APPLICATION OF ANAEROBIC BAFFLED REACTOR (ABR) FOR POLISHING OF TREATED PALM OIL MILL EFFLUENT (POME)

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CERTIFICATION OF APPROVAL

Application of Anaerobic Baffled Reactor (ABR) for Polishing of Treated Palm Oil Mill Effluent (POME)

by

Farhana Binti Abd Lahin

A project dissertation submitted to the
Civil Engineering Programme
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Approved by,

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JUNE 2010

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.

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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 polishing of treated POME. Samples were taken from treated effluent of Nasaruddin Palm Oil Mill, located at Bota District in Perak. The COD of the POME discharged to river was identified to be 1100 ± 100 mg/L which is overly exceeding the standard limit for industrial effluent in Malaysia. An ABR was constructed using ~~a~~ flexiglass sheets with the dimension of (0.48m × 0.20m × 0.29m) and divided into 6 compartments. The ABR system was equipped with influent and 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 materials. The ABR system was initially operated at 8 days of HRT and then it was decreased to 6, 4 and 2 days whenever steady-state conditions were achieved. Daily analysis was done for the produced methane gas, the sCOD and TSS of the effluent and the pH of every compartment. From the results, the best HRT was found to be 4 days with the maximum sCOD content reduction of 45% and methane gas production of $63cm^3$. The result shows that ABR system has a high potential of treating POME in short HRT because of the presence of baffles in the system.

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ABBREVIATIONS & NOMENCLATURES

ABR	Anaerobic Baffled Reactor
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
FFB	Fresh Fruit Bunch
HRT	Hydraulic Retention Time
MLVSS	Mixed Liquor Volatile Suspended Solids
OLR	Organic Loading Rate
POME	Palm oil mill effluent
sCOD	Soluble Chemical Oxygen Demand
TKN	Total Kjeldahl Nitrogen
TSS	Total Suspended Solid

CHAPTER 1
INTRODUCTION

1.1. Background of Study

Anaerobic treatment of wastewater has been considered to have a numbers of advantages over other biological treatments. It saves energy for aeration compared to aerobic treatment, coverts organic pollutant into methane gas, a readily usable gas, need low nutrient requirement and produces low biomass [1]. Anaerobic processes have wide application in the treatment of sewage sludge and high-strength industrial wastewater treatment. The success of new high-rate anaerobic technology had encourages environmental researchers to extend its application to treat wastewater of more complex nature [2].

The Anaerobic Baffled Reactor (ABR) includes a series of vertical baffles to redirect the flow of the wastewater under and over them and enabling, the wastewater comes into contact with a large active biological mass. This type of reactor system has been reported to have many advantages over other well established reactor systems. It is simple in 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].

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].

Although the palm oil industry is one of the major revenue earners for our country, it has been identified among the largest sources of water pollution source due to the palm oil mill effluent (POME) characteristic [5]. Presence of unrecovered palm oil inside the palm oil mill effluent, giving a high reading of degradable organic matter either in a raw or partially treated POME. Because of its characteristic, POME is a highly polluting wastewater that can therefore cause severe pollution of waterways due to oxygen reduction [6].

1.2. Problem Statement

In palm oil mills, liquid effluent is mainly generated from sterilization and clarification processes in which large amount of steam and hot water are used. For every ton of palm oil fresh fruit bunch, it was estimated that 0.5-0.75 tonnes of POME will be discharged. In general appearance, palm oil mill effluent POME is a yellowish acidic wastewater with fairly high polluting properties [5].

Therefore, POME can cause serious environmental damage as it contains high COD if discharged into water bodies without proper treatment. The discharges of POME without appropriate treatment can both deterioration of water quality and foul smell to the neighborhood of factory [7].

The treated POME effluent contains high amount of COD and BOD of 1143 mg/L, 618 mg/L which requires more treatment before to be discharged in water bodies. This wastewater is overly exceeding the standard of effluent discharged of Standard B which is 100 mg of COD/L and 50 mg of BOD/L [8]. The discharge of high COD wastewater will contribute to the increase of oxygen demand in the river causing the shortage of oxygen supply for the aquatic life, therefore causing the death of aquatic life.

1.3. Objectives

This project is to study the application of ABR in different HRTs for polishing treated POME and to:

1. Investigate the best percentage of COD reduction.
2. Study the ~~of~~ methane gas (CH_4) production rate.

1.4. Scope of study

In this project, ABR was employed to reduce the pollutant content of POME. Samples of POME were collected from Nasaruddin Palm Oil Mill located at Bota District in Perak. Laboratory scale ABR was run with the real sample without dilution and anaerobic sludge from the same POME treatment plant was incubated as seeding materials. Due to the characteristic of the ABR, the efficiency of COD removal and the production rate of methane gas were monitored. Series of experimental analysis were conducted to identify the best COD removal and biogas production rate at different HRT of 8, 6, 4 and 2 days.

CHAPTER 2
LITERATURE REVIEW

2.1. Anaerobic Treatment

Anaerobic digestion may be defined as the engineered methanogenic decomposition of organic matter. It involves different species of anaerobic microorganism that degrade organic matter [9]. In the anaerobic process, the decomposition of organic substrate is carried out in the absence of molecular oxygen. The biological conversion of the organic substrate occur in the mixture of primary settled and biological sludge under anaerobic condition followed by hydrolysis, acidogenesis and methagonesis to convert the intermediate compounds into simpler end products as methane (CH_4) and carbon dioxide (CO_2) [5]. 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 [10].

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 and the very low operating costs. Anaerobic treatment often is very cost-effective in reducing discharge levies combined with the production of reusable energy in the form of biogas. Anaerobic treatment of domestic wastewater can also be very interesting and cost-effective in countries were the priority in discharge control is in removal of organic pollutants [11].

2.2. Application of Anaerobic Treatment on POME

Anaerobic treatment is especially suitable for treating high range wastewater. Palm oil mill effluent (POME) in general having the average values of 25,000 mg/L BOD and 50,000 mg/L of COD, which shows that the most suitable and cost effective treatment is anaerobic treatment [12].

POME can be easily treated using 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, these byproducts can potentially be use as 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 types of anaerobic treatment including Anaerobic Stabilization Pond Anaerobic Digestion and ABR. POME is currently treated using stabilization pond and anaerobic digestion method.

2.2.1. Stabilization Ponds

Majority of palm oil mill in Malaysia are using anaerobic stabilization ponds as a treatment system for palm oil mill effluent. The stabilization pond system consists of series of anaerobic pond. Stabilization pond system has high efficiency on removing COD content from POME, because of the long retention time [5].

However, due to the open surface of the pond, the methane gas produced by this system is not being collected and released to the environment without being utilized. The open surface of the pond also contributes to the foul smell that could disturb the surrounding community especially the settlement nearby the palm oil mill.

One of the palm oil mill factory that is using this type of wastewater treatment is Nasaruddin Palm Oil Mill. The application of anaerobic stabilization ponds is preferred because of its low capital and operational cost [7]. However, it consumes a large area to operate and the foul smell generated from the system will disturb the surrounding community.

As shown in Figure 2.1, the influent POME is discharged through the cooling pond No. 1 and 2 for 3 days respectively. The wastewater then kept in the anaerobic ponds No. 1, 2, 3 and 4 for 40 days of retention time in each anaerobic pond. The wastewater will then be oxidized in the oxidation pond No. 1 for 8 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 disludging pond. The capacity and hydraulic retention time of each cooling ponds, anaerobic ponds, oxidation ponds and settling ponds are 1355 m^3, 22000 m^3, 4000 m^3, 500 m^3 and 3, 40, 8 and 1 day respectively.

