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AEROBIC TREATMENT OF ANAEROBICALY TREATED PALM OIL MILL EFFLUENT

By

Mohd Izzuddin Billah Bin Mamat Ali

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UniversitiTeknologi PETRONAS,
Bandar Seri Iskandar,
31750 Tronoh,
Perak Darul Ridzuan

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own expect as specified in the references and acknowledgements, and that original work contained herein have not been undertaken or done by unspecified sources or persons. I am also ready doing the cleaning process in the laboratory and submit all the apparatus that I use for my final year project.

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(MOHD IZZUDDIN BILLAH BIN MAMAT ALI)

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(MR. MOHD KHAIRUL ANUAR BIN JAMALUDIN)

Zaaba Bin Mohammad
Lab Technologist
Civil Engineering Department
Universiti Teknologi PETRONAS
Bandar Seri Iskandar, 31750 Tronoh
Perak Darul Ridzuan, MALAYSIA
Email: zaaba_mohammad@petronas.com.my

ABSTRACT

This report is basically the preliminary research done and basic understanding of the chosen topic, which is the Aerobic Treatment of the Anaerobically Treated Palm Oil Mill Effluent (POME). Anaerobically digestion is widely used as the method for the POME treatment but the result has difficulty meeting the discharge limits set by the Department of Environment (DOE) due to high organic strength of POME. Hence, aerobic treatment is introduce to treated the effluent from the anaerobically digestion. The Sequencing Batch Reactor (SBR) is an aerobic treatment system used for this research. The final result of Chemical Oxygen Demand (COD), Soluble Chemical Oxygen Demand (sCOD), Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), pH, temperature, Mixed Liquor Suspended Solids (MLSS) and Mixed Liquor Volatile Suspended Solids (MLVSS) are the parameters to evaluate the performance of the SBR in treating the anaerobically treated POME. A 5-litres SBR was fed with the anaerobic treated POME as the influent and seeded with the sludge from two different sources; Sewage Treatment Plant (STP) in UTP and Nasaruddin Palm Oil Mill in Bota, Perak. A 12-hours cycle and 24-hours cycle was conducted in treating the 5-litre of wastewater per cycle. Initially the wastewaterwas characterized according to the parameters of BOD, COD, sCOD, TSS, pH, temperature, MLSS and MLVSS. Some changes made during the research in order to get the most optimum parameters SBR performance; influent concentration, sludge concentration, aeration time and hydraulic retention time (HRT). The sCOD removal efficiency can achieved up to 32%. The optimum sludge concentration is ranging between 11000 to 14000 mg/L for MLVSS. It is envisaged that the SBR process could complement the anaerobic treatment to produce final treated effluent which meets the discharge limit.

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ABBREVIATIONS AND NOMENCLATURES

COD	Chemical Oxygen Demand
BOD	Biodegradable Oxygen Demand
TSS	Total Suspended Solids
MLSS	Mixed Liquor Suspended Solids
MLVSS	Mixed Liquor Volatile Suspended Solids
POME	Palm Oil Mill Effluent
SBR	Sequencing Batch Reactor
DOE	Department of Environment
EQA	Environmental Quality Act
STP	Sewage Treatment Plant
UTP	Universiti Teknologi PETRONAS

CHAPTER 1

INTRODUCTION

1.1 Background of study

Today, 4.49 million hectares of land in Malaysia is under oil palm cultivation, producing 17.73 millions tonnes of palm oil kernel oil. Malaysia currently accounts for 39% of world palm oil production and 44% of world exports. If taken into account of other oils and fats produced in the country, Malaysia accounts for 12% and 27% of the world total production and export of oils and fats (MPOC, 2009). The high rise in the palm oil industry in Malaysia shows the industry produced huge amount of the waste to the environment. The Palm Oil Mill Effluent (POME) discharge from the plant needs to be treated as required by the government for the environmental issues. Generally, 1 tonne of crude palm oil productions requires 5 – 7.5 tonne of water and more than 50% of the water will end up as POME (Ahmad, 2003). POME has been identified to be one of the major sources of the water pollution due to high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentrations. Hence the government had enacted Environmental Quality Act (EQA) in 1978 and set the parameter limits for the discharged of POME into the envronment (Y. J. Chan, 2010) as shown in **Table 1.1**.

