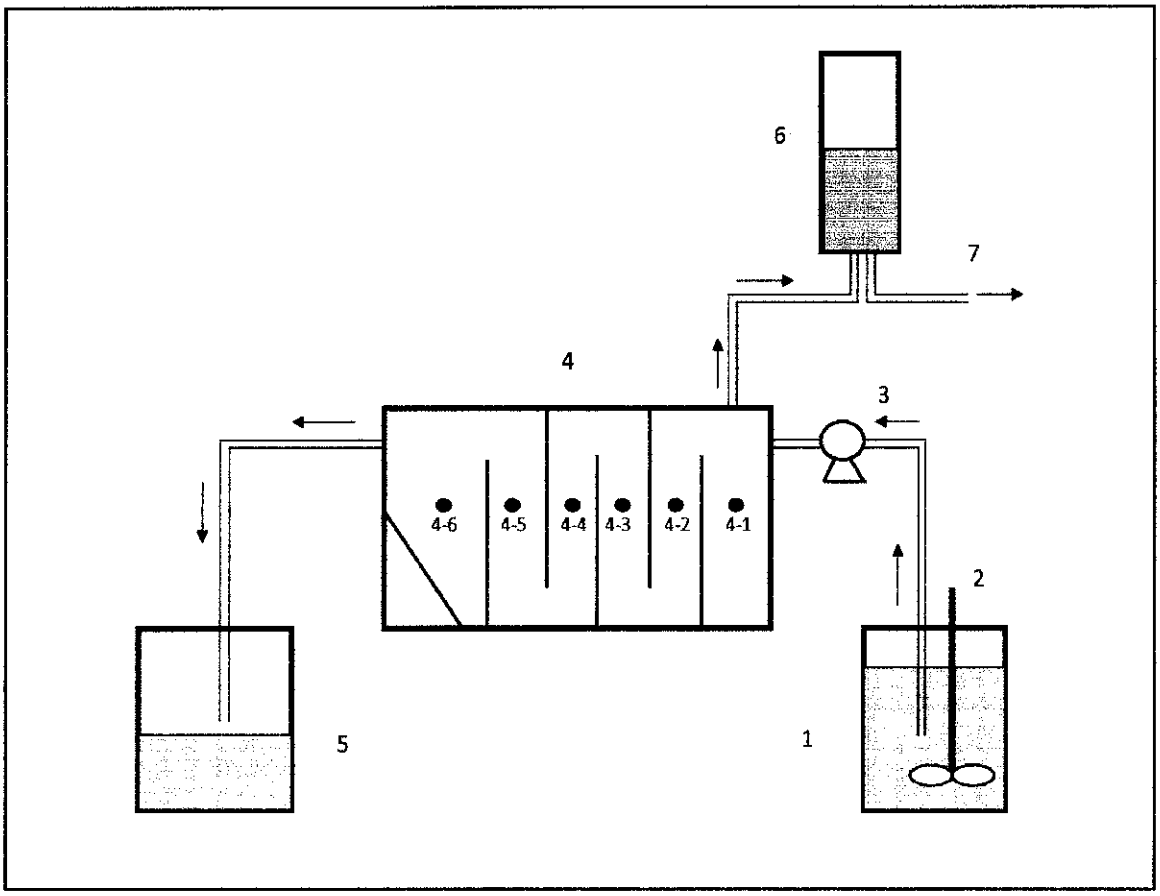


Figure 3.2: Laboratory Scale Anaerobic Baffled Reactor (I: Influent Tank, 2: Stirrer, 3: Water Pump, 4: ABR System, 4-1 to 4-6: Sampling points, 5: Effluent Tank, 6: Collection Chamber, 7: NaOH discharge)

3.5 Sampling and analysis

The effluent of the system was monitored daily for pH, COD, TSS and biogas production. Samples were taken from the effluent tank and from each compartment of the reactor to monitor behavior of the treatment system. The sampling is starting from the last compartment toward the first to prevent air intrusion and to maintain the anaerobic condition in the reactor.

CHAPTER 4

RESULTS AND DISCUSSION

Before the POME samples were used in the ABR system, it was analyzed to identify its characteristic by conducting experiments. Table 4.1 shows the identified characteristic of the POME sample. The COD and BOD content of the POME sample are 45,450 mg/l and 27,200 mg/l which are highly polluted to be discharged into the water. The discharge of this type of wastewater will affect the ecosystem of the water bodies as it will reduce the dissolved oxygen content in the water, leaving not enough oxygen for the aquatic life to live.

Table 4.1: Characteristic of POME

Parameters	Concentration
pH	4.65
BOD (mg/L)	27,200
COD (mg/L)	45,450
TKN (mg/L)	757
TSS (mg/L)	24,400

The ABR system was monitored daily by taking samples of the POME from each compartment and also the influent and effluent of the system. Figure 4.1 shows the percentage of COD removal. The TSS results of the effluent samples are depicted in Figure 4.2. Figure 4.3 shows the pH profile of the reactor. The methane gas produced by the ABR system is illustrated in Figure 4.4 and Table 4.2 show the comparative analysis of performance of anaerobic baffles reactor.