From the analysis conducted in the lab, comparing the influent and effluent wastewater taken from the anaerobic stabilization ponds shows the COD content of 25267 mg/L for influent and 800 mg/L for effluent. This gives the COD removal efficiency if 97 %.

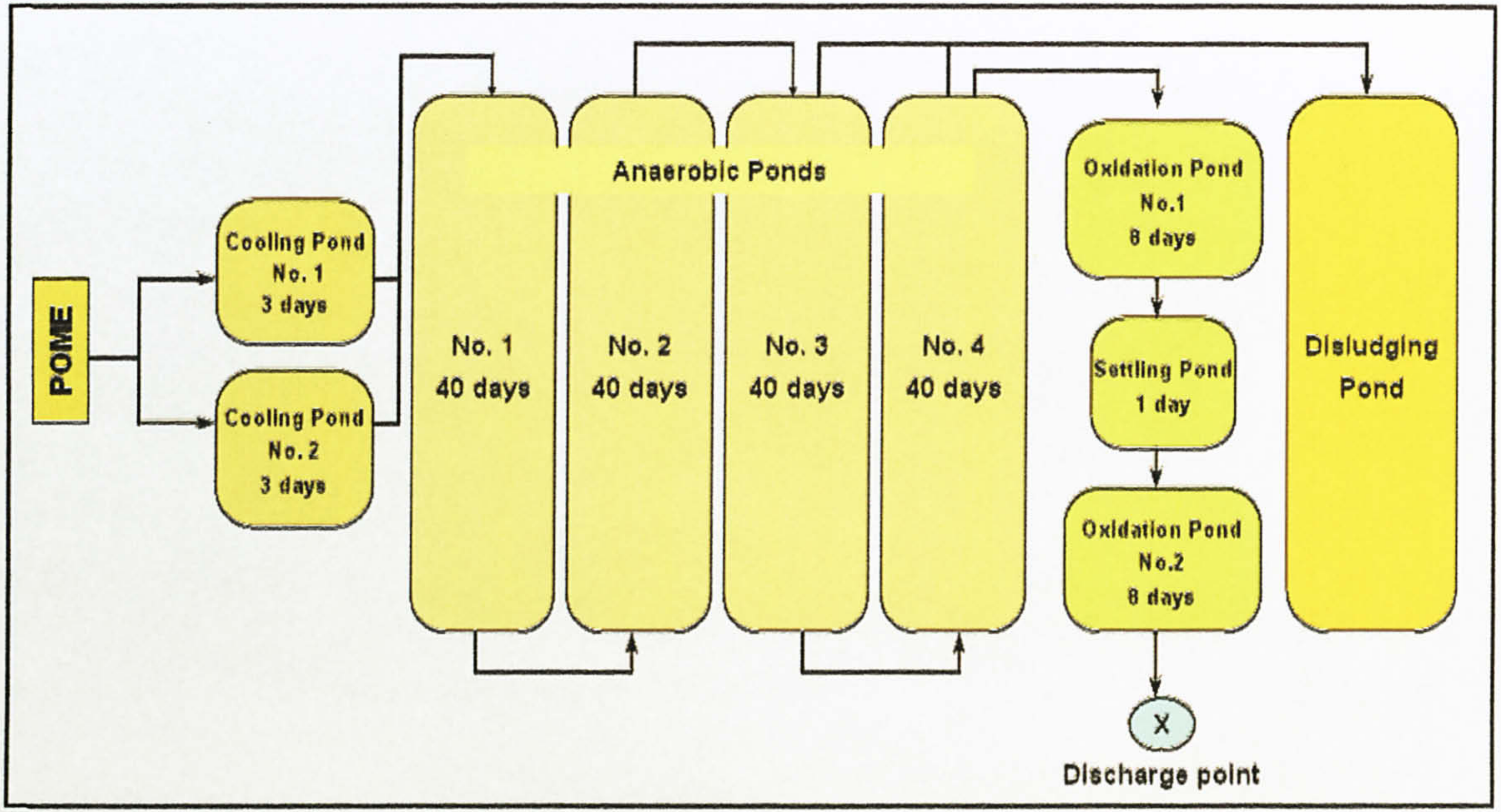

Figure 2.1: Anaerobic Stabilization Ponds System

2.2.2. Application of Anaerobic Digester

An experiment investigating the effect of hydraulic retention time (HRT) and organic loading rate (OLR) was done by Pechsuct et al. [2001], a cylinder digester with dimension of (10.5 cm dia. and 22 cm height) containing 1.9 L POME was used. In this experiment, the parameters of HRT and OLR were varied at room temperature. The experiment was conducted on effect of HRT on the treatment efficiency was conducted in room temperature (30°C±1.0°C). The HRT of the treatment was varied 12, 10, 7 and 5 days with OLR of 7.92, 9.50, 13.57 and 19.00 kg/m^3 respectively. The optimum COD removal was found to be 7 days of HRT giving the highest average of 62.5%. The lowest COD removal of 31.7% was obtained at HRT of 5 days. Therefore the optimum HRT for treatment of POME was 7 days. The production of biogas was measured by using water replacement method. The highest biogas production was on 12 days HRT and the lowest production identified on 5 days HRT. The high production of biogas on 12 days HRT was due to the fact that at low HRT with high OLR, the organic matter was degraded to volatile fatty acid (VFA), resulting on lower pH, at a higher rate than the degradation of VFA to biogas production. High concentration of VFA resulting in lower pH would cause the growth inhibition of the methanogen [13].

A study had been done by Puetpaiboon et al. [2001], investigating the performance of a full scale anaerobic digester. A full-scale anaerobic digester with a dimension of 13.5 m in diameter and 15.3 m in height with average volume of 2,100,000 L was used. The hydraulic retention time of the system was about 7 days with the average organic loading rate of 4.53 kgCOD/m^3.day. The temperatures before and after feeding to anaerobic digester were in a range of 40 - 45 and 36 - 40°C. The warm temperature of wastewater from palm oil mill production after pretreatment was appropriate to the biochemical reaction in the anaerobic digester which converted organic matter to biogas under mesophilic temperature range, between 30 and 38 °C [7].

The influent and effluent from anaerobic digester were analyzed for BOD_5, COD, pH, temperature, VFA and alkalinity every 3-4 days. The composition of gas produced was determined using gas chromatography. COD in the influent and effluent were found to be in the range of 21,560 – 39, 200 mg/L and 5,880 – 17, 640, respectively. The result shows a COD removal efficiency of 64%. The result of biogas composition analysis showed that methane (CH_4) concentration was at 66 – 67 % [7].

2.2.3. Anaerobic Baffled Reactor (ABR)

In ABR treatment, a series of vertical baffles are built inside the airtight reactor to force the wastewater to flow over and under it as it moves from the inlet to the outlet of the tank. The idea of ABR system was initially developed by McCarty and coworkers in Stanford University [14].

Microorganisms within the reactor gently rise and settle due to flow of wastewater and gas production in each compartment. However, the microorganism will move vertically down the reactor. Therefore, 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 [14].

The most significant advantage of the ABR is its ability to separate acidogenesis and methanogenesis longitudinally down the reactor, allowing the different bacterial groups to develop under most favorable conditions [14].

Taking into consideration the slow growth of many anaerobic microorganisms, particularly methanogenics, the main objective of the efficient reactor design must be high retention time of bacterial cells with very little loss of bacteria from the reactor. The technological challenge to improve the anaerobic digestion lies in enhancing the bacterial activity together with good mixing to ensure a high rate of contact between the cells and their substrate [1].

