COMBINED ASBR AND ADSORBENT FOR BIOLOGICAL TREATMENT OF DILUTED POME

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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 references and acknowledgements, and the original work contained herein have not been undertaken or done by unspecified source or persons. I also certify that all information sources or literature included in the study are indicated in this report.

……………………………

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SEPTEMBER 2011

CERTIFICATION OF APPROVAL

Combined ASBR and Adsorbent for Biological Treatment of Diluted POME

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A project dissertation submitted to the:
Civill Engineering Programme
Universiti Teknologi PETRONAS

In partial fulfillment of the requirement for the:
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
SEPTEMBER 2011

ABSTRACT

Palm Oil Mill Effluent (POME) and Empty Fruit Bunches (EFB) are two most abundant wastes produced in a palm oil mill. However, current method of treatment of POME and composting of EFB are insufficient in promoting an environmental friendly strategy for future sustainability. POME is believed to be one of the major contributors towards river pollution in Malaysia due to its high strength constituents. The EFB on the other hand, has also becomes an issue regarding the massive solid wastes production that causes insufficient amount of landfill for its disposal. Therefore, it is very crucial to find other solution to cater these issues effectively. This study will determine the COD removal of the ASBR, ASBR+PAC and ASBR+EFB combined system in treating diluted POME. It will also determine the potential of EFB to function as adsorbent in the ASBR combined system. Three conical flasks; R1, R2 and R3 with working volume of 1.0 L are filled with 700 mL of sludge and 300 mL of POME. They are operated under ASBR condition. R1 is as the control condition; operated without any addition of PAC or EFB. R2 is added with 3 g/L dose of commercial PAC while R3 will be added with 3g/L of EFB. The three ASBRs are operated with Cycle Time (CT) of 6 hours; 4 cycles per day with Hydraulic Retention Time (HRT) of 24 hours. The Cycle Time consists of feeding (15 minutes), reacting (255 minutes), settling (60 minutes), decanting (15 minutes) and idling (15 minutes) phase. All three reactors have similar Organic Loading Rate (OLR) of 1.608 kg COD/m^3/day in order to compare the treatment efficiency of all three conditions. The three reactors are operated under room temperature with the pH maintained between pH of 6 to 8. The initial Food to Microorganism Ratio (F/M) is 0.1. From the experiments, R1 (ASBR) manages to obtain highest total COD removal efficiency of 91.4% at day 41 while R2 (ASBR+PAC) managed to achieve up to 95.1% removal for the same day. The highest COD removal efficiency for R3 (ASBR+EFB) however is slightly lower at 85.8% in day 29. This study proves that EFB alone cannot contribute towards better wastewater constituent adsorption.

ACKNOWLEDGEMENT

In the Name of Allah, The Most Merciful and The Most Compassionate.

Alhamdulillah. Thank you Allah SWT for granting me opportunity, health and ability to complete this Final Year Project on 'Combined ASBR and Adsorbent for Biological Treatment of Diluted POME'. This project is a partial fulfilment In partial fulfilment of the requirement for the Bachelor of Engineering (Hons.) in Civil Engineering for September 2011 semester.

First of all, I would like to express my highest appreciations to Dr. Amirhossein Malakahmad for supervising me throughout the completion of this project A tremendously thanks to him upon his care, effort and commitment to make sure that any difficulties or critical situations faced during the implementation of this project can be successfully overcame. The advices, patient, encouragement and support that have been given to me during this period are greatly appreciated too.

I would also like to seize this opportunity to thank Madam Syukriyah Ishak and Mr. Taimur Khan for their kindness in sharing their knowledge and opinion for the betterment of this project. Their passion and deep knowledge in environmental engineering field are very admirable. Not to forget, all lecturers and technicians who have directly or indirectly contribute towards the implementation of this project. Thank you for all your support.

I would also like to express my deepest appreciation to both of my parents and all of my friends who have given me unending moral support and encouragement throughout the whole time.

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ABBREVIATIONS AND NOMENCLATURES

ASBR	Anaerobic Sequencing Batch Reactor
BOD	Biochemical Oxygen Demand
BOD_5	Biochemical Oxygen Demand at Day 5
COD	Chemical Oxygen Demand
CT	Cycle Time
EFB	Empty Fruit Bunches
F/M	Food to Microorganism Ratio
HRT	Hydraulic Retention Time
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
N	Nitrogen
OLR	Organic Loading Rate
P	Phosphorus
PAC	Powdered Activated Carbon
POME	Palm Oil Mill Effluent
SBR	Sequencing Batch Reactor (Aerobic)
SVI	Sludge Volume Index
TSS	Total Suspended Solids

CHAPTER 1
INTRODUCTION

1.1 PROJECT BACKGROUND

Malaysia currently accounts for 39 % of world palm oil production and 44% of world exports (MPOC, 2011). Palm Oil Mill Effluent (POME) is the wastewater generated from the palm oil processing and extraction industries. The wastewater or POME is a major source of pollution to nearby water bodies due to its large amount generated and high strength (Chaiprapat S. & Laklam T., 2011). Therefore, effective treatment of POME is very crucial since it is classified as a high strength wastewater which poses very high amount of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) along with significant amount of oil and grease and other constituents.

Anaerobic Batch Sequencing Reactor (ASBR) is one of the biological treatment methods for wastewater; especially for high-strength wastewater. It has been widely used in treating wastewater from slaughterhouse and food processing industries. The operation of ASBRs consist of four steps, namely as feed, react, settle, and decant/effluent withdrawal stage (Metcalf & Eddy, 2003). Anaerobic digestion provides a viable alternative to landfill for category 3 wastewater; these include food industry wastes, domestic wastes and some abattoir wastes (Ward et al., 2007).

ASBR is one of the alternatives in promoting an environmental-friendly wastewater treatment system. Anaerobic treatment provides a method of reducing pollution from agricultural and industrial operations while at the same time offsetting the operations' usage of fossil fuels (Chen et al., 2008). Other than that, the production of biogas through anaerobic digestion offers significant advantages over other forms of waste treatment as less biomass sludge is produced in comparison to aerobic treatment technologies (Ward et al., 2007). Thus, ASBR has the potential to offer high digestion rate and good stability of operation for POME treatment (Marzieh Badei et al., 2011). Other advantages of ASBR application in wastewater treatment can be listed as following:

- As the decomposition occurs in a form of container (reactor), the methane gas which is harmful towards the environment can be prevented from being released into the atmosphere (Ward et al., 2007).
- Energy from methane gas combustion can replace the consumption of current highly-demanded fossil fuel as (Ward et al., 2007).
- Less energy demands, minimum sludge formation, no unpleasant odour and production of methane due to efficient breakdown of organic substances by anaerobic bacteria (Rincon et al., 2006)
- Greenhouse gas emission reduction and contributes in energy production (Rodrigues et al., 2010)

The Empty Fruit Bunch (EFB) on the other hand, is the product of Fresh Fruit Bunch (FFB) stripping process; where the fruits are separated from their bunch. According to Siew (2011), the typical flow of palm oil milling processes comprise of sterilization, stripping, digestion, pressing, clarification, purification, drying and storage. The impacts of EFB dumping include this following:

- Insufficient amount of landfill to accommodate all EFB (Md. Zahangir et al., 2009)
- Burning of EFB produces bad emission into atmosphere (Md. Zahangir et al., 2009)

1.2 PROBLEM STATEMENT

Parveen (2010) stresses that the Environmental Quality (prescribed premises) Crude Palm Oil Regulation 1977, promulgated under the enabling powers of Section 51 of the Environmetal Quality Act (EQA), are the governing regulations and contain the effluent discharge standards as presented in **Table 1.1.**

Table 1.1: Effluent Discharge Standards for Crude Palm Oil Mills under the Environmental Quality Act 1974

Parameters	Unit	Parameter Units	Remarks
Biochemical Oxygen Demand*	mg/L	100	
Chemical Oxygen Demand (COD)	mg/L	400	
Total Suspended Solids (TSS)	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	℃	45	

* BOD_3; 3 days at 30℃

(Source: Chan et al., 2010)

In Malaysia, the conventional treatment method of Palm Oil Mill Effluent (POME) is the ponding systems which are known as waste stabilization pond and have been applied since 1982 (Parveen et al., 2010). The most frequently used method is biological treatments, which consist of anaerobic and facultative pond systems (Chan et. Al, 2010). However, the methane gas produced from the ponding system will eventually released into air; which is considered bad since methane is one of the greenhouse gases.

However, the application of ASBR in POME treatment is still rarely used since there is lack of development and studies regarding the ASBR itself (Mulligan & Gibbs, 2003). Therefore, the performance of ASBR in treating raw POME into required standard of discharge as presented in **Table 1.1** will be examined throughout this study. For this purpose, there are some parameters that should be identified (Marzieh Badei et al., 2011):

1. Organic Loading Rate (OLR)
2. Cyclic Time (CT)
3. Solid Retention Time (SRT)
4. Hydraulic Retention Time (HRT)
5. pH
6. Temperature
7. Initial Food to Microorganism Ratio (F/M)

Nowadays, there are a few strategies taken in order to reduce the amount of EFB transported into the landfills. The most favoured method is composting. Therefore, this study will also include the study in evaluating the potential of EFB as Powdered Activated Carbons (PAC) to be used in the ASBR of POME treatment system.

1.3 OBJECTIVES

The aims of the study are to determine the performance of ASBR, ASBR-PAC and ASBR-EFB combined system in Palm Oil Mill Effluent (POME). Thus, these objectives must be achieved:

1. To determine the COD removal efficiency of the ASBR, ASBR+PAC and ASBR+EFB combined system.
2. To determine the potential of EFB to be used as adsorbent in ASBR combined system.