COD removal

Figure 4.1 shows the COD content in reduction of the effluent POME from the ABR system. From the graph it is shown that in the early operation of the ABR system, fluctuation of COD content in effluent sample happened. This is due to the adaption of the microorganism with the new environment of the ABR system especially the cooler temperature in the laboratory which is around 24-25 °C compared to its original treatment facility which has higher temperature. In the early phase, the percentage of COD reduction was in the range of 40-70%, but at the day of 15, the percentage was increase until reach 95% of reduction. This is because of the microorganism in the reactor become stronger as the increases of the concentration of the sample.

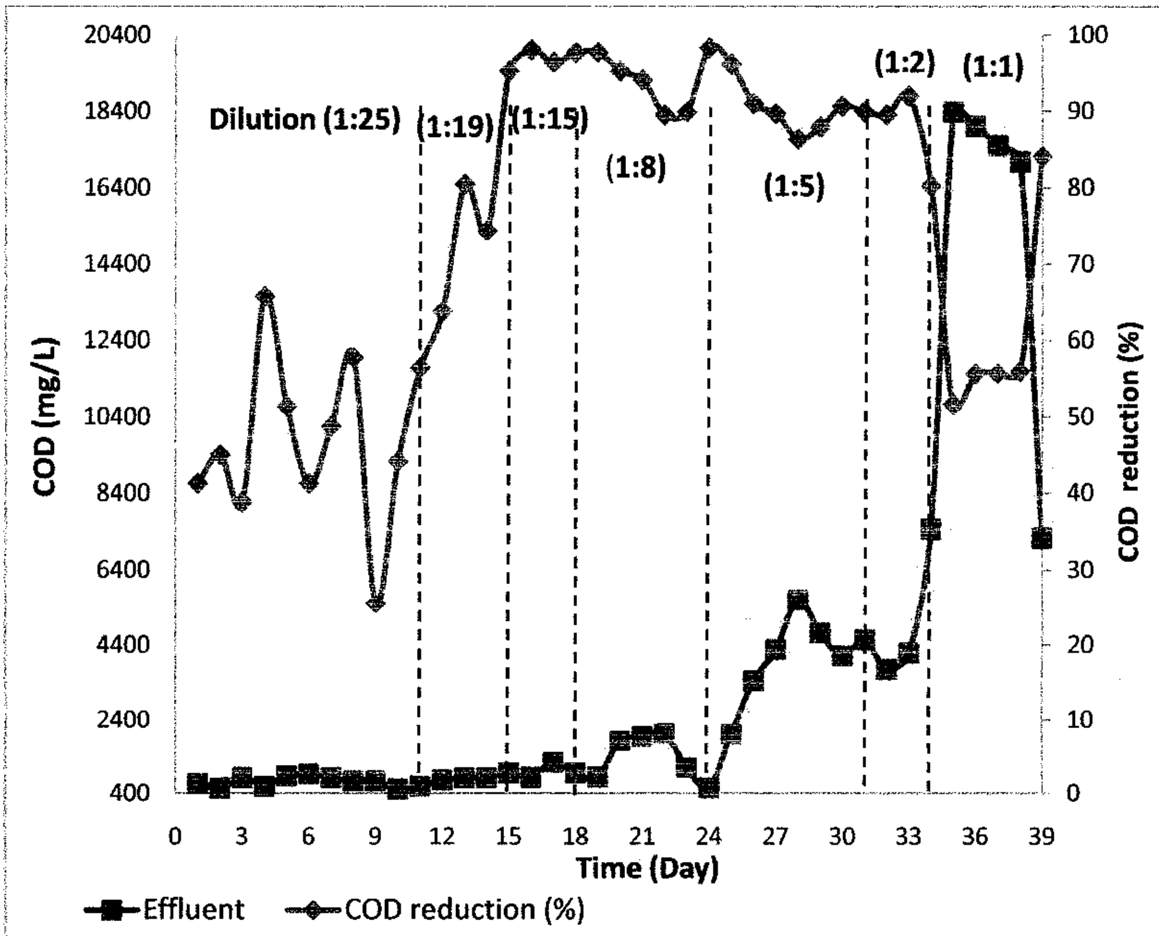


Figure 4.1: Graph of COD

TSS effluent reduction

The TSS of effluent sample was observed to be fluctuating in the beginning of the ABR system operation. This is due to the adaption period of the system to the new nature of environment. By passing the time, the TSS concentration in the wastewater was found to be decreasing and the fluctuation of TSS is slowly lessened.