A study on kinetic analysis of palm oil mill wastewater treatment by modified anaerobic baffled reactor was conducted by M. Faisal et al. [2000]. A modified baffled bioreactor (MABR) was studied under steady-state conditions for treating palm oil mill wastewater. A rectangular reactor of 50 cm in length, 16.5 cm width and 38.5 cm height was used. The reactor was divided into 5 compartments by baffles alternately hanging and standing. The seeding and acclimatization of anaerobic mixed culture and start-up bioreactor data were presented elsewhere. The steady-state performance was evaluated under hydraulic retention time of 3, 5, 6, 7 and 10 days with organic loading rate of 1.60-5.33 g-COD/L.day. At a given loading rate, the bioreactor was continuously operated until steady-state condition was achieved, when effluent COD, VSS and gas production rate in bioreactor became constant. Based on the effluent analysis, under steady-state condition at HRT of 3 – 10 days, the COD removal efficiency in the range of 77.3 – 95.3 % was achieved and the methane gas production was in the range of 0.32 – 0.421 CH_4/g-COD [1].

CHAPTER 3
METHODOLOGY

3.1. Project Activities

The project is divided 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. Wastewater source was identified and the sample of POME was 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 trouble shooting 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 is conducted in FYP II. In this phase, the anaerobic baffled reactor is put into operation and the efficiency of the anaerobic treatment were measured based the COD removal efficiency and the methane gas production by varying the HRT of the system. The project process flow is depicted is Figure 3.1.

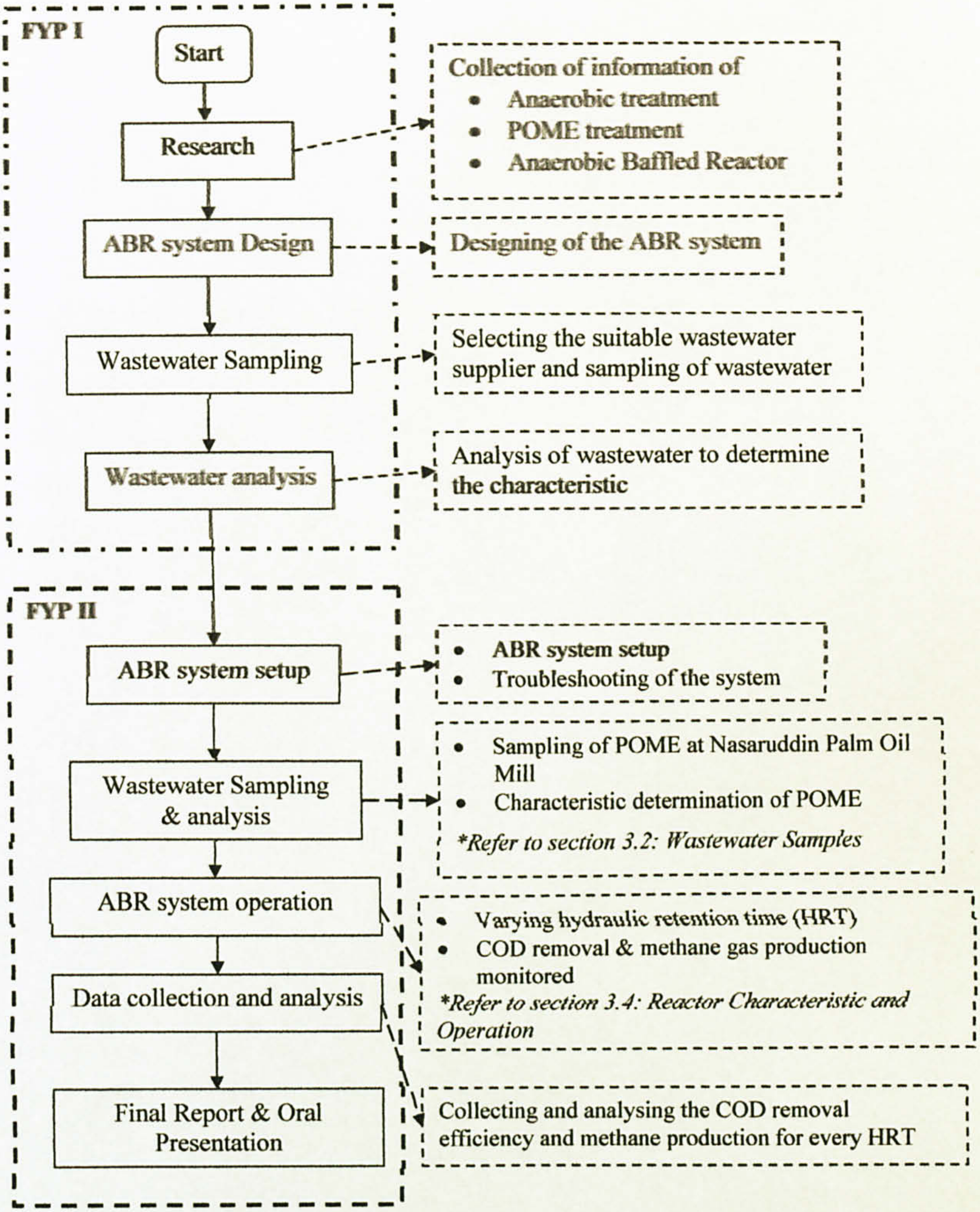

Figure 3.1: Project Process Flow

3.2. Wastewater samples

The wastewater samples used in the project was *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 samples were directly placed in the cool storage at temperature of 4°C 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 [1].

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, sCOD, Total Alkalinity, TKN, TOC, TSS and MLVSS.

3.2.1. pH determination

pH of the wastewater sample was determine using a digital pH meter based on the HACH method.

3.2.2. COD determination

The palm oil mill effluent (POME) sample was filtered to remove suspended solids in the sample and diluted to 1:50 before proceeding with the sCOD experiment. The sCOD of the wastewater sample was determined using the spectrophotometer based on the APHA method.

3.2.3. Total Alkalinity determination

Total alkalinity of the sample was determined based on the standard method of analyzing wastewater. The volume of 0.02N H_2SO_4 used to titrate 50 ml of the sample was recorded. The total alkalinity was determined using the equation of;

To determine Phenolphthalein alkalinity (P), as mg $CaCo_3$/L

$$= \frac{(mL\ H_sSO_4\ titrant\ used) \times Normality of\ H_2SO_4 \times 50000}{Sample\ size\ (mL)} \qquad (Eq.\ 1)$$

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

$$= \frac{(Total\ mL\ H_sSO_4\ titrant\ used) \times Normality\ of\ H_2SO_4 \times 50000}{Sample\ size\ (mL)} \qquad (Eq.\ 2)$$

3.2.4. BOD determination

The value of BOD was determined using the equation of;

To determine the BOD value without seed correction:

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

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

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

To determine the BOD value with seed correction and blank correction as well as dilution:

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

3.2.5. TKN Determination

The TKN value was determined based on the formula;

$$TKN = \frac{v_1 - v_2}{v_0} \times C \times F \times 1000 \qquad (Eq.\ 6)$$

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 blank

N = normality of sulfuric acid solution

F = milliequivalent weight to nitrogen (14mg).

v_0 = mL of sample digested.