CHAPTER 2

LITERATURE REVIEW

2.1 PALM OIL MILL EFFLUENT (POME) CHARACTERISTICS

In order to efficiently treat the POME, the significant constituents and characteristics of raw POME must be identified. **Table 2.1** provides the list and value for POME characteristics gathered from various sources:

Table 2.1: Characteristics of the Raw Palm Oil Mill Effluent (POME)

Parameters	Marzieh Badei et al. (2011)	Parveen et al. (2010)	K. Vijayaraghavan et al. (2007)	Puetpaiboon & Chotwattanasak (2004)
Sample Origin	Dengkil, Malaysia	-	Banting, Malaysia	Krabi, Thailand
Temperature (°C)	-	80-90	84 ± 1	42 ± 1
pH	4.5	4.7	3.5 ± 0.1	4.75 ± 0.05
Total Solids (mg/L)	720 000	40 500	-	-
Total Suspended Solids, TSS (mg/L)	-	18 000	18 479	-
Total Volatile Solids, TVS (mg/L)	48 631	34 000	-	-
Mixed Liquor Suspended Solids, MLSS (mg/L)	26 385	-	-	-
Mixed Liquor Volatile Suspended Solids, MLVSS (mg/L)	19 604	-	-	-
Chemical Oxygen Demand, COD (mg/L)	100 000	50 000	55 775	31 687 ± 6 371
Biochemical Oxygen Demand, BOD_5 (mg/L)	-	-	25 545	20 830 ± 2 861
Total Carbohydrate (mg/L)	24 686	-	-	-
Total Kjeldahl Nitrogen, TKN (mg/L)	970	750	-	-
Alkalinity (mg $CaCO_3$/L)	-	-	-	1 308 ± 165

Total Phosphorus (mg/L)	470	-	-	-
Total Nitrogen (mg/L)	-	-	711	-
Oil & Grease (mg/L)	-	4 000	8 020	-
Ammonia-Nitrate NH_3-N (mg/L)	-	35	36	-
Volatile Fatty Acid, VFA (mg/L)	-	-	-	6 902 ± 339

From the table, the typical characteristics of POME as high-strength wastewater can be clearly observed. The main highlights are the values of COD and TSS which are very high. Considering a case of raw POME with COD of 50 000 mg/L, in order to abide by the Department of Environment regulation for POME discharge limit, the POME treatment must be able to contribute up to 99.2% of removal efficiency.

2.2 POME TREATMENT SYSTEMS

Palm Oil Mill Effluent (POME) is the main concern for environmentalist nowadays. Therefore, various treatment systems have been analysed and studied in order to replace the conventional method of POME treatment using anaerobic and facultative ponds which are not environmental friendly. **Table 2.2** below presents various anaerobic treatment systems of POME and their typical performance (Poh and Chong, 2008):

Table 2.2: POME Anaerobic Treatment Systems and Their Typical Performance

System	OLR (kg COD/ m^3.day)	HRT (day)	Methane Composition (%)	COD Removal Efficiency (%)
Anaerobic Pond	1.40	40	54.4	97.8
Anaerobic Digester	2.16	20	36	80.7
Anaerobic Filtration	4.50	15	63	94.0
Fluidized Bed	40.00	0.25	N/A	78.0
UASB	10.63	4	54.2	98.4
UASFF	11.58	3	71.9	97.0
CSTR	3.33	18	62.5	80.0

*N/A: No data available
*UASB: Up-flow Anaerobic Sludge Blanket
*UASFF: Up-flow Anaerobic Sludge Fixed-film
*CSTR: Continuous Stirred Tank Reactor

(Source: Poh and Chong, 2008)

In term of anaerobic digesters (AD) application, Zainuri Busu et al. (2010) have compiled together the performance of various AD obtained from various sources as shown in **Table 2.3**:

Table 2.3: Types of Anaerobic Digester and Their Typical POME Treatment Performance

Type of Reactor	HRT (day)	Organic Loading Rate (kg COD/ m^3/day)	COD Removal Efficiency (%)
Up-flow Anaerobic Sludge Fixed Film	1.5	17.47	90.2
Digester Tank	10	5.55	>90
Modified Anaerobic Baffled	3.0	5.33	77.3
Anaerobic Hybrid	3.5	16.20	92.3
Anaerobic Filter	1.0	10.00	>90
Anaerobic Fluidized Bed	0.25	10.00	>90
Up-flow Anaerobic Sludge Blanket	4.0	10.60	96
Immobilized Cell	6.2	10.60	96.2
Stirred Tank	5.6	12.60	97

(Source: Zainuri Busu et al., 2010)

2.3 APPLICATION OF ASBR IN WASTEWATER TREATMENT

There are also various studies regarding the application of Anaerobic Sequencing Batch Reactor (ASBR) in other types of wastewater. **Table 2.4** summarizes the finding on ASBR application on various wastewater treatments. Each study involves different scale of reactors, experimental setup and initial parameters which result in different findings. However, generally we can observe that the removal efficiency of COD, Scod or TSS are very high for the treated wastewater which proves that ASBR is suitable for high-strength wastewater treatment.

Table 2.4: Application of ASBR in Various Wastewater Treatments

Source	Farina R. Et al.; 2004	Rodrigues et al.; 2010	Shao X. Et al.; 2007	Angenent et al.; 2002	Masse et al., 2000	Andres et al., 2009	Marzieh Badei et al. 2011
Type of Wastewater	Distillery	Dairy-based	Brewery	Swine	Slaughter-house	Low strength waste water with high TSS	Palm Oil Mill Effluent
Reactor Specification	Pilot scale reactor (6m length, 0.194m diameter) 180L working volume	Cylindrical acrylic reactor 8L working volume	2 pilot scale ASBR 45L working volume	Two parallel glass reactors 5L working volume	Four plexi-glass digesters Mixing 42L working volume	Double-jacked reactor 4L working volume	Laboratory scale ASBR 3L working volume
Mixing	Mixed with mixed liquor recirculation	Stirred by magnetic stirrer	-	Intermittently mixed with biogas recirculation	Intermittently mixed with biogas recirculation	Mixed with mixed liquor recirculation	Intermittently mixed with liquid recirculation
Initial F/M	-	0.3 kg COD/kg VS.day	-	0.05 kg COD/kg VS.day	-	-	-
Hydraulic Retention Time (d)	-	40	1	40	-	-	3
Cycle Time (hr)	8	-	8	24	48	1	24
Feed	0.5 hr	-	-	1 min	1 hr	-	0.5 hr
React	-	-	-	23.2 hr	41 hr	-	22 hr
Settle	-	-	-	45 min	-	-	1.0 hr
Decant	0.5 hr	-	-	2-5 min	-	-	0.5 hr
Organic Loading Rate	4 kg COD/ m^3.day	-	1.5 – 5.0 kg COD/ m^3.day	0.5kg VS/ m^3.day	11.5 kg COD/ m^3.day	0.4 – 0.8 kg COD/ m^3.day	6.6 kg COD/ m^3.day
Removal Efficiency	70-80 % sCOD	89% sCOD 53% tCOD 89% TS 91% VS	90% COD	High	95-97 % COD 73-95% VS 87-91% TSS	50-60 % organics	37% tCOD 50% sCOD
Biogas Production	-	0.25 m^3/kg sCOD	0.48 m^3/kg COD	0.46 m^3/kg VS	0.54-0.67 m^3/kg VS	-	6.7 L H_2/L/d

2.4 FACTORS AFFECTING THE PERFORMANCE OF ASBR .

In order to ensure the system achieves optimum result, there are some parameters that must be taken into account as they have significant impact towards the biodegradation process of the wastewater.

2.4.1 pH

According to Poh and Chong (2008), optimum pH for anaerobic digestion to take place ranges from 6.8 to 7.2. This is because, anaerobic microbial are very sensitive towards the pH of the surrounding that it will then affect the methano-genesis or the production of methane. Chen et al. (2008) also agrees that pH affect the growth of the anaerobic microbial community. However, since hydrolysis is optimum at pH 5.5 to 6.5, there are systems where both process involved in anaerobic digestion; namely the hydrolysis and methano-genesis to be separated in two-stage processes (Ward et al., 2008).

2.4.2 Mixing

Mixing provides contact between the wastewater substrate and the anaerobic microbial. Thus, it will improve the ASBR performance in treating wastewater with high organics loading (Poh and Chong, 2008). Mixing also ensure efficient transfer of wastewater substrates for the active anaerobic microbial biomass that will efficiently release gas bubbles trapped between the medium and prevent sedimentation of denser particulate materials (Ward et al., 2008)

2.4.3 Operating Temperature

Anaerobic digestion under thermo-philic condition (55 °C and above) will produce more methane gas that will be beneficial for energy harvesting in the future (Poh and Chong, 2008). However, due to practicality, most of anaerobic treatment implemented in Malaysia is under meso-philic condition (around 37 °C). Besides, it is much difficult to maintain and to control a thermo-philic condition as the microbial metabolism is dependent on the temperature change (Chen et al. 2008). However, Ward et al. (2008) states that there are lots of opinion and conflicting results regarding the anaerobic digestion performance for both condition.

2.4.4 Organic Loading Rate

A good balance between Organic Loading Rate (OLR) and Hydraulic Retention Time (HRT) is needed to ensure sufficient contact between wastewater substrates and the anaerobic microbial. Too much OLR and short HRT will reduce methano-genesis thus reducing the ASBR performance (Poh and Chong, 2008). Based on Metcalf & Eddy (2003), the OLR for ASBR ranged from 1.2 to 2.4 kg COD/m^3/day. Thus, this range is used throughout the study. As mentioned earlier, the OLR for the ASBR operation is 1.608 kg COD/m^3/day.

2.5 APPLICATION OF POWDERED ACTIVATED CARBON (PAC)

Powdered Activated Carbon (PAC) is an additional substance added into a biological treatment in order to enhance the adsorption of the wastewater constituent as to improve the efficiency of the treatment. In this study, the operating parameter will not be varied since the main objective is to see the impact of improvement in biological treatment of the ASBR by the addition of the PAC. PAC has been involved in various studies for various purposes that include:

1. Adsorption of phenol (Md. Zahangir et al., 2009)
2. Treatment of semi-aerobic landfill leachate (Nasrin A. et al., 2007)
3. Treatment of landfill leachate in Sequencing Batch Reactor (SBR) process (Shuokr Q.A., et al., 2011)

Table 2.5 summarizes the findings from all the studies.