Table 1.1: Characteristic of anaerobically digested POME and DOE standard

Parameters	Y.J. Chan et al. (2010)	Vijayaraghavan et al. (2007)	Phang and Ong (1988)	DOE standard
	Average concentrations	Average concentrations	Average concentrations	
pH	7.4	7.8	7.24	5 – 9.0
BOD	1355	-	1938	100
COD	13650	1372	20314	100
TSS	12750	512	14686	400
TN	320	134	-	200

All parameters in mg/L except pH
Sample for BOD incubated for 3 days at 30°

The anaerobic treatment for the POME is widely used in Malaysia but the anaerobic treatment alone hardly produce the effluents to a level complying with the DOE discharged limits as shown in **Table 1.1**. Anaerobic-aerobic treatment is the best option because of many research shows the results has better and higher treatment efficiency, lower energy requirement and less sludge production (Del Pozo, 2003).

1.2 Problem statement

POME is generated from three major sources, namely sterilizer condensate, hydrocyclone waste and separator sludge (Borja, 1994). POME is rich in organic carbon with a BOD higher than 20 g/L and Nitrogen content around 0.2 g/L as Ammonia Nitrogen 0.5 g/L of the total Nitrogen (Ma, 2001). The anaerobic treatment is widely accepted used as an effective method for the treatment of POME but the anaerobic treatment alone has difficulty meeting the discharged limits due to the high organic strength (Y. J. Chan, 2010).

Hence, subsequent post-treatment needed in order to advance the results. Anaerobic-aerobic treatment appears to be the most techno-economically viable approach. The anaerobic treatment process provides partial removal of organic matter before further treatment with aerobic treatment (Y. J. Chan, 2010).

First treatment is the conventional anaerobic-aerobic systems which are comprised of open tank digesters and extended aeration systems in POME treatment. In this system, POME is treated in two phase anaerobic digestion process followed by extended aeration in a pond with hydraulic retention time (HRT) of about 40 days. If it is properly operated and maintained, the treated effluent is able to meet the discharge limit (Ma, 1993). However, these conventional anaerobic-aerobic treatment systems frequently encounter problems associated to their large space requirement, long HRT, low organic loading rate (OLR) and thus could hardly keep pace with growing generation of effluent by the mills (Y. J. Chan, 2010).

Second is to use an activated sludge reactor as post-treatment. It was found that the COD removal efficiency declined from 83% to 42% and 57% to 27% at HRT of 36h and 24h respectively, when the influent concentrations increased from 1000 mg/L to 5000 mg/L. In addition, the effluent failed to meet the discharge standard. Activated sludge system appears to be one of the most effective aerobic treatment systems however is the least used by palm oil mills due to its higher operation cost (Y. J. Chan, 2010).

Sequencing batch reactor (SBR) ia another post-treatment for anaerobic-aerobic treatment. SBR is an improved version of activated sludge system and the term SBR stems from the sequencing of its step occur within the same vessel; filling, aeration, settling and decantation. For this research the SBR system is chosen for the treatment. The efficiency of the treatment is evaluate due to several factors that contribute to the performance of this treatment system.

1.3 Objective

The objective of the research is to evaluate the performance of the SBR system as the aerobic treatment for treating the anaerobically treated POME to produce high quality of effluent which complies with the effluent discharge standards.

1.4 Scope of study

The study focuses on the SBR system using the aerobic treatment to treat the anaerobically treated POME. The anaerobically treated POME sample taken from the Nasaruddin Palm Oil Mill in Bota, Perak and the sludge taken from Sewage Treatment Plant in Universiti Teknologi PETRONAS (UTP) in Perak. Set of tests and experiments were conducted according to some parameters for the influent and effluent of the SBR system. The parameters are BOD, COD, sCOD, TSS, pH, temperature, MLSS and MLVSS. The changes for some of the factors such as the concentration of sludge, aeration time, concentration of influent, type of sludge and number of cycles are introduce in the research in order to get the most efficient results.