3.2.6. TOC Determination

The 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. Total Organic Carbon (TOC) may be calculated by subtracting TIC from TC. The formula for TOC determination is:

$$TOC = TC - TIC \qquad (Eq.\ 7)$$

3.2.7. Total Suspended Solid Determination

Total suspended solid (TSS) is determined by filtering the 100 mL of wastewater samples using a 47 mm filter disc. The filter paper then dried in a drying oven of 105 °C for 1 hour. After the filter paper is cooled off in a desiccator, the filter paper is weighed to determine the suspended solid of the wastewater. The TSS is determined by the following formula:

$$TSS = \frac{(Weight\ of\ pan + filter\ paper\ after\ drying) - (Weight\ of\ pan + filter\ paper\ before\ drying)}{Sample\ size\ (L)} \qquad (Eq.\ 8)$$

3.2.8. MLVSS Determination

The *Mixed Liquor Volatile Suspended Solid* (MLVSS) is determined by filtering the samples using a 47 mm fiber glass filter paper. Fiber glass filter paper is used in the experiment to avoid burning of filter paper when it is exposed to high temperature of 550 °C. The fiber glass filter paper then dried in a drying oven of 105°C for 1 hour and weighed after it is cooled off in a desiccators. The filter paper then put 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 determination of MLVSS is by using the following formula:

To determine the MLSS of the sample:

$$= \frac{(Weight\ of\ pan + filter\ paper\ after\ drying) - (Weight\ of\ pan + filter\ paper\ before\ drying)}{Sample\ size\ (L)} \qquad (Eq.\ 9)$$

To determine the MLVSS of the sample:

$$= \frac{(Weight\ of\ pan + filter\ paper\ after\ furnace) - (Weight\ of\ pan + filter\ paper\ before\ furnace)}{Sample\ size\ (L)} \qquad (Eq.\ 10)$$

3.3. Seeding

Sludge was taken from the Anaerobic Pond No. 3 from Nasaruddin Palm Oil Mill (Figure 2.1). 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 sludge. The large particles and debris from the sludge were removed by passing it through American Society of Testing Materials (ASTM) sieve No. 16 (1.18 mm). It was then introduced equally to all 6 compartments of the ABR [15]. Amount of sludge needed in the system was calculated using Eq. 11 [16]. The calculation of food-to-microorganism is depicted in Appendix 1.

$$\frac{F}{M} = \frac{S_o}{\theta x} \qquad (Eq. 11)$$

Where:

F = Food

M =Microorganism

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

θ = Hydraulic detention time (day)

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

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

3.4. Reactor Characteristic and Operation

The reactor used in the experiment was a flexiglass cubic tank with 0.48 m in length, 0.20 m in depth and 0.29 m in height and divided into 6 compartments. The volume of the first compartment was 0.0054 m^3, the next 4 compartments each having 0.0044 m^3 of volume and the last compartment with volume of 0.0048 m^3. The first compartment is designed with bigger volume compared to the 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 [17].

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

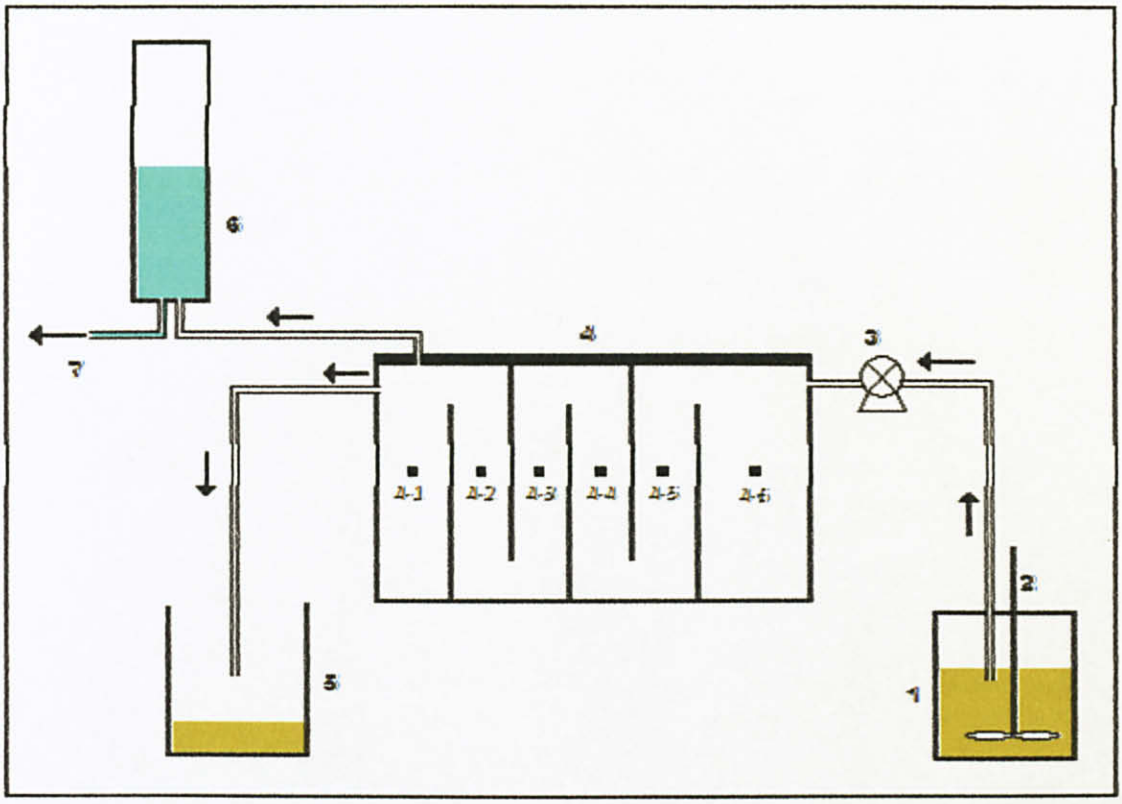

Figure 3.2a: Laboratory Scale Anaerobic Baffled Reactor (1: Influent Tank, 2: Stirrer, 3: Water Pump, 4:ABR System, 4-1 to 4-6: Sampling points, 5: Effluent Tank, 6: Gas Collection Chamber, 7: NaOH discharge)

Tubes were installed at the middle elevation of the reactor in each compartment. The installation of the tube is for the purpose of taking samples in every compartment. Samples were taken daily to analyze the sCOD of the POME to observe the behaviour of the ABR treatment system. The real picture of the ABR system is shown in Appendix 8.

A cylinder shaped gas collection chamber was designed to collect and measure the volume of methane gas produce from the system. Water displacement method was used to collect and determine the volume of methane gas produced by the system. The collection chamber was filled with solution of Sodium Hydroxide (NaOH) in order to dissolve and separate the CO_2 in the biogas produced, leaving only the methane gas [15]. The Solution of NaOH was prepared by diluting NaOH of 47% into 2.5%.

The ABR system initially uses a longer HRT and was reduced in stepwise fashion. This has been observed to provide a greater reactor stability and superior performance [15]. At given HRT, the ABR was continuously operated until steady-state condition was achieved when the sCOD of the effluent became stable. The HRT and its corresponding flow rate are shown in Table 3.1.

Table 3.1: Feeding flow rate

HRT (day)	Flow rate (ml/s)
8	0.039
6	0.052
4	0.078
2	0.156

3.5. Sampling and analysis

The effluent of the system is monitored daily for pH, sCOD, 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 was done by starting from the last compartment toward the first to prevent air intrusion and to maintain the anaerobic condition in the reactor [15].

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 sCOD and BOD content of the POME sample are 1,143 mg/L and 618 mg/L respectively which are very high to be discharged into any water bodies. 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

Parameter	Concentration
pH	8.6
COD (mg/L)	1,143
BOD (mg/L)	618
Total Alkalinity ($CaCO_3$/L)	150
TKN (mg/L)	7.94
TOC (ppm)	810.034
TSS (mg/L)	160

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 sCOD content of influent and effluent of the system and also the sCOD reduction. The TSS results of the effluent samples are depicted in Figure 4.2. Figure 4.3 shows the pH profile of the reactor for each HRT. The methane gas produced by the ABR system is illustrated in Figure 4.4.