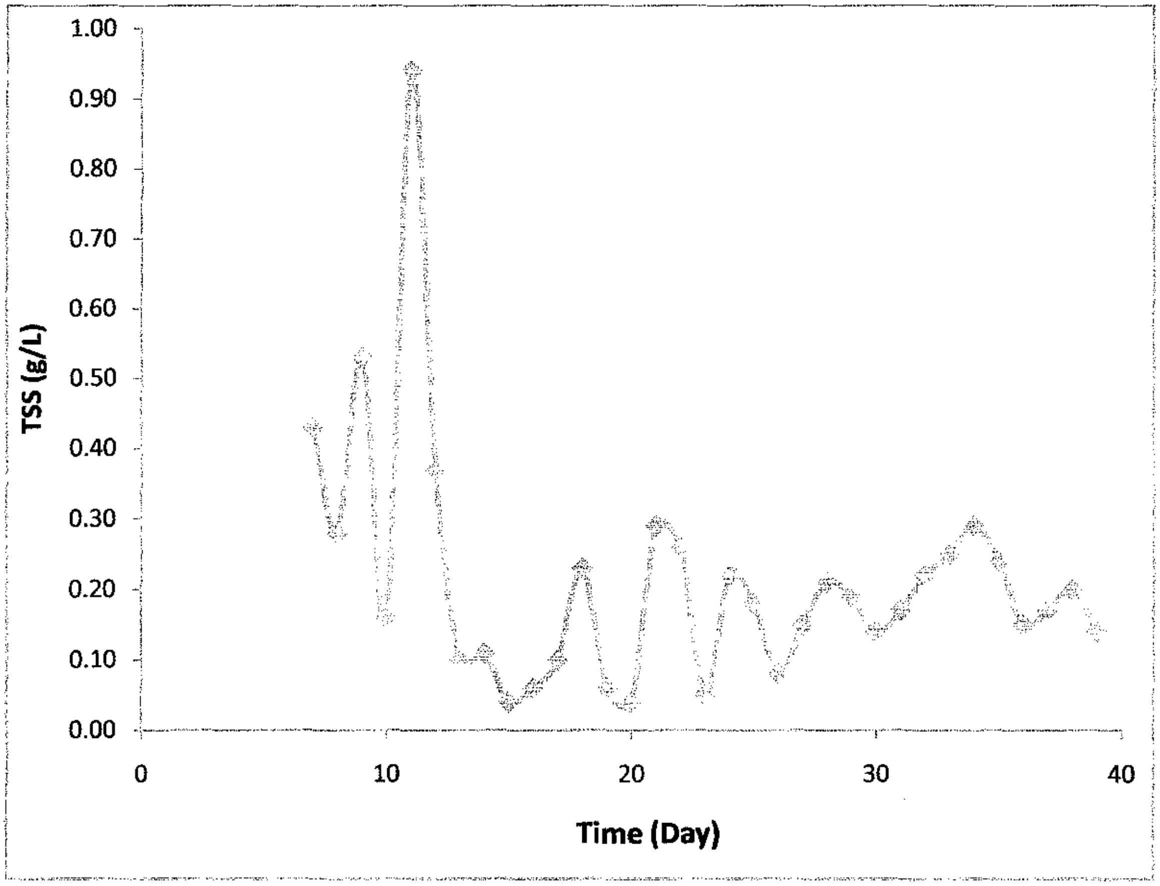


Figure 4.2: Graph of TSS

Volatile fatty acid profile and pH

Figure 4.3 show the pH profile of the 4 day of HRT used in the project. The graph shows the difference of pH in every compartment of the reactor which can demonstrate the behavior of anaerobic digestion in the ABR system. pH is decreasing as the POME flows from compartment 1to compartment 2 which is illustrate the high development rate of volatile fatty acid by the microorganism. As the POME flows from compartment 3 to compartment 5, the pH rises as methanogenesis phase is taken place in the system. In this phase, the development of CO_3HNH_4 from CO_2 and NH_3, which produce during the anaerobic process, had caused the increase alkalinity of the system. All this result indicates growth of microorganism happened inside the reactor according to its function in each compartment.