Table 2.5: Applications of AC in Various Studies

Source	Type Of Wastewater/Solution	Purpose of Activated Carbon	Materials of Activated Carbon	Properties of Activated Carbon	Dosing (mg/L)	Parameters Removed	Removal Efficiency (%)
Md. Zahangir et al., 2009	Phenol aqueous solution	Adsorption of phenol	Palm Oil Empty Fruit Bunches PAC	Activated at 900 °C, for 15 minutes and 0.1L/min CO_2 gas 60 minutes contact time		Phenol	97.36
	Phenol aqueous solution	Adsorption of phenol	Commercial PAC	60 minutes contact time		Phenol	98.78
Nasrin A. et al., 2007	Semi-aerobic landfill leachate	Improvement of aerobic biological treatment	PAC sized 75-150 µm	-		COD Colour NH_4-N	49.00 50.00 69.00
Shuokr Q.A., et al., 2011	Landfill leachate	Improvement of aerobic Sequencing Batch Reactor (SBR) treatment	PAC sized 75-150 µm	-	10	COD Colour NH_3-N TDS	69.80 82.30 99.66 17.80

From the table, we can observe that the performance of PAC in wastewater treatment is dependable.

CHAPTER 3

METHODOLOGY

3.1 SAMPLING AND CHARACTERIZATION

The raw POME sample used throughout this study was collected from the final discharge point of Palm Oil Mill, FELCRA Nasaruddin, Bota, Perak. The aerobic sludge sample was collected from the Universiti Teknologi PETRONAS Sewage Treatment Plant (STP) which is to be cultured as anaerobic sludge throughout this project. The samples collected were stored in cool room at 4 °C to minimize self-biodegradation of the wastewater substrate. EFB was also collected from the palm oil mill and further processed to produce powdered activated carbon (PAC) that is used throughout this study. The POME was diluted with factor of 1:50 for further application in the ASBRs. The POME and concentrated sludge characterization was carried out according to the Standard Methods for Examination of Water and Wastewater (APHA, 1992) and summarized as in **Table 3.1** below.

Table 3.1: Characteristics of POME and Anaerobic Sludge Collected From the Sewage Treatment Plant

Parameters	Raw POME	Diluted POME
Chemical Oxygen Demand (COD)	57 967 mg/L	1340 mg/L
Biochemical Oxygen Demand (BOD$_5$)	39 420 mg/L	920 mg/L
BOD$_5$/COD	0.68	0.69
Total Suspended Solids (TSS)	16800 mg/L	910 mg/L
Temperature	80 °C	30 °C
pH	4.82	6.22
Total Phosphorus	420 mg/L	21.7 mg/L
Total Ammonia	370 mg/L	5.2 mg/L
Mixed Liquor Suspended Solids (MLSS)	26067 mg/L	
Mixed Liquor Volatile Suspended Solids (MLVSS)	14000 mg/L	

3.2 EFB PREPARATION

The raw EFB obtained from FELCRA Nasaruddin was washed several times using tap water and dried at 105 ^{0}C for 24 hours in an oven to remove the water content (dehydration) until it reaches constant weight. The dried sample was then grinded to size $\leq$0.5 mm and stored at room temperature. It was then sieved to obtain EFB with size ranged from 63 to 150 μm.

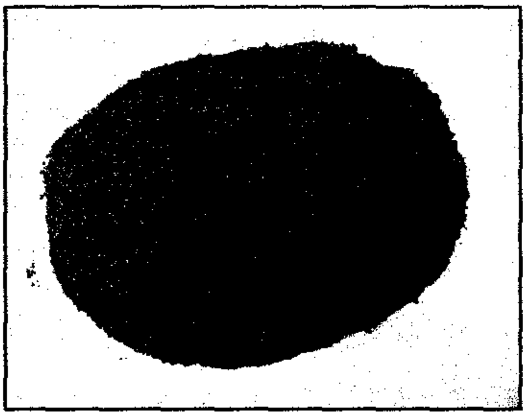

Figure 3.1: Empty Fruit Bunches (EFB)

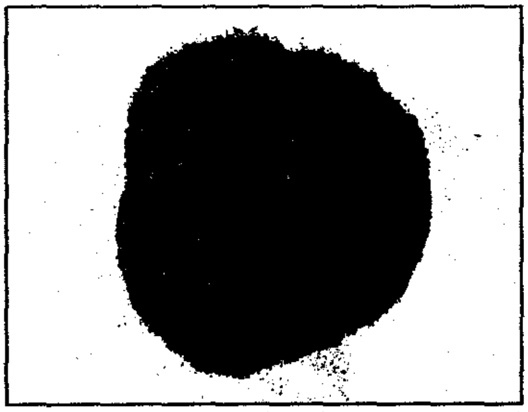

Figure 3.2: Commercial Powdered Activated Carbon (PAC)

3.3 ASBR SETUP

Three conical flasks with working volume of 1L each are used throughout this study. The conical flasks are equipped with rubber stoppers to prevent air from entering the systems so that anaerobic condition can be developed. Holes were drilled through the rubber stopper for these purposes:

1. Influent flow into the reactor
2. Effluent flow out from the reactor
3. Sludge decantation

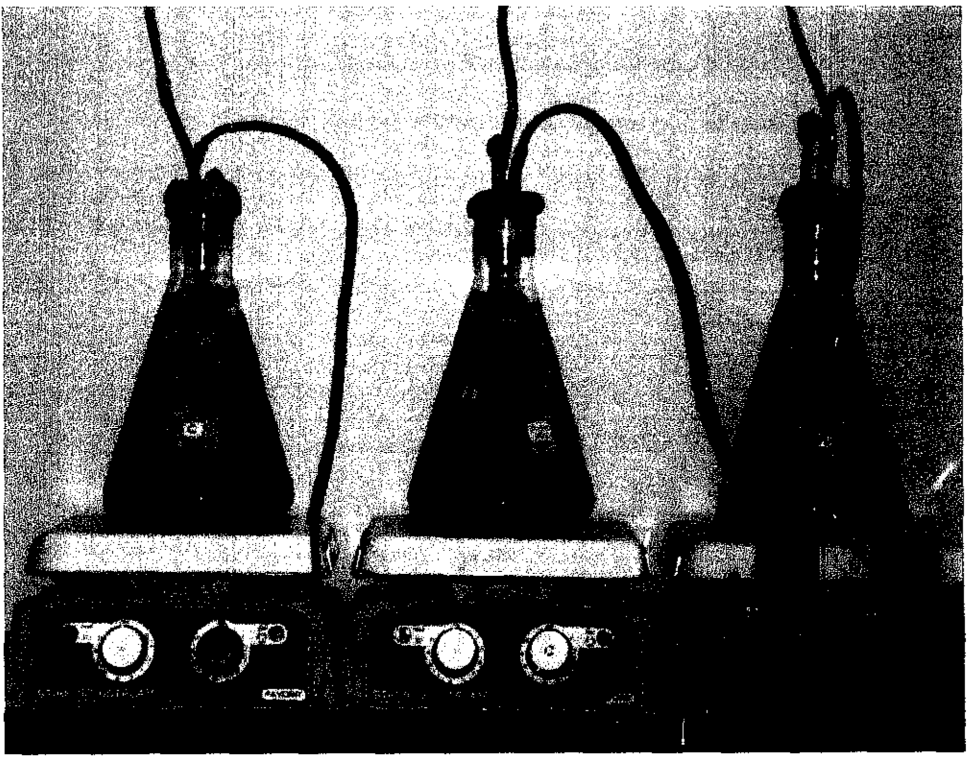

Figure 3.3: ASBR Setup
(From left: ASBR+EFB, ASBR+PAC, ASBR)

3.4 EXPERIMENTAL PROCEDURES

3.4.1 ASBR Operation

Three conical flasks; R1, R2 and R3 with working volume of 1.0 L are filled with 700 mL of sludge and 300 mL of POME. They are then operated under ASBR condition. R1 is as the control condition; operated without any addition of PAC or EFB. R2 is added with commercial PAC while R3 will be added with EFB. The three ASBRs are operated with Cycle Time (CT) of 6 hours; 4 cycles per day with Hydraulic Retention Time (HRT) of 24 hours. The Cycle Time consists of feeding (15 minutes), reacting (255 minutes), settling (60 minutes), decanting (15 minutes) and idling (15 minutes) phase. Magnetic stirrers are used for the reaction phase of the ASBR. All three reactors have similar Organic Loading Rate (OLR) of 1.608 kg COD/m^3/day in order to compare the treatment efficiency of all three conditions. The three reactors are operated under room temperature with the pH maintained between pH of 6 to 8.

Feeding and decanting volume, V = 0.3 L
Feeding and decanting period, t = 15 minutes
Feeding and decanting rate, Q = 0.3/15
= 0.02 L/min
= 20 mL/min

Total volume = 1.0 L
Feeding and decanting = 0.3 L/cycle
HRT = 1.0/0.3
= 4 cycles
Since total cycle time = 6 hours
HRT = 4 X 6
= 24 hours

The influent is fed into the ASBR using a peristaltic pump with 20 mL/min rate for every cycle. After feeding is completed, reaction phase takes place. After 255 minutes (1 hour and 15 minutes), the mixing stops to allow for settling to take place for 60 minutes. After that, peristaltic pump is used to decant the supernatant at 20 mL/min rate. This is followed by 15 minutes of idle for sludge wasting. The processes are repeated until stable results are obtained.

Table 3.3 shows the operating condition for R1, R2 and R3.