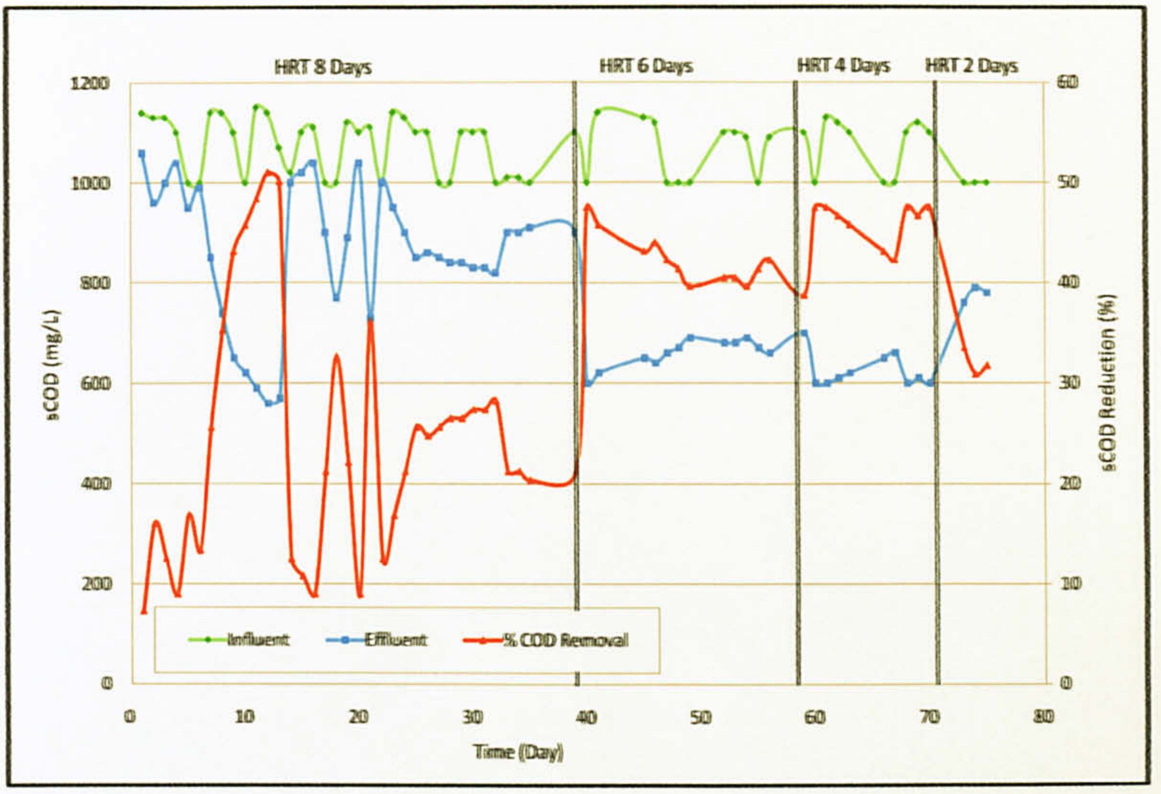

Figure 4.1: Graph of sCOD

Figure 4.1 shows the sCOD content in reduction of the effluent POME from the ABR system. As shown in the graph, the influent sample of POME was kept in the range of 1000 – 1200 mg/L of sCOD throughout the ABR system operation. From the graph it is shown that in the early operation of the ABR system, fluctuation of sCOD content in effluent sample happened. This is due to the adaptation 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. After 20 days of operation, the sCOD content became more stabilized and reached steady-state condition at the day of 40. After reaching steady state condition, the HRT has been reduced to 6 days and the sCOD reduction was increased. The HRT was further change to a shorter HRT after the system reaches a state. The sCOD reduction was observed the highest at the HRT of 4 days and decreased drastically in the HRT of 2 days. The result of sCOD content in influent and effluent are depicted in Appendix 3.

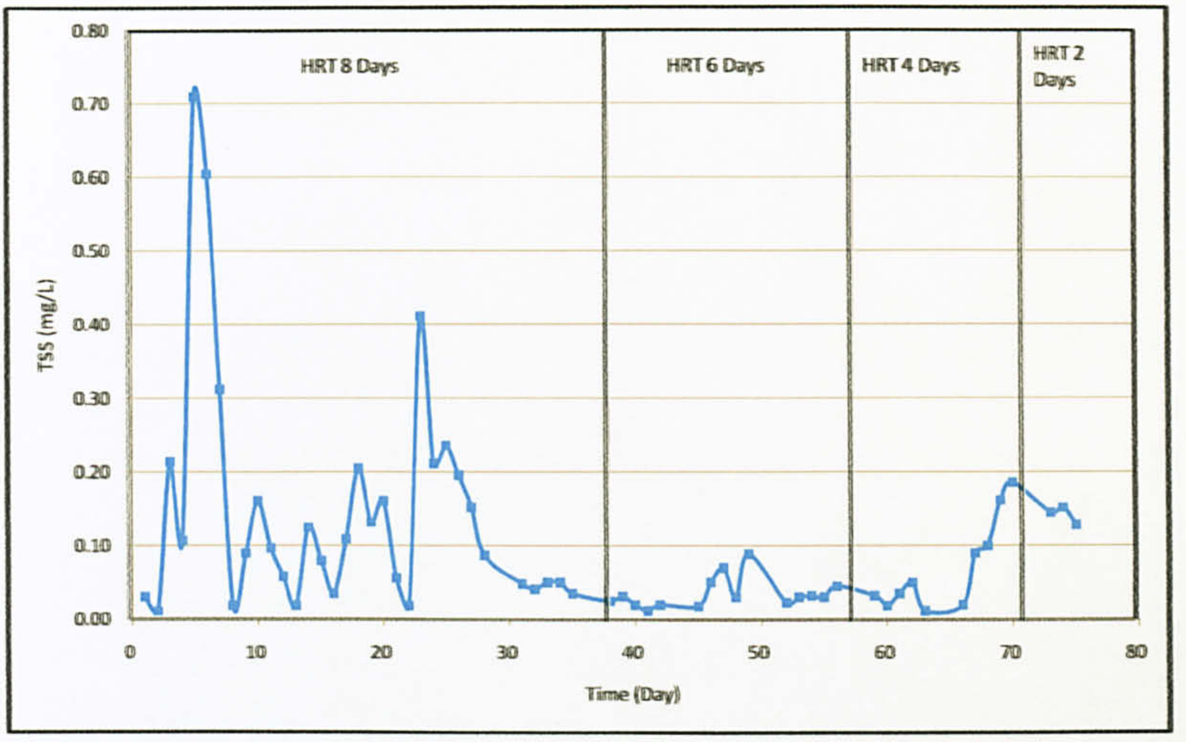

Figure 4.2: Graph of TSS

The TSS of effluent sample was observed to be fluctuating in the beginning of the ABR system operation. This is due to the adaptation 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. According to the graph, the TSS content in the effluent samples is relatively the same at the end of HRT 8, HRT 6 and 4 days. It is shown that the TSS increased in the HRT of 2 days. This is because of higher feeding flow rate that interrupted the particles settlement in the reactor. The TSS of the influent and each compartment is depicted in Appendix 4.