CHAPTER 2

LITERATURE REVIEW

2.1 Biological treatment

Biological treatment is the usage of microorganism (bacteria) to oxidized the organic matter produce the biomass or sludge. The objective of the biological treatment is to transform (oxidized) dissolved and particulate biodegradable constituents into acceptable end products, capture and incorporate suspended and non-settleable colloidal solids into a biological floc or biofilm, transform or remove nutrients, such as nitrogen and phosphorus, remove specific trace organic constituents and compounds and for the industrial wastewater is to remove or reduce the concentration of organic and inorganic compounds (Metcalf, 2003).

The microorganism plays the important roles in the biological treatment processes. The microorganism is the agent used to oxidized the dissolve and particulate cabonaceous organic matter into the simple end products and addition biomass. The following equation represented the equation for the biological oxidation of organic matter;

$$V_1(\text{organic material}) + V_2O_2 + V_3NH_4 + V_4PO_4^{3-} \xrightarrow{\text{microorganism}} V_5\,(\text{new cells}) + V_6CO_2 + V_7H_2O$$

The equation shows that the organic material is oxidized by the microorganism in the presence of oxygen, O_2 (for the aerobic digestion), ammonia (NH_3) and phosphate (PO_4^{3-}) to produce the new cells that is the biomass, carbon doixide (CO_2) and water (H_2O). The new cells or biomass is the simple end products (Metcalf, 2003).

The microorganism can be classified into two classes that are the heterotrophs (organisms that used organic carbon for the formation of the new biomass) and autotrophs (organisms that derived cells carbon from carbon dioxide) according to the nutritional requirementof microbes. For heterotrophs, these organisms tend to take the source of carbon from the arganic carbon (BOD, COD and TOC) and source of energy from the oxidation-reduction reaction of organic matter. Meanwhile the autotrophs organism take the source of carbon from the inorganic carbon sources (CO_2 and HCO_3) and the sources of energy from the sunlight (photosynthesis), oxidation reduction reaction involving inorganic substances and chemosynthetic (Metcalf, 2003).

2.2 Aerobic treatment

The aerobic treatment is the biological treatment process. The principle of the aerobic treatment is the usage of free or dissolved oxygen by microorganisms in the degradation of organic wastes. The process required sufficient contact time between the wastewater and heterotrophic microorganisms, and sufficient oxygen and nutrient. The nutrient, such as ammonia and phosphate is used to complete the reaction. A wide variety of microorganisms are found in aerobic suspended and attached growth treatment processes used for the removal of organic material. The most common microorganisms are the aerobic heterotropic, protozoa and rotifiers. The aerobic heterotropic bacteria able to produce extracellular biopolymers that result in the formation of biological flocsor biofilm for attached growth processes that can be separated from thetreated liquid by gravity settling with relatively low concentrations offree bacteria and suspended solids. Protozoa on the other hands can consume free bacteria and colloidal particulates but protozoa required a long SRT than aerobic heterotropic bacteria, prefer more dissolved oxygen concentration and sensitive to toxic material. The rotifiers can be found in activated sludge and biofilms, as well as nematodes and other muticellular microorganisms (Metcalf, 2003).

In aerobic treatment, the conversion of organic matter is carried out by mixed bacterial cultures in general accordance with the stoichiometry below,

Oxidation and synthesis;

$$\text{COHNS (organic matter)} + O_2 + \text{nutrients} \xrightarrow{\text{Bacteria}} CO_2 + NH_3 + C_5N_7HO_2 + \text{other end products}$$

Endogenous respiration;

$$C_5N_7HO_2 + 5O_2 \xrightarrow{\text{Bacteria}} 5CO_2 + 2H_2O + NH_3 + \text{energy}$$

The oxidation and synthesis is the organic matter being oxidized by the bacteria in the presence of enough oxygen and nutrients and produce the new cells (biomass), carbon dioxide, ammonia and other end products. Meanwhile the endogenous respirations occur because of the low nutrient or food for the oxidation of the aerobic treatment. These microorganisms tend to eat their own biomass in order to react and continue to live. Because of this endogenous respiration, another step of wastewater treatment can be perform by using the extended aeration tank (Metcalf, 2003). The extended aeration is to give the organisms some times to perform endorgenous respiration in order to reduce the amount of biomass produces.