Table 3.2: Operating Condition for R1, R2 dnd R3

Reactor	R1	R2	R3
Condition	ASBR	ASBR + PAC	ASBR + EFB
HRT (hr)	24	24	24
Cycle Time (hr)	6	6	6
Organic Loading Rate (kg COD/m^3/day)	1.608	1.608	1.608
pH	6-8	6-8	6-8
Initial F/M (kg VSS/kg COD/day)	0.1	0.1	0.1

3.4.2 PAC Dosage

The dosage of PAC applied is 3 g/L. As to feed the PAC into R2 and R3, the PAC and EFB are mixed and diluted into 300 mL influent that will flow into the ASBRs during the first cycle for everyday. The amount of PAC and EFB added to the system is calculated as following:

Dosage = 3 g/L POME
Volume of POME = 0.3 L/cycle × 4 cycle
= 1.2 L
Total addition = 3 × 1.2
= 3.6 g

3.4.3 Nutrient Supply

As to optimize the ASBR operation, nutrients are supplied to fulfil the ideal COD:N:P ratio to be 300:5:1 during the start-up and 600:5:1 during steady-state operation (Metcalf & Eddy, 2003). In order to obtain the amount of nutrients to be added; Total Phosphorus and Total Nitrogen of the diluted POME must be determined beforehand.

Diluted POME:

COD = 1340 mg/L
Total Ammonia = 5.2 mg/L
Total Phosphate = 21.7 mg/L

For start-up operation

Since $\frac{COD}{N} = \frac{300}{5} = 60$

Therefore N $= \frac{COD}{60}$

$= \frac{1340}{60}$

= 22.3 mg/L

N available = 5.2 mg/L
N required = 22.3 – 5.2
= 17.1 mg/L

Since $\frac{COD}{P} = \frac{300}{1} = 300$

Therefore N $= \frac{COD}{300}$

$= \frac{1340}{300}$

= 4.46 mg/L

N available = 21.7 mg/L
N excess = 21.7 – 4.46
= 17.24 mg/L

3.4.4 Effluent Parameters Measurement

Effluent parameters test are conducted based on the Standard Methods for Examination of Water and Wastewater (APHA, 1992). This includes the determination of these following parameters:

1. pH
2. Chemical Oxygen Demand (COD)
3. Mixed Liquor Suspended Solids (MLSS)
4. Mixed Liquor Volatile Suspended Solids (MLVSS)
5. Sludge Volume Index (SVI)

pH and COD are measured for every 24 hours while MLSS, MLVSS and SVI are measured for every 48 hours sample.

Sludge Volume Index (SVI)

The sludge sample from both reactors is tested for every two days. For the Sludge Volume Index (SVI), 10 mL of MLSS (sludge) is settled for 30 minutes in a 10 mL graduated cylinder. The volume occupied by the settlement is then converted in term of settlement per one liter. The SVI is calculated as:

$$\text{SVI} = \frac{Volume\ Occupied\ (\frac{mL}{L})}{MLSS\ (\frac{mg}{L})}$$

Removal Efficiency

On the other hand, removal efficiency is calculated as following:

$$\text{Removal Efficiency (\%)} = \frac{Ci - Cf}{Ci} \times 100\%$$

where Ci is the initial concentration (influent) while Cf is the final concentration (effluent).

Chemical Oxygen Demand (COD) Determination

Chemical Oxygen Demand (COD) can be defined as the oxygen requirement for both organics and non-organics content in wastewater to be oxidized. Effluent sample is diluted in factor of 1:10 in a volumetric flask for preparation of COD measurement samples. One blank sample is prepared by inserting 2 mL of distilled water into COD vials which will be used for calibrating purpose during the COD reading stage. Three COD vials are used for each diluted effluent sample from both ASBRs in other to increase precision of the outcome. The filled vials are then mixed before being inserted into the COD reactor at temperature of 150 °C for 2 hours. After 2 hours, the samples are cooled down to room temperature. Then, the blank sample is wiped clean and inserted into the spectrophotometer slot. It is used to set the 'ZERO' reading in the spectrophotometer as to calibrate it. The remaining COD vials that contain the effluent sample are also wiped clean and inserted into the spectrophotometer in order to get the COD reading in mg/L. The final COD measurement can be calculated as:

$$\text{Final COD} = \frac{\text{COD Reading in Spectrophotometer}}{\text{Dilution Factor}}$$

Mixed Liquor Suspended Solids (MLSS) Determination

MLSS determination procedures are quite similar with the determination of Total Suspended Solids. Glass Micro-fibre filter disk is used to avoid it from burning during MLVSS determination afterwards. One day before the MLSS test is conducted; the filter disks are washed with distilled water. They are then put inside aluminium dishes and kept in oven at 105 °C for 24 hours to remove the moisture content. Then, the dried filter disks are then stabilized inside a desiccator. After that, W1 which is the weight of the dried filter disks together with the aluminium dish without sample is measured. 2 mL of sludge withdrawn from the ASBRs during mixing stage is diluted into a 100 mL volumetric flask. Each sludge sample consists of three 100 mL diluted sludge. The diluted sludge is then poured and vacuumed trough the filter disk by the pump. Distilled water is used to wash out the leftover of sludge that may smudge the filtration apparatus. The filter disks are then dried at 105 °C for one hour before being stabilized inside the desiccator. After that, W2 is measured as the weight of the filter disk and aluminium dish with dried sample. MLSS concentration is calculated as:

$$\text{MLSS} = \left(\frac{W2-W1}{Volume\ of\ Diluted\ Sample \times Dilution\ Factor}\right)\left(\frac{mg}{L}\right)$$

Mixed Liquor Volatile Suspended Solids (MLVSS) Determination

The filter disks from MLSS determination are burned at 550 °C for 15 minutes inside the furnace. After 20 minutes, the filter disks are stabilized inside the desiccator. W3 is then measured as the weight of the filter disk and aluminium dish with samples after burned at 550 °C.

$$\text{MLVSS} = \left(\frac{W3-W1}{Volume\ of\ Diluted\ Sample \times Dilution\ Factor}\right)\left(\frac{mg}{L}\right)$$

3.4.5 Microbiological Identification

Microbiological identification was done regularly in order to determine the most abundant microorganism species in the ASBRs. This is important in ensuring that the systems are able to operate under anaerobic condition and develop anaerobic microorganism growth. The mixed liquor samples from each reactor were analyzed under a microscope from 40 to 100 times magnification.

CHAPTER 4:

RESULTS AND DISCUSSION

4.1 EXPERIMENTAL RESULTS

R1 (ASBR) and R2 (ASBR+PAC) have been operated for 42 days while R3 (ASBR+EFB) is operated for 30 days under Organic Loading Rate of 1.608 kg COD/m^3/day. However, all three ASBRs managed to operate until they reached stabilized performance. COD and pH measurement are conducted every day at the end of fourth cycle, while MLSS, MLVSS and SVI test are conducted for every two days interval. **Appendix 1** summarizes the findings for R1 (ASBR), R2 (ASBR+PAC) and R3 (ASBR+EFB).

Figure 4.1 shows the COD removal efficiency of all three ASBRs. For the early 20 days of operation, all reactors have fluctuation in performance as they were acclimatizing towards the new surroundings. As they stabilized, R2 (ASBR+PAC) has the highest removal efficiency which is 95.1 percents of total COD in Day 41. This is expected since the PAC help to improve the adsorption of the POME constituent that increases the sludge settleability producing effluent with lower COD. Application of PAC with Sequencing Batch Reactor in previous study manages to improve the performance of SBR to 69.8 percents of COD removal (Shuokr Q.A., et al., 2011). Thus, it shows that COD removal efficiency ASBR combined system with PAC is more efficient as compared to SBR with aerobic system. R1 (ASBR) managed to achieve COD removal efficiency up to 91.4 percents in Day 41. This is so much higher than what have been achieved by other study of ASBR treating POME (Marzieh Badei et. al. 2011); which managed to remove 37 percents of total COD and 50 percents of soluble COD. This also supports the finding that ASBR is capable of treating high strength wastewater such as swine wastewater with very high COD removal efficiency (Angenent et. al., 2010). R3 (ASBR+EFB) on the other hand has improvement in term of COD removal efficiency but still do not manage to cope up with the other two ASBRs. The highest COD removal efficiency recorded for R3 is in Day 29 with 85.8 percents total COD removal. R3 (ASBR+EFB) is to determine the ability of EFB to act as an adsorbent without undergoing any chemical process or preparation. From the result obtain, the EFB do not manage to cope up with the performance of the other two ASBRs. This may be caused by the nature of the EFB itself that contain high organic content which subsequently contribute toward higher loading rate to the microorganism. Beside, the addition of EFB causes the effluent to be more turbid due to the presence of suspended solids from the EFB; thus the COD of the effluent is much higher.