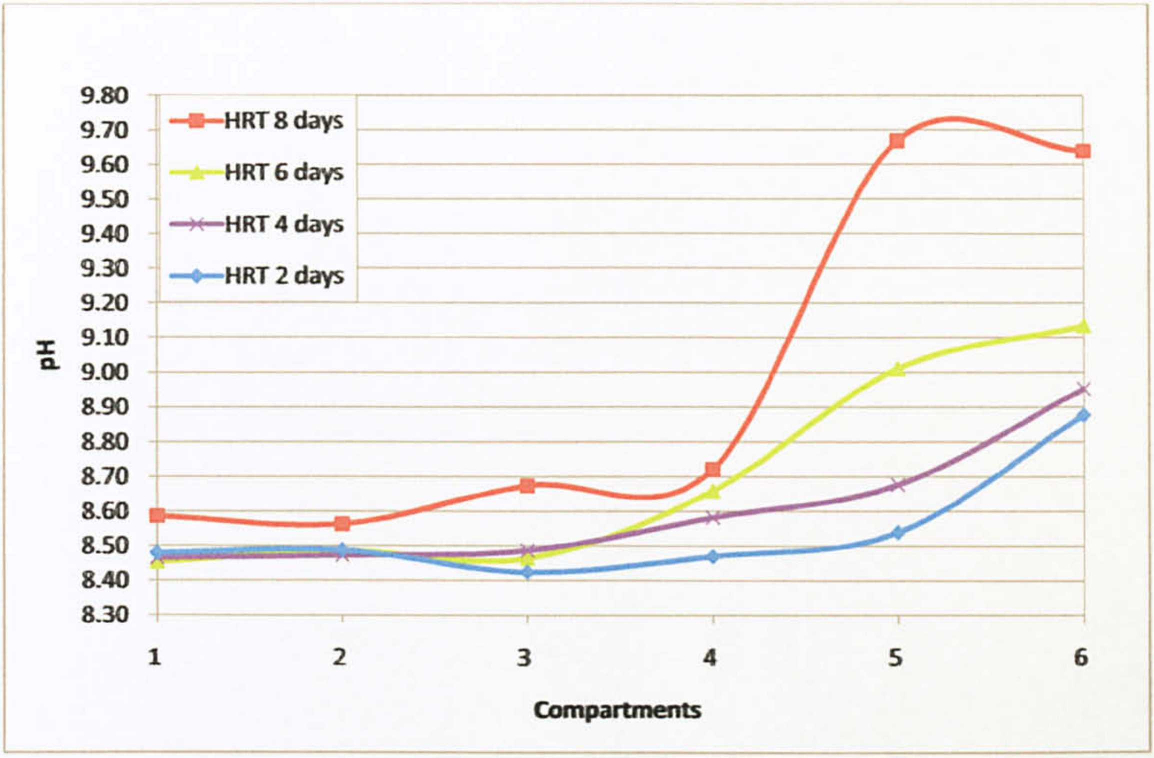

Figure 4.3: Graph of pH

Figure 4.4 show the pH profile of the different HRTs 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 1 to compartment 2 and this illustrate formation of acid in the acidogenesis phase where the amount of volatile acids are high. As the POME flows to compartment 4 to compartment 6, the pH rises as methanogenesis phase is happening to the system. In this phase, biogas which contains of methane and carbon dioxide is produced by the system. Based on the graph, the best pH profile is obtained in the HRT of 2 days. This is because, after operating for 75 days, growth of microorganism happened inside the reactor according to its function in different compartments.

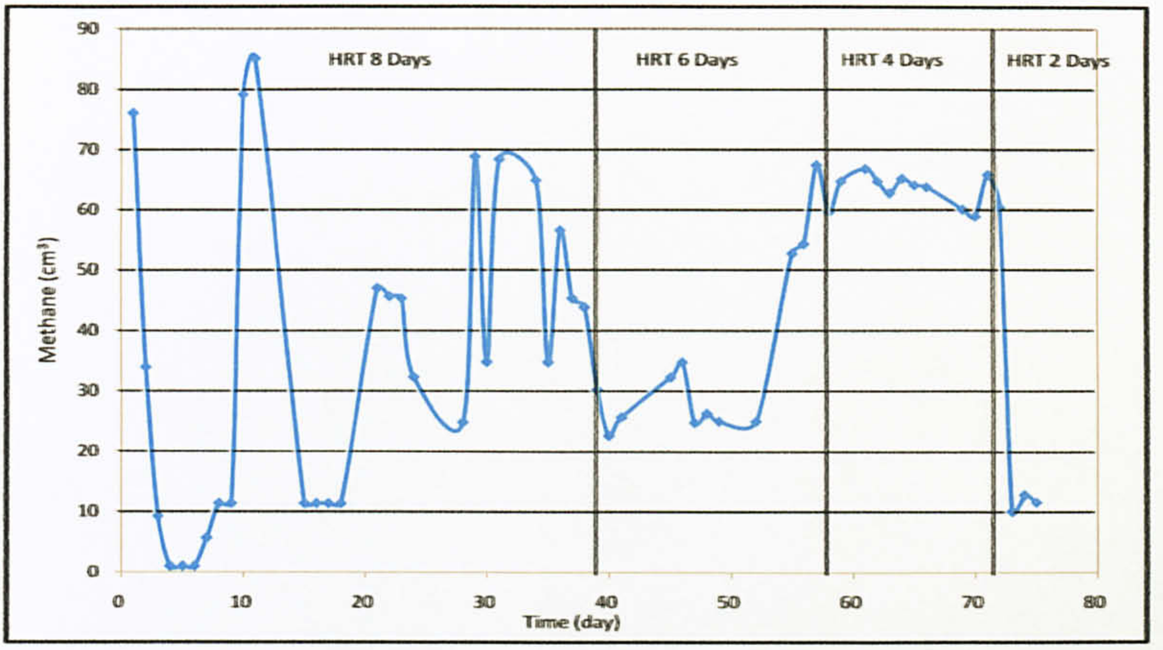

Figure 4.4: Graph of methane produced

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 methane gas production then become more stabilized and it gradually decreased by time. This behavior is caused by the fact that the microorganism in the ABR system has became more familiar with the wastewater. The presence of baffles also contributed to the stabilization of methane gas production as the methanogenic microorganisms are now segregated from the other type of microorganisms and this enhanced its efficiency in producing methane gas. The maximum production of methane gas was observed at HRT of 4 days which is $63\pm2cm^3$. The production of methane decreased drastically when the HRT was changed to 2 days.

CHAPTER 5
ECONOMIC BENEFITS

In this project, the cost spent in constructing the anaerobic baffled reactor system was 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 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 using gravity force to flow the POME through the system thus eliminating the cost for energy consumption. However, the cost of constructing a full scale anaerobic baffled reactor cannot be easily determined as the design will require the characteristic of POME and flow rate of POME discharged from Palm Oil Mill and the type of raw material needed in the construction. This study will require more information and time.

In comparison with the current treatment application, stabilization ponds 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. Based on the current situation, of the high COD discharged from Nassaruddin Palm Oil Mill will cause into additional cost which is the penalty for disobeying the regulation specified by the Department of Environment of Malaysia.

Indirect cost such as environmental quality deterioration also involved because of the high content of COD discharge. POME with COD of 1143 mg/L will require a very long time and distance to be diluted into an acceptable degree of COD. This scenario will cause pollution in water bodies and cause a cost in the environmental aspects.

CHAPTER 6
CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The results obtained in the project indicate that the ABR system has the potential in treating palm oil wastewater. The characteristic 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 characteristic. This can prevent the wastewater to have a contact with different types of microorganisms and reduce the efficiency of the treatment system. From the data analysis, the best HRT for the ABR system was found to be 4 days which reduced the sCOD content at 45% of reduction and methane gas production of $63cm^3$. This shows that the ABR treatment system has high potential in the Palm Oil industry as it can treat POME in short HRT compared to the stabilization pond that requires long period of time to operate.

6.2. Recommendation

Based on the achieved result, the recommendations are:

i. Study on the ABR performance with number and area of baffles variation.
ii. Study on application of the aerobic system for the treated wastewater in ABR as it still has not reached the quality of wastewater required by Malaysia standards (Standard B).