2.3 Sequencing Batch Reactor

The SBR is a fill and draw activated sludge system. Wastewater is added to a single batch reactor, treated to remove undesired components, and then discharged. Equalization, aeration and clarification can all be achieved within a single batch reactor. To optimize the performance of the SBR system, two or more batch reactors are used in a predetermined sequence of operations (USEPA, 1999).

SBR technology is not new. In fact, it precedes the use of continuous flow activated sludge technology. The precursor to this is a fill-and-draw system operated on batch, similar to the SBR. Between 1914 and 1920, many difficulties were associated with operating these fill-and-draw systems, most resulting from the process required to switch from one reactor to another, operator attention required. Interest in SBRs was revived in the late 1950s and early 1960s, with the development of new equipment and technology. Improvement in aeration device (i.e. motorized valve, pneumatically actuated valves) and controls (level sensors, flowmeters, automatic timers, microprocessors) have allowed SBRs to succesfully compete with the conventional activated sludge system (Teresa, 2005).

There are five stages in the SBR process,

1. Fill – Raw wastewater flows into the reactor and mixes with the biomass held in the reactor. Statics fill is characterized by no mixing or aeration, meaning there will be a high substrate(food) concentrations when mixing begins. Additionally, static fill conditions favor microorganisms that introduce internal storage products with high substrate condition, a reqirement for biological phosphorus remival (Artan, 2002).
2. React – During the react period, the biomass consumes the substrate under controlled environmental conditions (Metcalf, 2003).
3. Settle – Solids are allowed to seperate from the liquid under quiescent conditions, resulting in a clarified supernatant that can be discharge as effluent (Metcalf, 2003).
4. Decant – Clarified effluent is removed during the decant period. Many types of decanting mechanisms can be used, with the most popular being floating or adjustable weirs (Metcalf, 2003).
5. Idle – An idle period is used in a multitank system to provide time for one reactor to complete its phase before switching to another unit. Because idle is not a necessary phase, it is sometimes omitted (Metcalf, 2003).

The advantage of SBR,

1. Easily modified operation is edaquate for sludge bulking control. The cyclic change of substrate concentration is known to be a selection factor against certain strains of filementous bacteria (Artan, 2002).
2. Equalization, primary clarification, biological treatment and secondary clarification can be achieved in a single reactor vessel (USEPA, 1999).
3. Potential capital cost savings by eliminating clarrifier and other equipments (USEPA, 1999).
4. The ability to hold contaminants until they have been completely degraded makes the system excellent for the treatment of hazardous compound (Artan, 2002).

But, the SBR also have some disadvantages,

1. A higher level of sophistication is required especially for larger systems of timing units and controls (USEPA, 1999).
2. Higher level of maintenance associated with more sophisticated controls, automated switches and automated valves (USEPA, 1999).
3. Potential of discharging floating and settle sludge during the draw or decant phase with some SBR configurations (USEPA, 1999).

2.4 Industrial wastewater – POME

Industrial wastewater is the point source pollution because comes from a specific distinguishable point such as industrial effluent from a pipe. In Malaysia, the regulation covers the point source pollution as stated in;

- Environmental Quality Act (EQA) 1974
- Environmental Quality (Scheduled Wastes) Regulations 1989