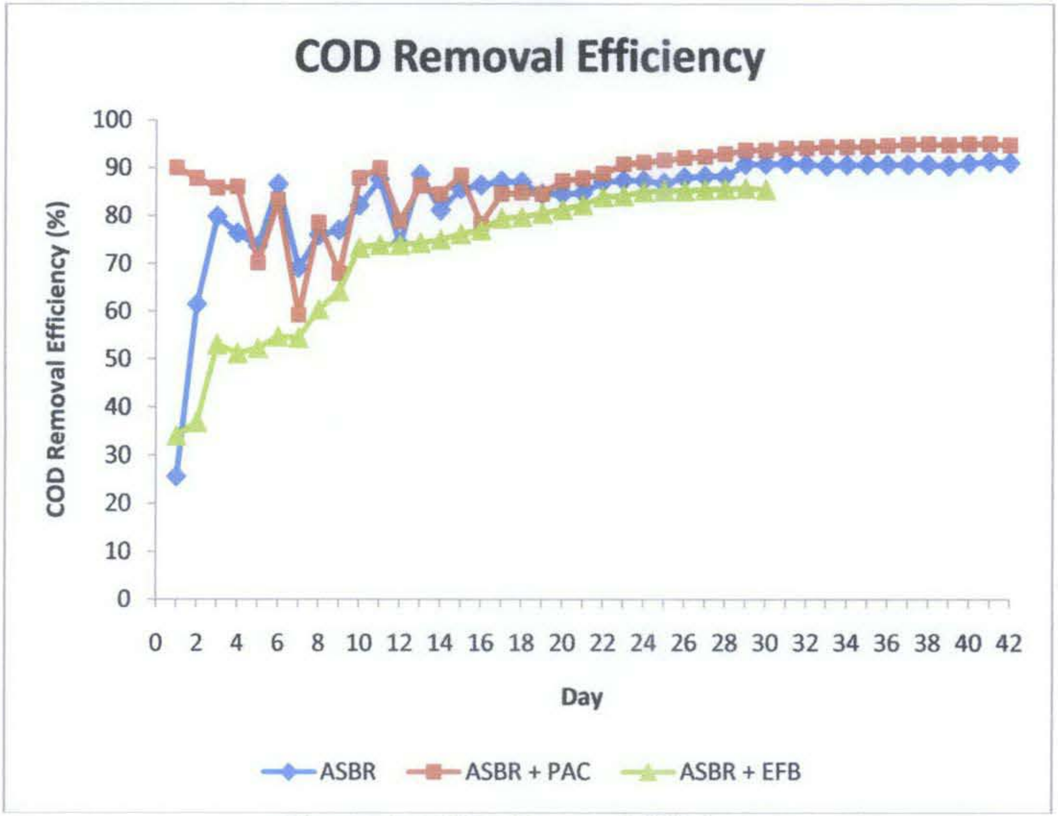

Figure 4.1: COD Removal Efficiency

Figure 4.2 on the other hand shows the pH values recorded throughout the operation of the ASBRs. The pH values are maintained between 6 to 8 as pre-required earlier. pH of the operated ASBRs range between 6.2 and 6.5. The system operated does not manage to produce collectible methane gas since the system is very small. Besides, according to Gerardi M.H. (2003), the performance of methane-performing bacteria is optimum at pH between 6.8 and 7.2. This is also supported by Poh and Chong (2008) that the optimum pH for anaerobic digestion to take place ranges from 6.8 to 7.2. However, since hydrolysis by microorganism is optimum at pH 5.5 to 6.5 (Ward et al., 2008), the result is still acceptable.

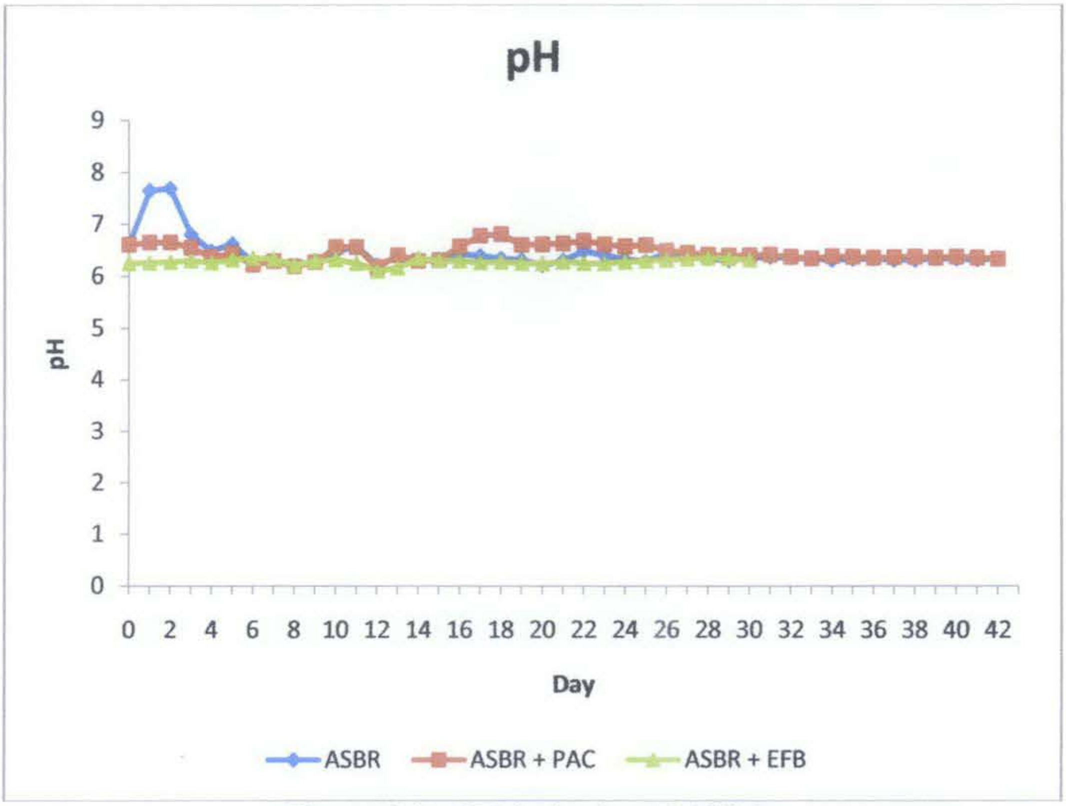

Figure 4.2: pH Monitoring of ASBRs

Figure 4.3 shows the MLSS concentration for all three ASBRs. MLSS is the measure of suspended solids in the operating ASBRs. From the result, MLSS concentration of R2 (ASBR+PAC) and R3 (ASBR+EFB) are much higher than R1 (ASBR) due to the addition of PAC and EFB into the systems. The dosage is added at the earliest stage of the reactor operation and the amount is gradually decreased as the reactors stabilize. The MLSS concentration began to stabilize at Day 21. At the stabilization stage, R1 (ASBR) has MLSS concentration ranges from 6900 mg/L to 7200 mg/L. R2 (ASBR+PAC) has the highest range of MLSS concentration with 19000 mg/L to 22000 mg/L. R3

(ASBR+EFB) on the other hand has an MLSS concentration from 17000 mg/L to 19000 mg/L.

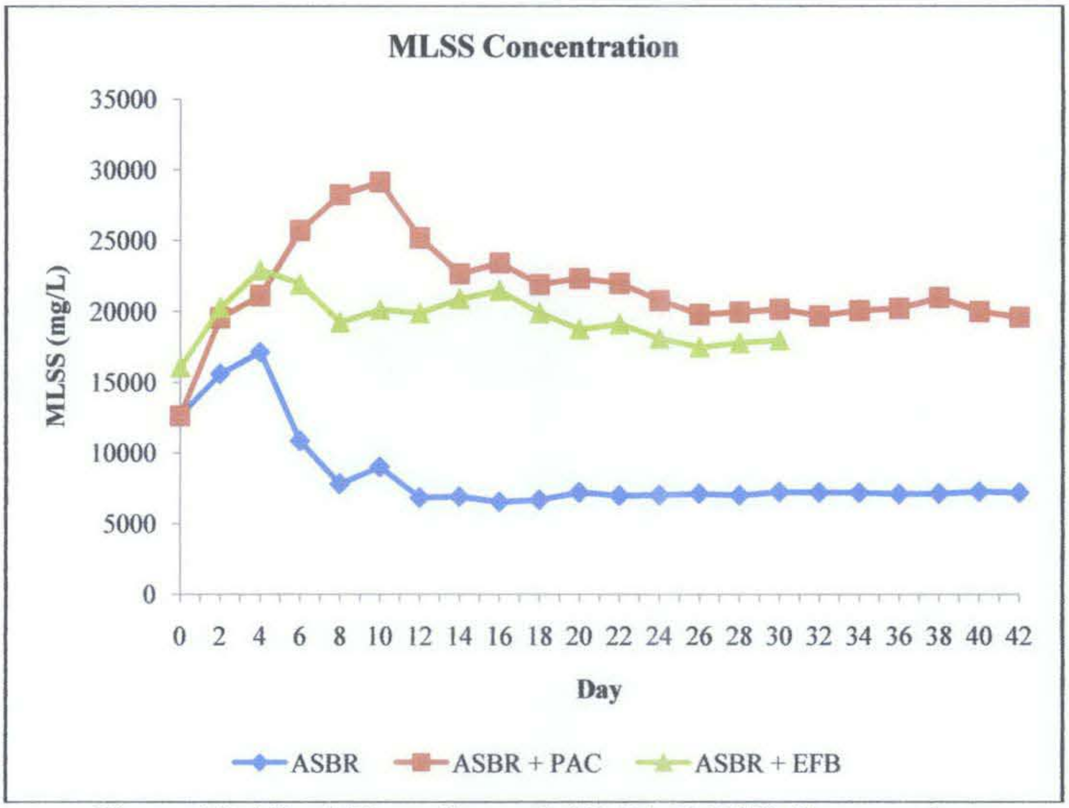

Figure 4.3: Mixed Liquor Suspended Solids (MLSS) Concentration

Figure 4.4 shows the Mixed Liquor Volatile Suspended Solids (MLVSS) concentration in the ASBRs. MLVSS represents the microorganism growth inside the biological system. As initial Food to Microorganism is at 0.1, thus the initial concentration of MLVSS for all three reactors is about the same between 5900 mg/L to 6400 mg/L. R2 (ASBR+PAC) has higher amount of microorganism throughout the stabilized operation period (between 9600 mg/L to 9900 mg/L). R3 (ASBR+EFB) also has high concentration of MLVSS during the stabilization period which range about 7400 mg/L to 8400 mg/L. These two reactors; R2 (ASBR+PAC) and R3 (ASBR+EFB) are added with EFB and PAC which offer a better medium for the microorganism to cling on and multiply. R1 (ASBR) on the other hand has lower MLVSS concentration (7000 mg/L to 7200 mg/L) as compared to the other two reactors. The concentration of MLVSS will affect the operating Food to Microorganism Ratio (F/M) of the ASBRs.