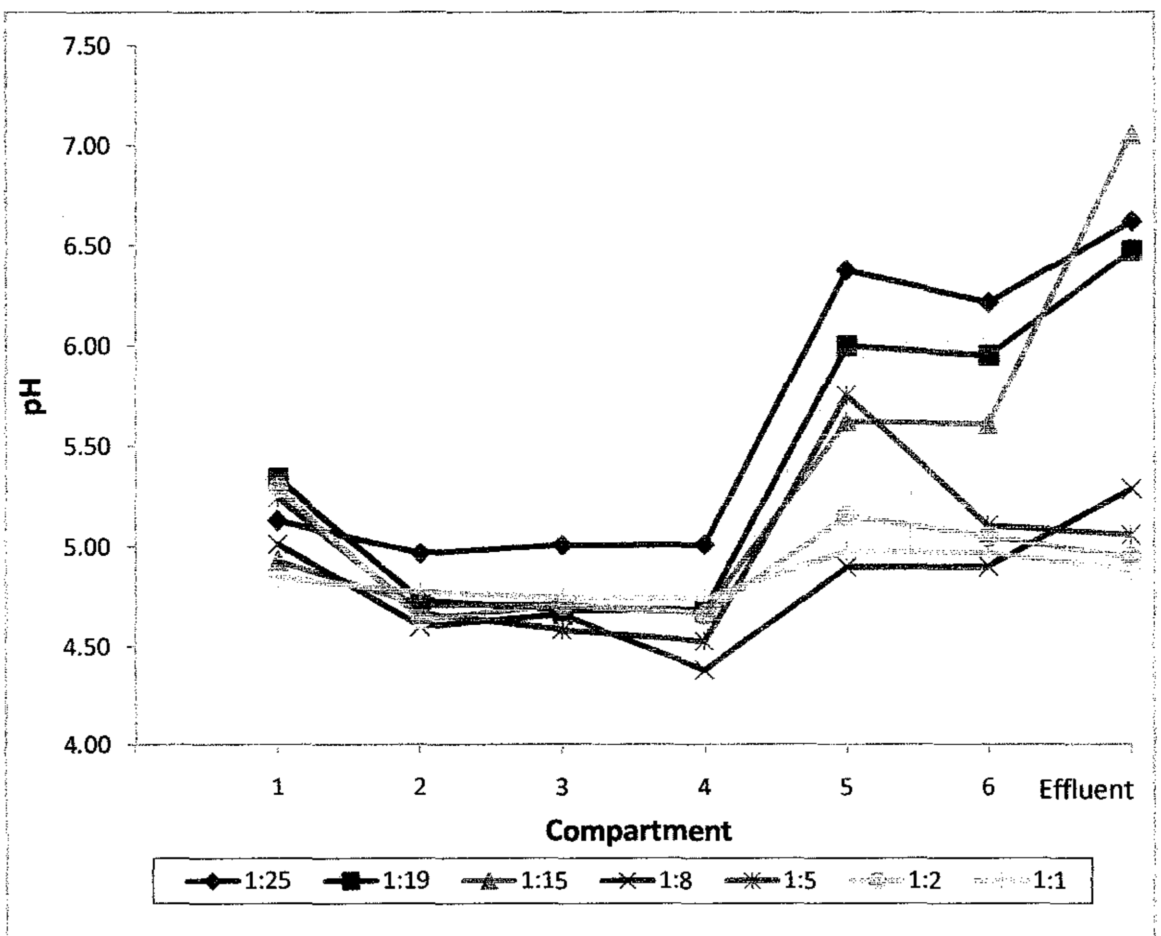


Figure 4.3: Graph of pH

Gas methane production

In the initial stage of operation, the methane gas produce was very high. This is due to the aggressive consumption on organic matter by the microorganism after being put into storage area for several days. The rapidly decrease and increase pattern of methane production is due to changes of the dilution factor of the samples. The methane gas production then become more stabilized and it slowly decreased by time. This behavior is caused by the fact that the microorganism in the ABR system has became more familiar with the wastewater.