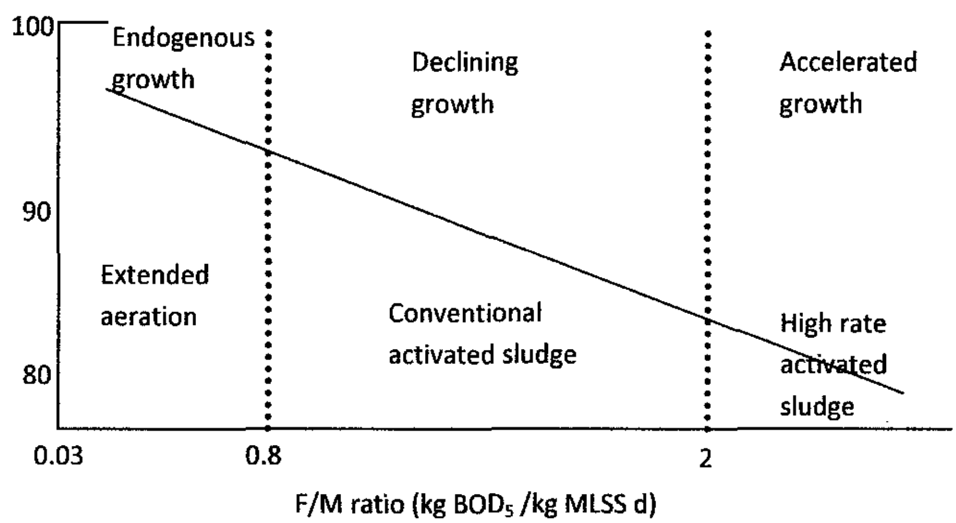
Source of industrial wastewater comes from the agricultural waste, iron and steel industry, mines and quarries, food industry, complex organic chemical industry and nuclear industry. For this research the wastewater comes from the agricultural industry that is the production of the palm oil.

POME is the waste from the production of the palm oil industry. For the research, POME is get from the Nasaruddin Plm Oil Mill factory in Bota, Perak. The raw POME is treated anaerobically at the plant. The results of the treatment still cannot satisfy with the limit stated by the DOE.

POME is oily wastewater generated by the palm oil processing mills in Malaysia. About 0.67 tonne of POME generated for every tonne of fresh fruit bunch (FFB) processed. POME is a colloidal suspension that contains 95-96% of water, 0.6-0.7% of oil and grease and 4-5% of total solids including 4-5% suspended solids originated from the mixture of sterilized condensate, separator sludge and hydrocyclone wastewater (Ma, 2001).

2.5 F/M ratio

The F/M ratio (food to microorganism) is the most useful design and operational parameter of activated sludge systems. The activated sludge systemis a continues process with growth and decay of microorganism. A system achieves equilibrium when the food substrate and the microorganism consuming it are in balance. Out of balance can mean too much substrate, too little substrate, too many organism, too little organism and others. The equilibrium parameter is known as the F/Mratio or the food to microbes ratio. This ratiocontrols the rate of biological oxidation and the mass of organism, by maintaining microbial growth in either the log, declining or endogenous phase. The type of activated sludge system can be defined by its F/M ratio (**Figure 2.1**)(Kiely, 1998).



Extended aeration – 0.03 < F/M <0.8

Conventional – 0.8 <F/M < 2

High rate – F/M > 2

Figure 2.1: Schematics of F/M ratio (not to scale)

(Source: Environmental Engineering, 1999)

The F/M ratio is defined as

$$\frac{F}{M} = \frac{\text{BOD of sewage (kg/m) x influent flow (m/d)}}{\text{Reactor solid (kg/m) x Reactor volume (m)}}$$

In the log or accelerated growth phase there is an excess of substrate, characterizing a high F/M ratio (>1.0). In the endogenous phase the F/M ratio is low at values generally less than 0.4 and ideally at around 0.2 for plug flow and 0.1 for complex mix system. Removal rates of BOD are then highest, and this is conventionally called extended aeration (Kiely, 1998).

CHAPTER 3

METHODOLOGY

3.1 Experimental setup

3.1.1 Sample preparation

Sample of anaerobic treated POME is taking from the Nasaruddin Palm Oil Mill in Bota, Perak. The sample is exactly the effluent after the anaerobic treatment before being discharge into the river water. About 25L of sample is taken back to UTP for another post-treatment by using the SBR methods.

In order to prevent the wastewater from undergoing biodegradation due to microbial action, it was preserved at temperature less than 4°C, but above its freezing point. Before any experiment conducted, the sample must be thawed to the room temperature (28°C) (Y. J. Chan, 2010).

3.1.2 Reactor setup

A bioreactor is used for the operation of the SBR with the effective working volume of 5L. An aquarium pump (HAILEA, model of ACO-5505) is used to supply the air to the reactor that was located at the base of the reactor for the aeration in the react phase. The air output of the aquarium pump is 5.5L/m. It is important because the aerobic treatment need sufficient oxygen to occurs. Another pump also used to suck out the effluent from the reactor. The MasterFlex console drive, 77390-00 model by Cole-Parmer is the PTFE tubing pump used to suck out the effluent in 600ml in 15 minutes or the flowrates is 6.67×10^{-7} m^3s^{-1}. The timer used to set the time for each phase in the SBR operation. **Figure 3.1** illustrate the schematics and experimental setup of the system and **Figure 3.3** showing the laboratory reactor setup.