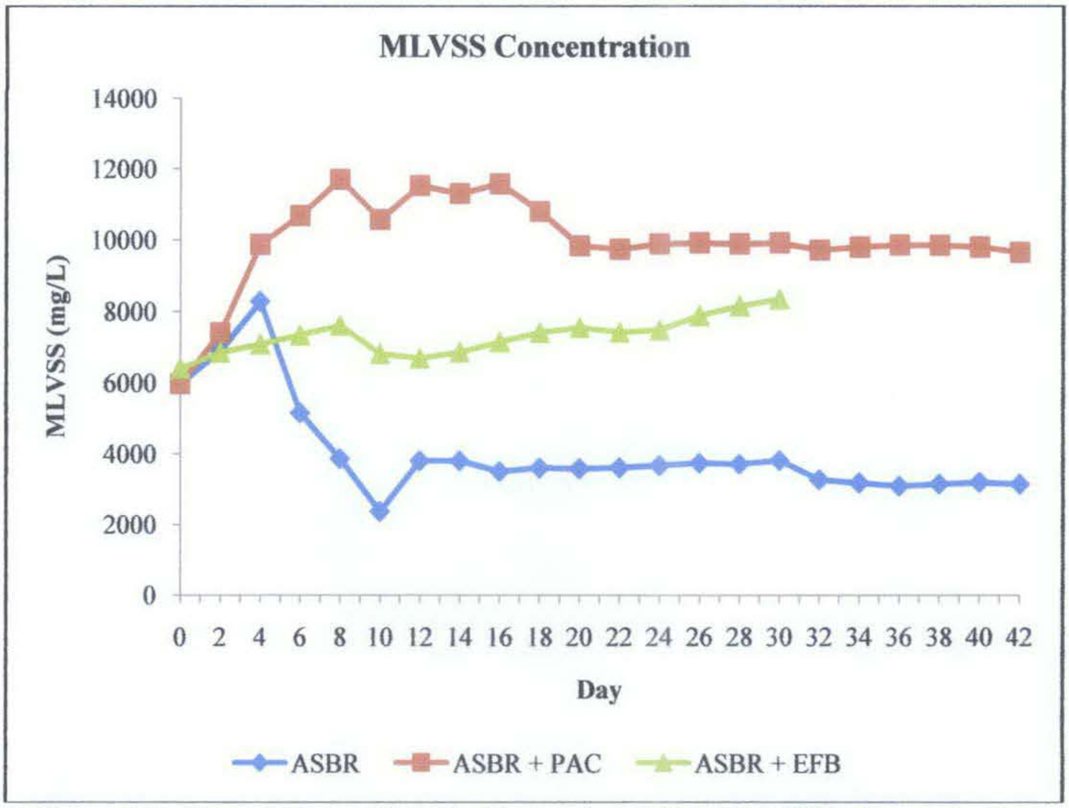

Figure 4.4: Mixed Liquor Volatile Suspended Solids (MLVSS) Concentration

Figure 4.5 shows the Food to Microorganism Ratio (F/M) of all three reactors. Since the MLVSS concentration in R1 (ASBR) is lower as compared to the other two ASBRs, the F/M for R1 is higher (from 0.14 to 0.18). R2 (ASBR+PAC) has the lowest range of F/M during stabilized period of operation which ranges between 0.05 and 0.06. R3 (ASBR+EFB) also has low F/M which is from 0.07 to 0.08. Higher F/M means higher amount of COD to be consumed by a unit of microorganism inside the biological system and vice-versa. The F/M of R1 (ASBR) increases from Day 32 due to the varying in COD of the influent which increases from 1190 mg/L to 1270 mg/L and 1290 mg/L at the end of the ASBR operation. Since the concentration of MLVSS is stabilized in the ASBR which represents the amount of microorganism in the system, therefore the F/M increases.

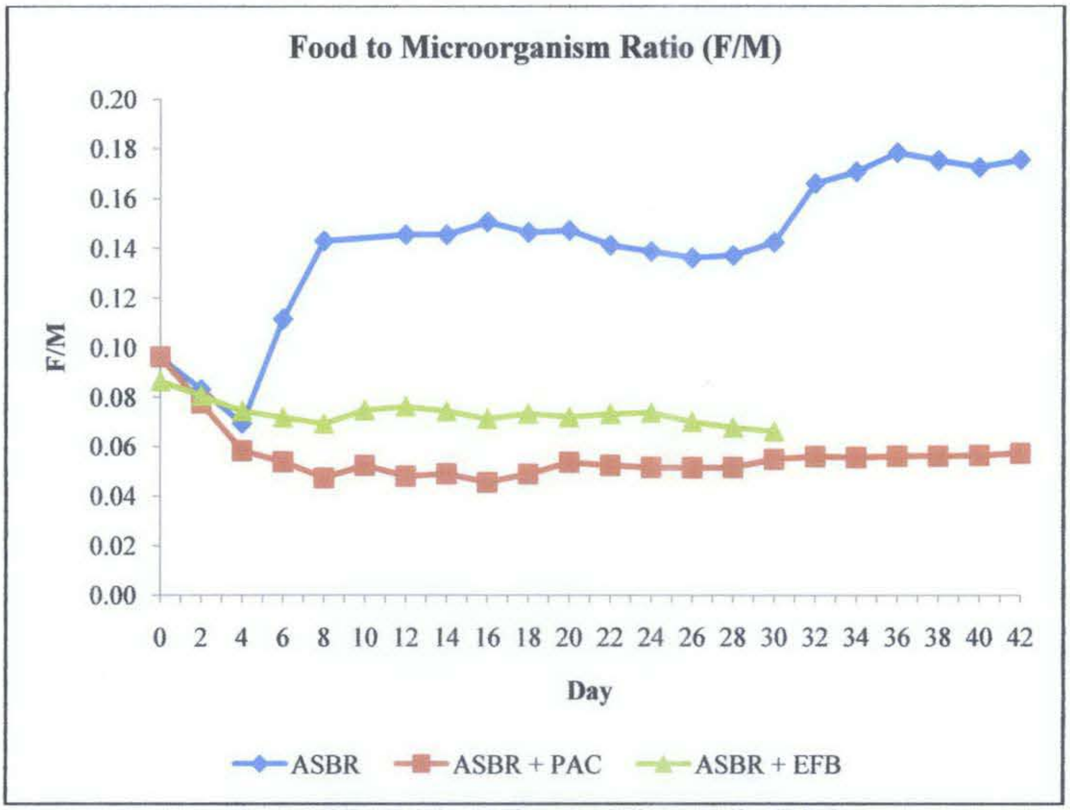

Figure 4.5: Food to Microorganism Ratio (F/M)

Figure 4.6 shows the Sludge Volume Index (SVI) of the reactors conducted for every two days interval. Overall, the sludge of R2 (ASBR+PAC) has the highest settleability. During the stabilized operation period (Day 21 to Day 42), the SVI of R2 (ASBR+PAC) ranges from 8 to 9 mL/g while R3 (ASBR+EFB) records slightly higher SVI between 11 to 15 mL/g. R1 (ASBR) on the other hand has higher SVI ranges between 33 and 36 mL/g that contribute to lower settleability of the sludge. This results support the finding that application of PAC produced sludge with high settleability as observed in SBR-PAC combined system (Shuokr Q.A., et al., 2011).

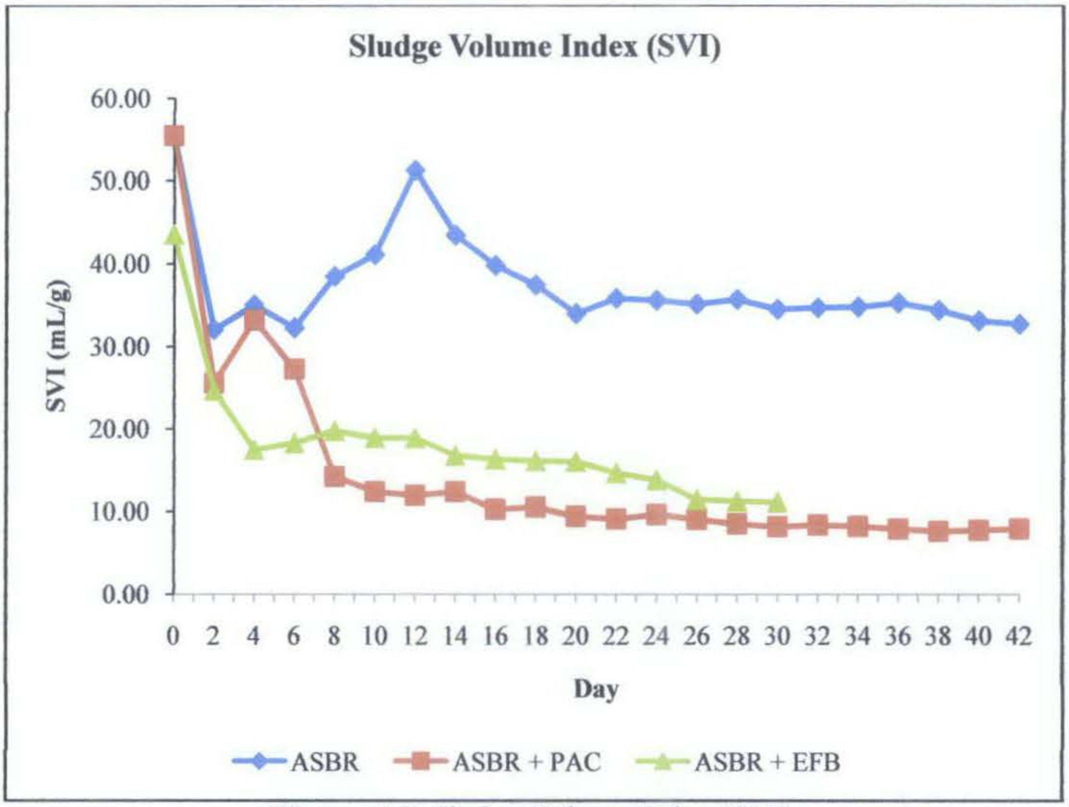

Figure 4.6: Sludge Volume Index (SVI)

4.2 MICROBIOLOGICAL IDENTIFICATION

In order to analyze the activeness of the biological system, the microorganism content in all reactors is analyzed under microscope at 40 to 100 times magnification. The microbiological identification process is conducted based on the Standard Method.