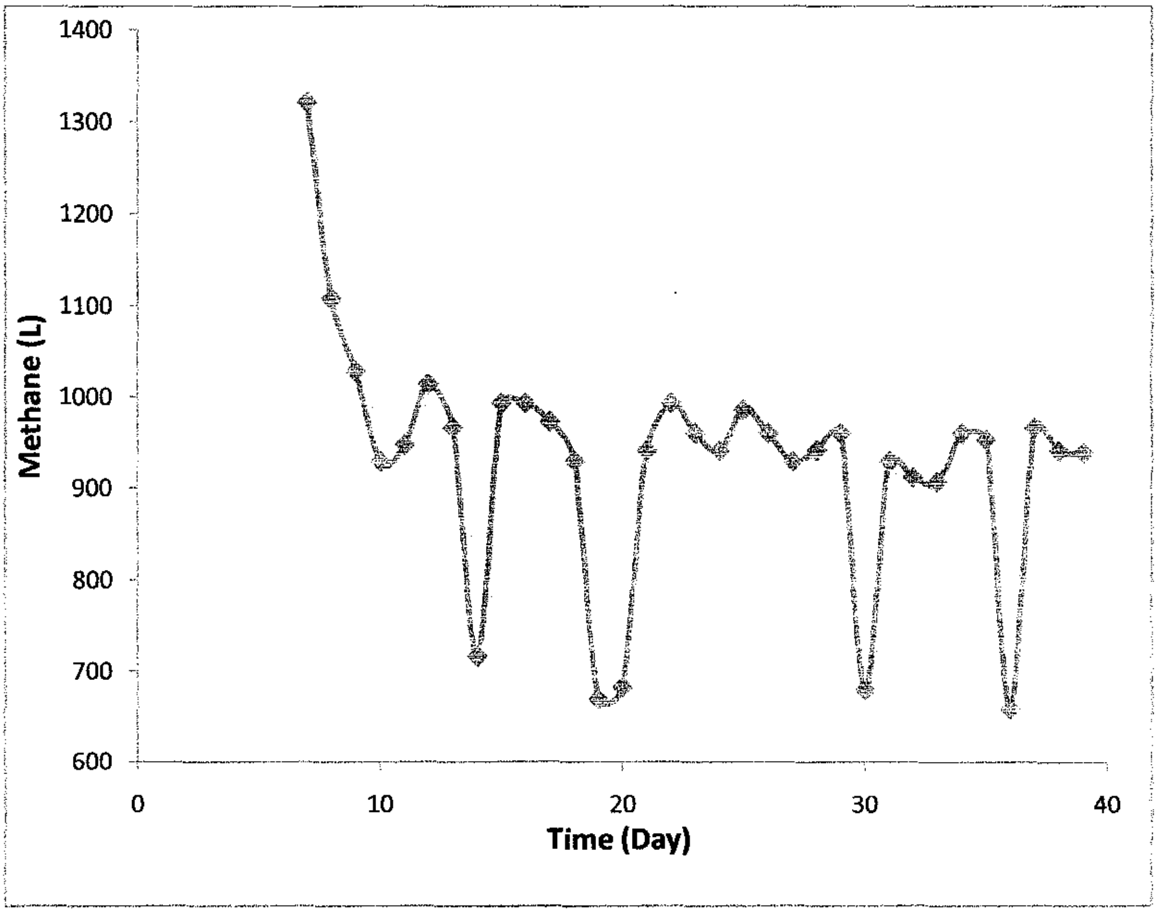


Figure 4.4: Graph of methane produce

The Comparative analysis of performance of anaerobic baffled reactors

Table 4.2: Comparative analysis of performance of anaerobic baffled reactors.

	Malakahmad et al.,2011 [2]	Faisal and Hajime Unno, 2001 [14]	Bodkhe, 2009 [15]	This study
Type of wastewater	Kitchen waste	POME[a]	Municipal waste	POME
Influent COD (mg/L)	25100	16000	400	45450
COD removal (%)	74.5	77.31	84	**84.06**
HRT (d)	3	3	6	4
Reactor volume (L)	85	20	32	28

a: Palm Oil Mill Effluent

Table 4.2 show the comparative analysis of performance of anaerobic baffled reactors. From that, it show that the ABR system for this study is achieve the higher percentage of COD removal even the influent of COD is higher compare to others study. Also the ABR system for this study can achieve a better performance in the short of hydraulic retention time which is 4 days.

CHAPTER 5

ECONOMIC BENEFITS

In this project, the cost spent in constructing the anaerobic baffled reactor system is involving construction of the laboratory scaled reactor, methane gas collection chamber, the influent and effluent tank. The total cost was undetectable as most of the other's material and equipment was already available in the laboratory.

In general, construction of a full scale anaerobic baffled reactor system include the construction of the reactor, biogas collection chamber, influent and effluent tank. The additional mechanical equipment such as the pump can be eliminated by applies the concept of gravity force to flow the POME through the system thus eliminating the cost for energy consumption.

In comparison with the current treatment application, anaerobic pond treatment will need a large area of land to operate. Acquisition of land area is very costly especially with the current rapidly growing development industry in Malaysia. The methane gas capture from ABR system is an excellent energy source as fuel in combined heat and power unit. The calculation of the construction cost and energy recovers for ABR and AP's has been determined. Tables 5.1 show the design criteria for the ABR system. Table 5.2 show comparison cost of the construction between ABR and AP's system which show the construction cost of the treatment and Table 5.3 show comparison of energy recovery between ABR and AP's system.

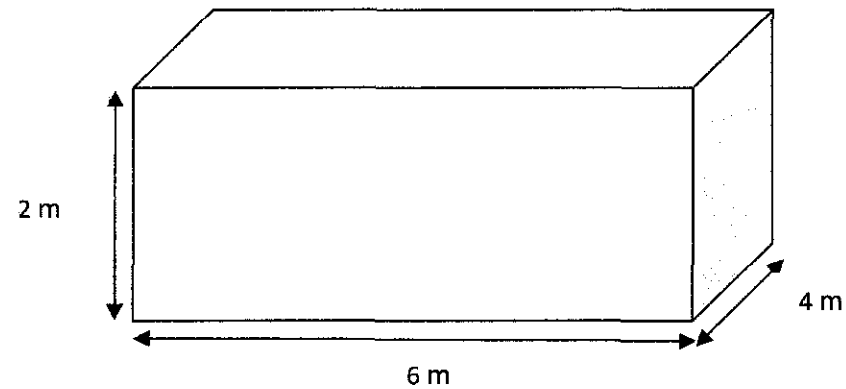


Figure 5.1: ABR reactor

Table 5.1: Design criteria for ABR reactor

Parameter	
Flowrate, Q (m^3/day)	10
Velocity in, V (m/h)	2
Number of up-flow chamber (No.)	6
HRT (day)	5
Volume of ABR reactor (m^3)	48
Material	Concrete

Table 5.2: Comparison cost of the construction between ABR and AP's system.