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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:

$$\frac{F}{M} = \frac{S_o}{\theta \mathrm{x}} \qquad (Eq.\ 11)$$

Where:

F= Food

M=Microorganism

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

θ = Hydraulic detention time (day)

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

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

Data obtained from experiments;

MLVSS = 3330 mg/L

COD = 1143 mg/L

$$\frac{F}{M} = \frac{S_o}{\theta X} = \frac{1143}{8 \times 3330} = 0.043 d^{-1}$$

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:

$$m_1v_1 = m_2v_2$$

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

$$v_1 = \frac{(2.5)(1)}{47}$$

$$v_1 = 0.053L$$

From the calculation it is determined that, in preparing 1L of NaOH with the concentration of 2.5%, 0.053L 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 the solution do not have the ability to dissolve CO_2 anymore and need to be changed.

APPENDIX 3: sCOD CONTENT

Table A3-1: sCOD content

HRT	Day	Influent (mg/L)	Effluent (mg/L)	Reduction (%)
8	1	1140	1060	7.26
8	2	1130	960	16.01
8	3	1130	1000	12.51
8	4	1100	1040	9.01
8	5	1000	950	16.89
8	6	1000	990	13.39
8	7	1140	850	25.63
8	8	1140	740	35.26
8	9	1100	650	43.13
8	10	1000	620	45.76
8	11	1150	590	48.38
8	12	1140	560	51.01
8	13	1070	570	50.13
8	14	1020	1000	12.51
8	15	1100	1020	10.76
8	16	1110	1040	9.01
8	17	1000	900	21.26
8	18	1000	770	32.63
8	19	1120	890	22.13
8	20	1100	1040	9.01
8	21	1110	730	36.13
8	22	1000	1000	12.51
8	23	1140	950	16.89
8	24	1130	900	21.26
8	25	1100	850	25.63
8	26	1100	860	24.76
8	27	1000	850	25.63
8	28	1000	840	26.51
8	29	1100	840	26.51
8	30	1100	830	27.38
8	31	1100	830	27.38
8	32	1000	820	28.26
8	33	1010	900	21.26
8	34	1010	900	21.26
8	35	1000	910	20.38

Table A3-1(cont): sCOD content

HRT	Day	Influent (mg/L)	Effluent (mg/L)	Reduction (%)
6	39	1100	900	21.26
6	40	1000	600	47.51
6	41	1140	620	45.76
6	45	1130	650	43.13
6	46	1120	640	44.01
6	47	1000	660	42.26
6	48	1000	670	41.38
6	49	1000	690	39.63
6	52	1100	680	40.51
6	53	1100	680	40.51
6	54	1090	690	39.63
6	55	1000	670	41.38
6	56	1090	660	42.26
4	59	1100	700	38.76
4	60	1000	600	47.51
4	61	1130	600	47.51
4	62	1120	610	46.63
4	63	1100	620	45.76
4	66	1000	650	43.13
4	67	1000	660	42.26
4	68	1100	600	47.51
4	69	1120	610	46.63
4	70	1100	600	47.51
2	73	1000	760	33.51
2	74	1000	790	30.88
2	75	1000	780	31.76

APPENDIX 4: TSS

Table A4-1: TSS

HRT	Day	Effluent (g/L)
8	1	0.030
8	2	0.011
8	3	0.214
8	4	0.107
8	5	0.709
8	6	0.604
8	7	0.312
8	8	0.019
8	9	0.090
8	10	0.160
8	11	0.097
8	12	0.058
8	13	0.019
8	14	0.125
8	15	0.080
8	16	0.035
8	17	0.109
8	18	0.205
8	19	0.132
8	20	0.160
8	21	0.056
8	22	0.019
8	23	0.411
8	24	0.211
8	25	0.236
8	26	0.196
8	27	0.152
8	28	0.087
8	29	0.048
8	30	0.041
8	31	0.050
8	32	0.050
8	33	0.035
8	34	0.025
8	35	0.031

Table A4-1(cont): TSS

HRT	Day	Influent (g/L)
6	39	0.020
6	40	0.012
6	41	0.020
6	45	0.018
6	46	0.050
6	47	0.070
6	48	0.030
6	49	0.089
6	52	0.023
6	53	0.030
6	54	0.032
6	55	0.030
6	56	0.045
4	59	0.032
4	60	0.019
4	61	0.035
4	62	0.050
4	63	0.012
4	66	0.020
4	67	0.090
4	68	0.100
4	69	0.162
4	70	0.186
2	73	0.145
2	74	0.152
2	75	0.129

APPENDIX 5: pH

Table A5-1:pH

HRT	Day	1	2	3	4	5	6	Effluent
8	1	8.69	8.73	9.09	8.99	10.27	9.90	9.23
8	2	8.62	8.61	8.99	8.82	10.12	9.87	9.19
8	3	8.67	8.59	9.02	8.83	10.19	10.13	9.25
8	4	8.86	8.65	8.90	8.94	10.26	10.11	9.10
8	5	8.62	8.62	8.84	8.82	10.15	10.10	8.86
8	6	8.50	8.51	8.81	8.78	10.08	9.93	8.68
8	7	8.63	8.63	8.79	8.86	10.01	9.93	8.73
8	8	8.64	8.48	8.47	8.91	9.89	9.72	8.59
8	9	8.67	8.39	8.31	8.76	9.80	9.60	8.59
8	10	8.55	8.29	8.35	8.52	9.70	9.50	8.60
8	11	8.58	8.45	8.50	8.70	9.87	9.85	8.71
8	12	8.59	8.53	8.70	8.85	9.70	9.65	8.70
8	13	8.60	8.62	9.01	8.83	10.02	9.63	8.90
8	14	8.65	8.63	8.98	8.92	10.07	9.80	9.08
8	15	8.70	8.68	8.95	9.00	10.11	9.97	9.11
8	16	8.74	8.70	8.78	8.92	9.86	9.97	9.00
8	17	8.60	8.46	8.61	8.90	9.50	9.71	8.99
8	18	8.57	8.60	8.65	8.81	9.62	9.60	8.97
8	19	8.68	8.80	8.86	8.71	9.51	9.58	8.88
8	20	8.63	8.65	8.69	8.65	9.47	9.54	8.89
8	21	8.58	8.51	8.52	8.58	9.43	9.50	8.90
8	22	8.51	8.58	8.53	8.59	9.32	9.43	8.96
8	23	8.49	8.60	8.52	8.55	9.33	9.42	8.98
8	24	8.46	8.59	8.50	8.59	9.40	9.38	8.97
8	25	8.43	8.57	8.49	8.54	9.21	9.36	8.96
8	26	8.47	8.53	8.48	8.52	9.33	9.37	8.93
8	27	8.52	8.52	8.52	8.54	9.30	9.37	8.90
8	28	8.49	8.53	8.54	8.52	9.31	9.36	8.91
8	29	8.50	8.50	8.57	8.51	9.25	9.31	8.89
8	30	8.51	8.49	8.57	8.56	9.19	9.29	8.85
8	31	8.51	8.50	8.52	8.53	9.11	9.30	8.88
8	32	8.53	8.51	8.51	8.52	9.02	9.31	8.83
8	33	8.40	8.31	8.37	8.70	8.93	8.94	8.41
8	34	8.36	8.39	8.39	8.60	8.92	9.07	8.58
8	35	8.41	8.32	8.39	8.46	8.94	9.05	8.55