Bacteria

The most common bacteria species identified is *Spirillum sp.* like. It is a methane-forming bacterium that can only survive in anaerobic condition (Gerardi M.H., 2003). Thus it proves that the ASBRs manage to operate under anaerobic condition. The same species of bacteria also identified in Anaerobic Baffled Reactor for converting kitchen waste to biogas study (Malakahmad A., et. al., 2009). **Figure 4.7** shows the image of *Spirillum sp.* like bacteria in 100 times magnification.

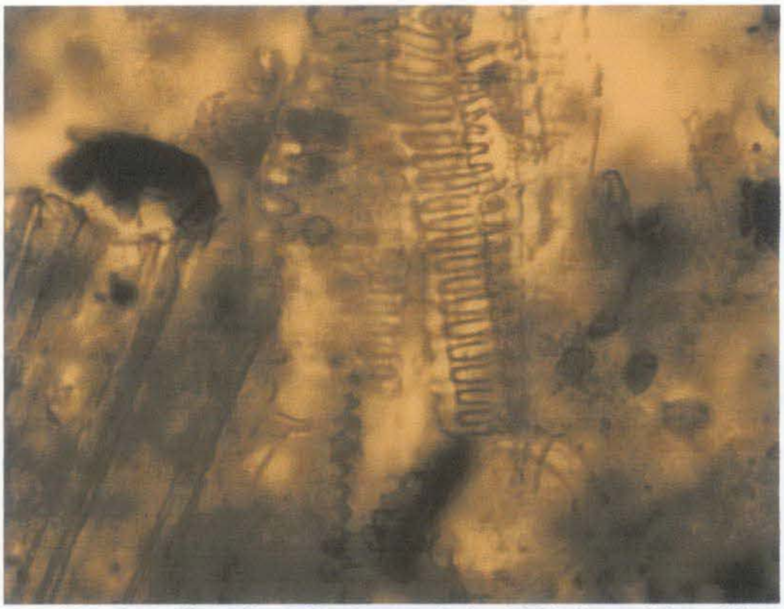

Figure 4.7: *Spirillum Sp.* Like Bacteria in 100 Times Magnification

Protozoa, Rotifers and Free Living Nematode

According to Gerardi M.H. (2003), the degradation of organic compounds in anaerobic digesters is not enhanced by the activity of ciliated protozoa, rotifers and free living nematodes. Anaerobic protozoa usually are very small in number in anaerobic digesters. Rotifers and free living nematodes on the other hand are strict aerobes and will die in anaerobic condition. **Figure 4.8** shows the presence of *Euglypha sp.* like and **Figure 4.9** shows the *Arcella sp.* like protozoa in the early stage of the ASBRs operation due to the application of aerobic sludge obtained from the sewage treatment plant.

Figure 4.8: *Euglypha sp.* Like Protozoa Presence in Early Stage of ASBR Operation

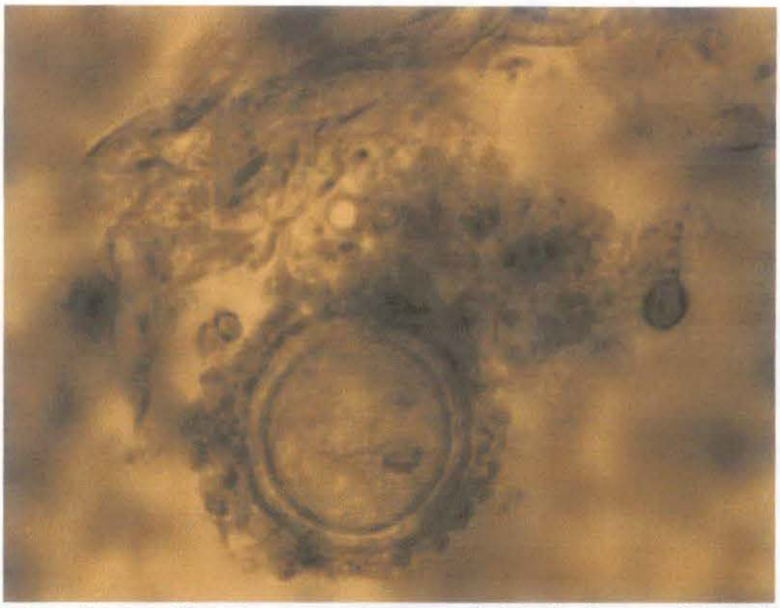

Figure 4.9: *Arcella sp.* Like Protozoa Presence in Early Stage of ASBR Operation

As the ASBRs gradually achieve facultative and anaerobic condition, the amount of protozoa in the reactors also decreases. **Figure 4.10** shows the image in 100 times magnification of *Euglypha sp.* like protozoa burst obtained during Day 8 of ASBR operation .

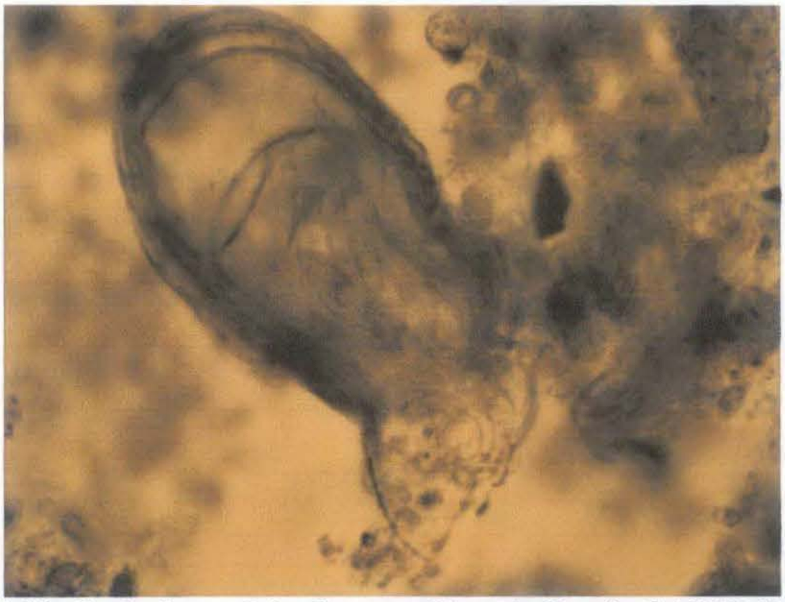

Figure 4.10: *Euglypha sp.* Like Protozoa Burst in Day 8 of ASBR Operation

The only surviving ciliates are from *Vorticella sp.* like stalked ciliate that can be found even at Day 42 operation of ASBRs. **Figure 4.11** is the image of *Vorticella sp.* like stalked ciliate in 100 times magnification.

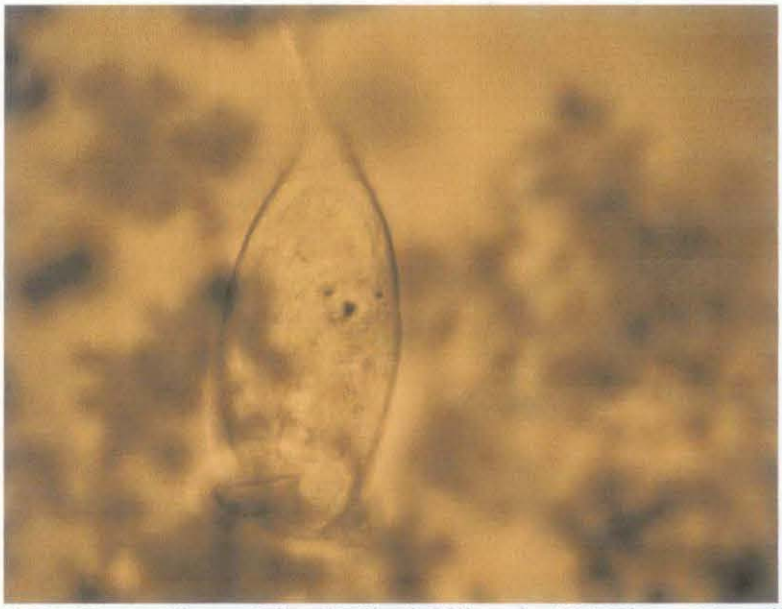

Figure 4.11: *Verticella sp.* Like Stalked Ciliate in 100 Times Magnification

Figure 4.12 shows the 100 times magnified image of *Philodina sp.* like rotifer which can be found at the early stage of ASBR operation. The species however no longer present in the system starting from Day 6 of operation.