			Anaerobic baffles reactor			Anaerobic pond		
Item	Descriptions	Unit	Quantity	Unit rate (RM)	Total (RM)	Quantity	Unit rate (RM)	Total (RM)
1	Concrete brick wall	No.	1500	9.00/ unit [a]	13 500.00	500	9.00/ unit	4500.00
2	Land area	m^2	50	15.00/m^2 [b]	750.00	600	15.00/m^2	9000.00
Total cost					14 250.00			13 500.00

a: http://www.demxx.com/index.php/product-catalogue/commercialindustrial

b: http://www.iproperty.com.my/propertylisting/101137/Pusing_Agricultural_Land_ForSale

Table 5.3: Comparison of the energy recovers between ABR and AP's system.

			Anaerobic baffles reactor			Anaerobic pond		
Item	Descriptions	Unit	Quantity	Unit rate (RM)	Total (RM)	Quantity	Unit rate (RM)	Total (RM)
1	Biogas	L	80 L/day	20.00/ 25 L	64.00/day	–	–	–
Total cost					64.00			

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The results obtained in this project indicate that the ABR system has the high potential in treating palm oil wastewater. The characteristics of ABR reactor that has baffles to direct the wastewater flow up and down maximize the contact time of wastewater and microorganism thus increase the rate of biological digestion in the system. The baffles also act as divider of the microorganism in the anaerobic process, allocating them according to its characteristics. This can prevent the wastewater to have a contact with different types of microorganism and reduce the efficiency of the treatment system. From the data analysis, the highest percentage of COD removal was found to be at dilution factor of 8 where 34,000 mg/L of COD influent with 98% of COD removal and methane gas production of 941 L/day. This shows that the ABR treatment system has a high potential in the Palm Oil industry as it can treat POME in short HRT compared to the stabilization pond that requires long periods of time to operate.

6.2 RECOMMENDATION

Based on the achieve result, the recommendation are:

i. Study on the effect shock loads on the performance of an anaerobic baffles reactor.
ii. Study on performance of anaerobic baffles reactor treating wastewater influenced by decreasing COD/SO_4 ratios.

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APPENDIX 1: CALCULATION OF FOOD-TO-MICROORGANISM RATIO

The determination of the food-to-microorganism is done by the following equation:

$$\frac{F}{M} = \frac{So}{\emptyset x} \qquad (Eq. 6)$$

Where:

F = Food

M = Microorganism

S_o = Influent BOD and COD concentration, mg/L (g/m^3)

Θ = hydraulic detention time (day)

$$\Theta = \frac{\text{Volume}}{\text{Flow rate}}$$

X = concentration of volatile suspended solids in tank, mg/L (g/m^3)

Data obtained from experiments;

MLVSS = 32560 mg/L

COD = 3143.3 mg/L

$$\frac{\boldsymbol{F}}{M} = \frac{3143.3}{(4x32560)} = 0.024/day$$

APPENDIX 2: PREPARATION OF NaOH SOLUTION

Preparation of the NaOH solution used in the methane gas collection chamber was done diluting NaOH of 47% concentration to 2.5%. The volume of NaOH with concentration of 47% needed for the dilution was calculated using the following equation:

$$m_1v_1 = m_2v_2$$

$$47(v_1) = 2.5(1)$$

$$v_1=2.5(1)/47$$

$$v_1 = 0.053L$$

From the calculation it is determined that, in preparing 1L of NaOH with the concentration of 2.5%, 0.053 L of NaOH with the concentration of 47% is needed. Bromothymol Blue was added into the solution of NaOH to determine the pH of the solution. Blue colour in the solution indicates that the solution has the pH of 7.6 and above, change in colour of the solution indicate that solution do not have the ability to dissolve CO_2 anymore and need to be changed.

APPENDIX 3: DESIGN CALCULATION OF ABR SYSTEM

Calculation for HRT:

Flowrate, Q = 10 m^3/day

Volume of ABR reactor = 48 m^3

HRT = 48 / 10

= 4.8 days ~ 5 days

APPENDIX 4: COD CONTENT

Table A4-1: COD content

HRT	DAY	INFLUENT (mg/L)	EFFLUENT (mg/L)	COD REMOVAL (%)
4	1	1150	675	41.30
4	2	1000	550	45.00
4	3	1350	825	38.89
4	4	1750	600	65.71
4	5	1800	875	51.39
4	6	1575	925	41.27
4	7	1620	830	48.77
4	8	1730	730	57.80
4	9	980	730	25.51
4	10	940	525	44.15
4	11	1400	610	56.43
4	12	2100	760	63.81
4	13	4200	820	80.48
4	14	3200	820	74.38
4	15	20200	945	95.32
4	16	43400	832.5	98.08
4	17	34600	1237	96.42
4	18	40875	945	97.69
4	19	37400	840	97.75
4	20	38850	1830	95.29
4	21	33150	1950	94.12
4	22	19250	2025	89.48
4	23	11000	1110	89.91
4	24	34000	555	98.37
4	25	52350	2010	96.16
4	26	38350	3450	91.00
4	27	41450	4275	89.69
4	28	41050	5610	86.33
4	29	38950	4725	87.87
4	30	44000	4110	90.66
4	31	44950	4530	89.92
4	32	35800	3750	89.53
4	33	52150	4185	91.98
4	34	37800	7470	80.24
4	35	38000	18375	51.64