Table A5-1(cont):pH

HRT	Day	1	2	3	4	5	6	Effluent
6	39	8.43	8.41	8.40	8.59	8.95	9.16	8.66
6	40	8.47	8.59	8.52	8.59	9.33	9.12	8.79
6	41	8.52	8.51	8.50	8.55	9.30	9.21	8.97
6	45	8.50	8.50	8.52	8.53	9.25	9.37	8.98
6	46	8.51	8.54	8.52	8.61	9.30	9.37	8.94
6	47	8.45	8.53	8.50	8.70	9.29	9.36	8.91
6	48	8.40	8.53	8.44	8.88	9.20	9.35	8.91
6	49	8.45	8.54	8.46	8.82	9.00	9.24	8.70
6	52	8.48	8.54	8.48	8.76	8.80	8.95	8.71
6	53	8.49	8.55	8.47	8.70	8.65	8.96	8.79
6	54	8.47	8.53	8.50	8.71	8.63	8.95	8.80
6	55	8.48	8.50	8.51	8.68	8.67	8.90	8.89
6	56	8.50	8.49	8.49	8.67	8.70	9.00	9.03
4	59	8.49	8.47	8.50	8.62	8.68	9.03	8.99
4	60	8.48	8.48	8.52	8.60	8.69	9.00	8.85
4	61	8.45	8.46	8.49	8.62	8.70	9.00	8.80
4	62	8.44	8.48	8.48	8.52	8.73	8.90	8.78
4	63	8.45	8.50	8.50	8.56	8.70	8.92	8.93
4	66	8.47	8.47	8.48	8.57	8.63	8.90	8.95
4	67	8.47	8.46	8.47	8.52	8.64	8.92	9.01
4	68	8.45	8.45	8.45	8.56	8.62	8.90	8.86
4	69	8.46	8.47	8.44	8.50	8.58	8.86	8.83
4	70	8.48	8.49	8.43	8.50	8.57	8.87	8.80
2	73	8.49	8.50	8.41	8.43	8.50	8.88	8.79
2	74	8.49	8.49	8.42	8.45	8.51	8.90	8.80
2	75	8.48	8.50	8.42	8.50	8.53	8.90	8.89

APPENDIX 6: METHANE GAS PRODUCED

Table A6-1: Methane gas produced

HRT	Day	Methane (cm^3)
8	1	76.00
8	2	33.90
8	3	0.00
8	4	0.00
8	5	0.00
8	6	0.00
8	7	0.00
8	8	11.30
8	9	11.30
8	10	79.16
8	11	85.00
8	12	11.30
8	13	11.30
8	14	11.30
8	15	11.30
8	16	46.98
8	17	45.57
8	18	45.23
8	19	32.23
8	20	24.78
8	21	68.79
8	22	34.79
8	23	68.34
8	24	64.89
8	25	34.76
8	26	56.54
8	27	45.24
8	28	43.78
8	29	30.15
8	30	22.61
8	31	25.67
8	32	32.23
8	33	34.76
8	34	24.78
8	35	26.34

Table A6-1(cont): Methane gas produced

HRT	Day	Methane (cm^3)
6	39	25.00
6	40	25.00
6	41	52.78
6	45	54.34
6	46	67.46
6	47	59.65
6	48	60.91
6	49	66.86
6	52	65.90
6	53	62.77
6	54	65.23
6	55	64.09
6	56	63.79
4	59	60.09
4	60	63.89
4	61	65.88
4	62	65.43
4	63	64.77
4	66	64.76
4	67	59.98
4	68	58.90
4	69	59.98
4	70	60.45
2	73	10.10
2	74	12.88
2	75	11.65

APPENDIX 7: GANTT CHART

Table A7-1: Gantt chart for FYP I

No	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Title	X							Mid Semester Break							
2	Research (Literature Review)		X	X	X											
3	Design of ABR Reactor				X											
4	Find potential Fabrication company					X										
5	Fabrication of Reactor						X									
6	Preparation of Progress Report I & II					X										
7	Submission of Progress Report I & II						•									
8	Wastewater Analysis (pH, COD)									X						
9	Wastewater Analysis (Total Alkalinity)										X					
10	Wastewater Analysis (TKN)											X				
11	Wastewater Analysis (TOC,BOD5)												X			
12	Preparation of Interim Report											X	X			
13	Submission of Interim Report													•		
14	Oral Presentation														•	

• **Milestone**

X **Process**

Table A7-2: Gantt chart for FYP II

No	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Assembly of fully functional ABR system		X						Mid Semester Break							
2	Test run of the ABR system			X												
3	Operation of ABR system (Varying HRT)				X	X	X	X		X	X	X				
4	Submission of Progress Report I							•								
6	Effluent analysis				X	X	X	X		X	X	X				
7	Data collection & analysis				X	X	X	X		X	X	X	X			
8	Submission of Progress Report II									•						
9	Poster Preparation										X	X				
10	Poster Exhibition												•			
11	Preparation of Dissertation												X	X	X	
12	Submission of Dissertation (soft bound)													•		
13	Oral Presentation															•
14	Submission of Dissertation (hard bound)															•

• **Milestone**

X **Process**

APPENDIX 8: PICTURES

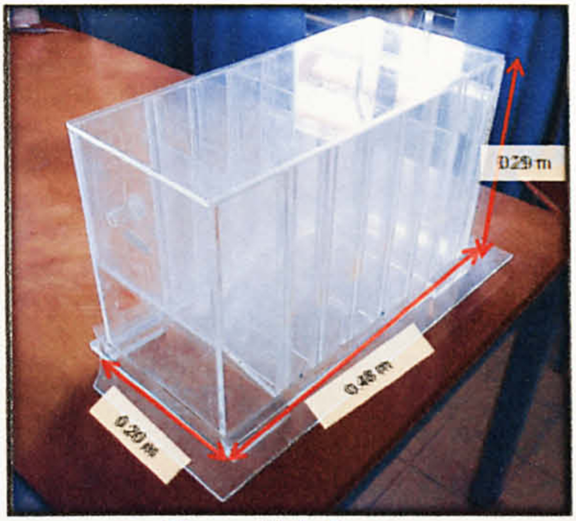

Figure A8-1: Reactor

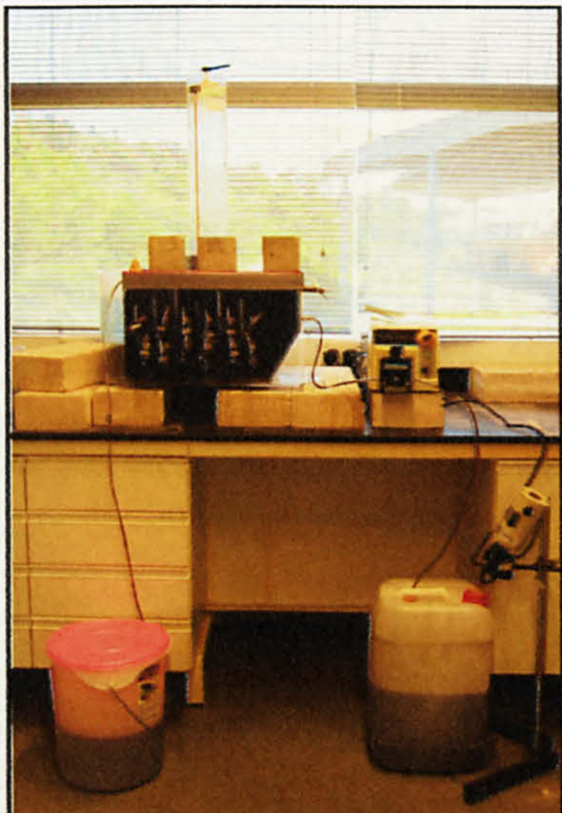

Figure A8-2: ABR system