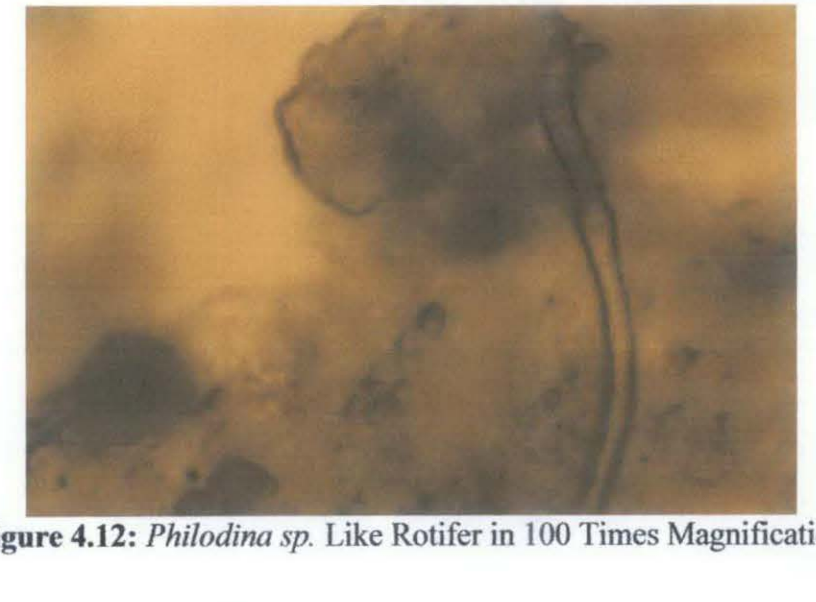

Figure 4.12: *Philodina sp.* Like Rotifer in 100 Times Magnification

CONCLUSION

In conclusion, Anaerobic Sequencing Batch Reactor (ASBR) is dependable in treating high-strength wastewater such as Palm Oil Mill Effluent (POME). Application of ASBR alone without any adsorbent addition manages to reach up to 91.4 percents COD removal. Addition of Powdered Activated Carbon (PAC) as adsorbent subsequently improves the ASBR performance up to 95.1 percents COD removal. The Empty Fruit Bunches (EFB) however, do not manage to act as adsorbent in ASBR. Chemical process such as activation is perhaps important for the EFB to be able to function as adsorbent and cope with the commercial PAC performance. Besides, optimum condition and balance between other operating condition such as pH and temperature is very important in improving the performance of the ASBR.

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APPENDIX 1

Results of the R1 (ASBR) Operation

Day	**COD**			**MLSS (mg/L)**	**MLVSS (mg/L)**	**Food to Micro-organism Ratio (F/M)**	**pH**	**Volume Occupied (mL/L)**	**Sludge Volume Index (mL/g)**
	Influent COD (mg/L)	**Effluent COD (mg/L)**	**Removal Efficiency (%)**						
0	1340	-		12633	5967	0.10	6.61	700	55.41
1	1340	997	25.62				7.65		
2	1340	517	61.44	15600	6900	0.08	7.69	500	32.05
3	1340	270	79.85				6.80		
4	1340	317	76.37	17133	8283	0.07	6.48	600	35.02
5	1340	353	73.63				6.62		
6	1340	180	86.57	10850	5150	0.11	6.26	350	32.26
7	1340	413	69.15				6.29		
8	1290	310	75.97	7800	3867	0.14	6.21	300	38.46
9	1290	297	77.00				6.30		
10	1290	230	82.17	9000	2367		6.47	370	41.11
11	1290	160	87.60				6.58		
12	1290	333	74.16	6830	3800	0.15	6.21	350	51.24
13	1290	147	88.63				6.38		
14	1290	243	81.16	6900	3800	0.15	6.30	300	43.48
15	1230	177	85.61				6.33		
16	1230	167	86.42	6533	3500	0.15	6.43	260	39.80
17	1230	157	87.24				6.39		
18	1230	160	86.99	6678	3600	0.15	6.34	250	37.44
19	1230	190	84.55				6.31		
20	1230	190	84.55	7210	3580	0.15	6.21	245	33.98
21	1230	187	84.80				6.30		
22	1190	153	87.14	6980	3610	0.14	6.48	250	35.82

23	1190	150	87.39				6.40		
24	1190	150	87.39	7025	3675	0.14	6.32	250	35.59
25	1190	157	86.81				6.29		
26	1190	143	87.98	7115	3745	0.14	6.45	250	35.14
27	1190	140	88.24				6.39		
28	1190	140	88.24	7004	3717	0.14	6.34	250	35.69
29	1270	117	90.79				6.30		
30	1270	117	90.79	7244	3820	0.14	6.35	250	34.51
31	1270	115	90.94				6.37		
32	1270	117	90.79	7207	3277	0.17	6.35	250	34.69
33	1270	121	90.47				6.34		
34	1270	119	90.63	7185	3187	0.17	6.31	250	34.79
35	1270	118	90.71				6.33		
36	1290	120	90.70	7089	3099	0.18	6.34	250	35.27
37	1290	120	90.70				6.31		
38	1290	120	90.70	7127	3154	0.18	6.31	245	34.38
39	1290	123	90.47				6.34		
40	1290	117	90.93	7250	3205	0.17	6.33	240	33.10
41	1290	111	91.40				6.32		
42	1290	115	91.09	7188	3150	0.18	6.34	235	32.69
Average	1265		81.14	8660.13	4227.60	0.13	6.46		37.44
Standard Dev.	56		13	653	1490	0.03	0.35		4.96

Note: MLSS, MLVSS and SVI tests are conducted for every two days

APPENDIX 1

Results of the R2 (ASBR+PAC) Operation

Day	COD			MLSS (mg/L)	MLVSS (mg/L)	Food to Micro-organism Ratio (F/M)	pH	Volume Occupied (mL/L)	Sludge Volume Index (mL/g)
	Influent COD (mg/L)	Effluent COD (mg/L)	Removal Efficiency (%)						
0	1340	-		12633	5967	0.10	6.61	700	55.410
1	1340	133	90.05				6.65		
2	1340	163	87.81	19550	7400	0.08	6.65	500	25.575
3	1340	190	85.82				6.55		
4	1340	187	86.04	21100	9870	0.06	6.37	700	33.175
5	1340	400	70.15				6.43		
6	1340	223	83.33	25687	10675	0.05	6.22	700	27.251
7	1340	547	59.20				6.29		
8	1290	277	78.55	28225	11700	0.05	6.19	400	14.172
9	1290	413	67.96				6.27		
10	1290	157	87.86	29117	10567	0.05	6.56	360	12.364
11	1290	130	89.92				6.56		
12	1290	273	78.84	25174	11525	0.05	6.17	300	11.917
13	1290	177	86.30				6.40		
14	1290	200	84.50	22625	11300	0.05	6.29	280	12.376
15	1230	143	88.37				6.31		
16	1230	267	78.29	23400	11575	0.05	6.57	240	10.256
17	1230	190	84.55				6.78		
18	1230	187	84.80	21890	10790	0.05	6.81	230	10.507
19	1230	190	84.55				6.60		
20	1230	157	87.24	22310	9830	0.05	6.61	210	9.413
21	1230	150	87.80				6.63		
22	1190	133	88.82	21965	9735	0.05	6.68	200	9.105

23	1190	110	90.76				6.61		
24	1190	105	91.18	20765	9885	0.05	6.57	200	9.632
25	1190	100	91.60				6.60		
26	1190	94	92.10	19787	9915	0.05	6.49	180	9.097
27	1190	91	92.35				6.45		
28	1190	84	92.94	19950	9887	0.05	6.41	170	8.521
29	1270	80	93.70				6.39		
30	1270	80	93.70	20155	9915	0.05	6.40	165	8.187
31	1270	74	94.17				6.41		
32	1270	74	94.17	19680	9717	0.06	6.37	165	8.384
33	1270	71	94.41				6.34		
34	1270	71	94.41	20055	9795	0.06	6.38	165	8.227
35	1270	70	94.49				6.37		
36	1290	68	94.73	20210	9854	0.06	6.35	160	7.917
37	1290	65	94.96				6.36		
38	1290	64	95.04	20965	9847	0.06	6.37	160	7.632
39	1290	67	94.81				6.35		
40	1290	64	95.04	19987	9795	0.06	6.37	155	7.755
41	1290	63	95.12				6.35		
42	1290	67	94.81	19585	9650	0.06	6.33	155	7.914
Average	1265		85.30	22780.00	10304.60	0.05	6.48		14.10
Standard Dev.	56		8	2735	1079	0.01	0.17		7.86

Note: MLSS, MLVSS and SVI tests are conducted for every two days

Results of the R3 (ASBR+EFB) Operation

Day	**COD**			**MLSS (mg/L)**	**MLVSS (mg/L)**	**Food to Micro-organism Ratio (F/M)**	**pH**	**Volume Occupied (mL/L)**	**Sludge Volume Index (mL/g)**
	Influent COD (mg/L)	**Effluent COD (mg/L)**	**Removal Efficiency (%)**						
0	1290	-		16067	6400	0.09	6.25	700	43.568
1	1290	850	34.11				6.26		
2	1290	813	36.98	20267	6850	0.08	6.27	500	24.671
3	1230	577	53.09				6.30		
4	1230	600	51.22	22900	7083	0.07	6.26	400	17.467
5	1230	587	52.28				6.32		
6	1230	557	54.72	21910	7340	0.07	6.35	400	18.257
7	1230	560	54.47				6.33		
8	1230	487	60.41	19230	7610	0.07	6.21	380	19.761
9	1230	440	64.23				6.29		
10	1190	317	73.36	20110	6815	0.07	6.32	380	18.896
11	1190	310	73.95				6.25		
12	1190	310	73.95	19875	6687	0.08	6.10	375	18.868
13	1190	305	74.37				6.16		
14	1190	297	75.04	20875	6857	0.07	6.34	350	16.766
15	1190	283	76.22				6.30		
16	1190	273	77.06	21457	7150	0.07	6.29	350	16.312
17	1270	260	79.53				6.26		
18	1270	257	79.76	19887	7407	0.07	6.27	320	16.091
19	1270	247	80.55				6.25		
20	1270	237	81.34	18745	7553	0.07	6.24	300	16.004
21	1270	225	82.28				6.27		
22	1270	203	84.02	19110	7417	0.07	6.25	280	14.652

23	1270	200	84.25				6.24		
24	1290	193	85.04	18090	7487	0.07	6.27	250	13.820
25	1290	190	85.27				6.29		
26	1290	190	85.27	17477	7883	0.07	6.31	200	11.444
27	1290	187	85.50				6.33		
28	1290	185	85.66	17787	8150	0.07	6.35	200	11.244
29	1290	183	85.81				6.34		
30	1290	187	85.50	17980	8345	0.07	6.31	200	11.123
Average	1249		71.84	19713.33	7375.60	0.07	6.28		16.36
Standard Dev.	39		15	1325	491	0.00	0.05		3.64

Note: MLSS, MLVSS and SVI tests are conducted for every two days