HRT	DAY	INFLUENT (mg/L)	EFFLUENT (mg/L)	COD REMOVAL (%)
4	36	40600	18000	55.67
4	37	39500	17500	55.70
4	38	38750	17070	55.95
4	39	45450	7245	84.06

APPENDIX 5: TSS CONTENT

Table A5-1: TSS

HRT	DAY	EFFLUENT (g/L)
4	7	0.43
4	8	0.28
4	9	0.53
4	10	0.16
4	11	0.94
4	12	0.37
4	13	0.10
4	14	0.11
4	15	0.04
4	16	0.06
4	17	0.10
4	18	0.23
4	19	0.06
4	20	0.04
4	21	0.29
4	22	0.26
4	23	0.05
4	24	0.22
4	25	0.18
4	26	0.08
4	27	0.15
4	28	0.21
4	29	0.19
4	30	0.14
4	31	0.17
4	32	0.22
4	33	0.25
4	34	0.29
4	35	0.24
4	36	0.15
4	37	0.17
4	38	0.20
4	39	0.14

APPENDIX 6: pH

Table A6-1: pH

HRT	DAY	1	2	3	4	5	6	7
4	1	6.53	5.23	5.51	5.45	5.72	5.24	5.83
4	2	4.99	4.74	4.95	4.95	6.68	6.35	6.87
4	3	4.82	4.73	4.77	4.84	6.62	6.41	6.55
4	4	4.97	4.86	4.93	5.03	6.44	6.27	6.44
4	5	5.41	5.28	5.27	5.20	6.52	6.39	7.02
4	6	4.81	4.84	4.85	4.88	6.20	6.00	6.55
4	7	5.81	5.78	5.81	5.73	6.56	6.37	6.58
4	8	4.94	4.87	4.85	4.87	6.56	6.48	6.88
4	9	4.74	4.89	4.78	4.83	6.42	6.42	6.73
4	10	4.76	4.71	4.68	4.68	6.21	6.21	6.79
4	11	4.68	4.72	4.71	4.69	6.25	6.26	6.60
4	12	5.24	4.82	4.83	4.80	6.21	6.25	6.79
4	13	4.91	4.71	4.48	4.57	6.07	5.87	6.77
4	14	5.98	4.79	4.82	4.77	5.95	5.96	6.18
4	15	5.23	4.62	4.61	4.61	5.77	5.73	6.17
4	16	5.01	4.63	4.62	4.64	5.28	5.28	5.98
4	17	4.72	4.7	4.71	4.65	5.67	5.66	7.5
4	18	5.07	4.80	4.80	4.73	5.92	5.89	7.69
4	19	5.01	4.67	4.66	4.65	5.32	5.31	6.50
4	20	4.77	4.62	4.79	4.63	4.63	4.84	5.31
4	21	5.01	4.66	4.70	4.58	4.98	4.97	5.10
4	22	5.19	4.57	4.69	3.40	4.78	4.77	5.15
4	23	5.12	4.57	4.62	4.55	4.80	4.77	4.76
4	24	5.02	4.52	4.51	4.50	4.89	4.76	4.91
4	25	5.10	4.44	4.42	4.33	5.77	4.95	4.72
4	26	5.52	4.88	4.74	4.64	5.63	5.32	5.70
4	27	5.28	4.67	4.59	4.47	5.69	4.96	5.30
4	28	5.46	4.72	4.46	4.52	5.47	5.02	5.50
4	29	4.98	4.66	4.68	4.57	5.80	5.02	4.65
4	30	5.13	4.61	4.63	4.57	6.03	5.25	4.69
4	31	5.26	4.70	4.58	4.60	5.89	5.23	4.87
4	32	5.33	4.75	4.78	4.72	5.37	5.27	5.14
4	33	5.30	4.60	4.69	4.72	4.58	5.11	5.16
4	34	5.26	4.57	4.66	4.55	5.51	4.78	4.55
4	35	4.55	4.53	4.56	4.51	5.23	4.82	4.60
4	36	4.65	4.43	4.45	4.52	4.81	4.87	4.73

HRT	DAY	1	2	3	4	5	6	7
4	37	4.91	4.90	4.88	4.87	4.94	5.03	4.98
4	38	5.01	4.98	4.86	4.89	4.95	5.05	5.06
4	39	5.12	5.03	4.98	4.92	4.97	5.09	5.05

APPENDIX 7: METHANE GAS PRODUCED

Table A7-1: Methane gas produced

HRT	DAY	METHANE (L/day)
4	7	1321
4	8	1108
4	9	1029
4	10	929
4	11	947
4	12	1014
4	13	966
4	14	716
4	15	993
4	16	993
4	17	973
4	18	929
4	19	670
4	20	682
4	21	941
4	22	993
4	23	960
4	24	941
4	25	986
4	26	960
4	27	929
4	28	941
4	29	960
4	30	679
4	31	929
4	32	911
4	33	906
4	34	960
4	35	953
4	36	659
4	37	966
4	38	941
4	39	939

APPENDIX 8: LABORATORY SCALE OF REACTOR

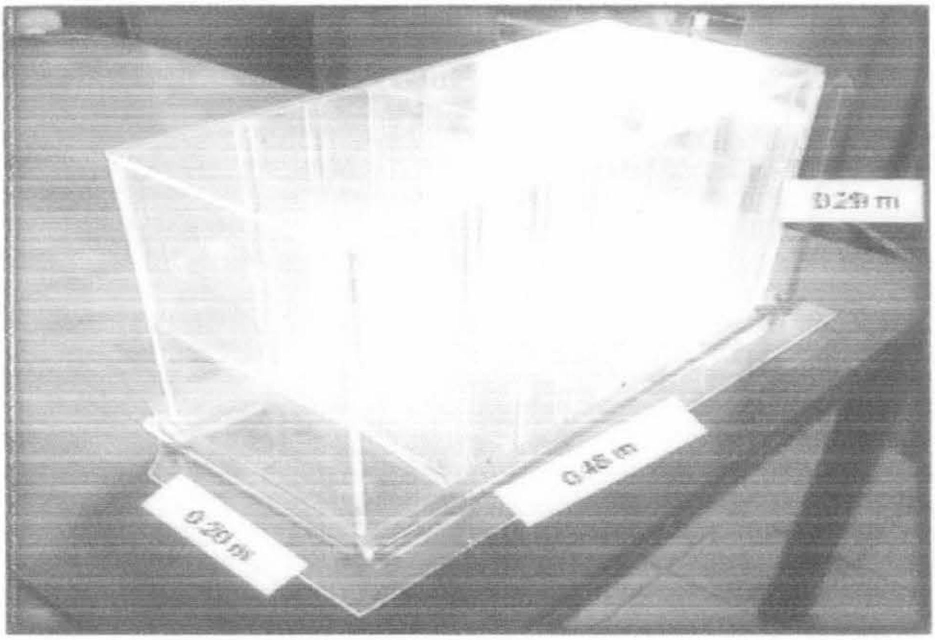

Figure A8-1: Reactor

Figure A8-2: ABR system

APPENDIX 9: GAS COLLECTION CHAMBER

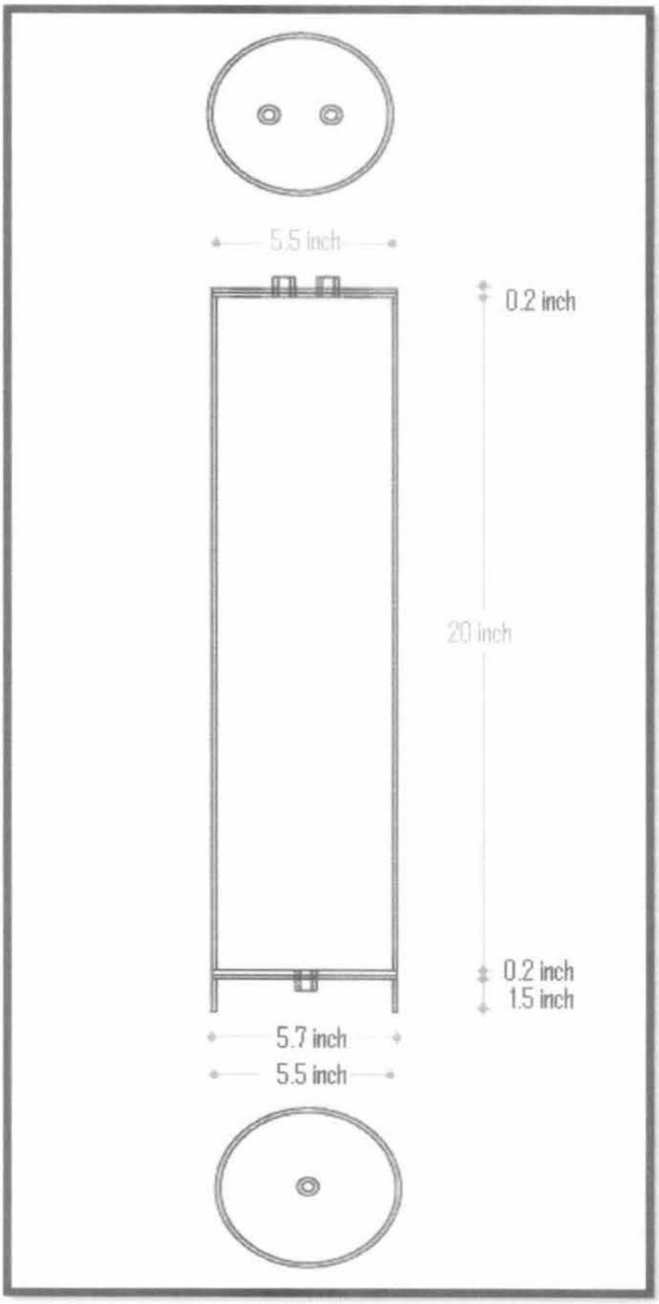

Figure A9-Design Gas collection chamber