3.1.3 Operation of SBR

The SBR is operated in a 12-h cycles and 24-h cycles basis which consists of five distinct modes; fill, react, settle, decant and idle. The SBR treating 5L volume in the reactor per cycle and 2 cycles per day (12-h cycles) and 1 cycles per day (24-h cycles). Because of only one pump used in the research the filling of the influent must be done manually. A sample of treated effluent for every cycles is collected for the analysis. Subsequently, the reactor was filled for next cycle of reaction without any downtime. **Figure 3.2** shows every phase in SBR.

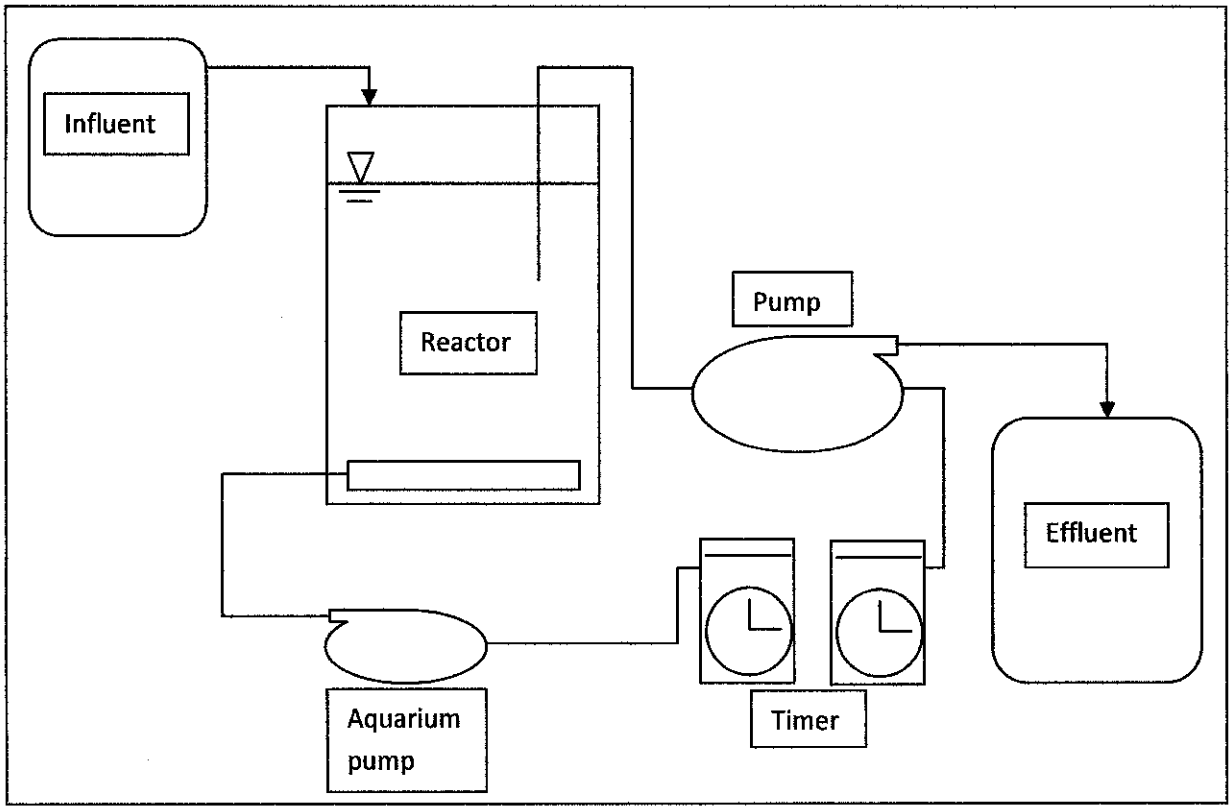


Figure 3.1: Schematic diagram of SBR system

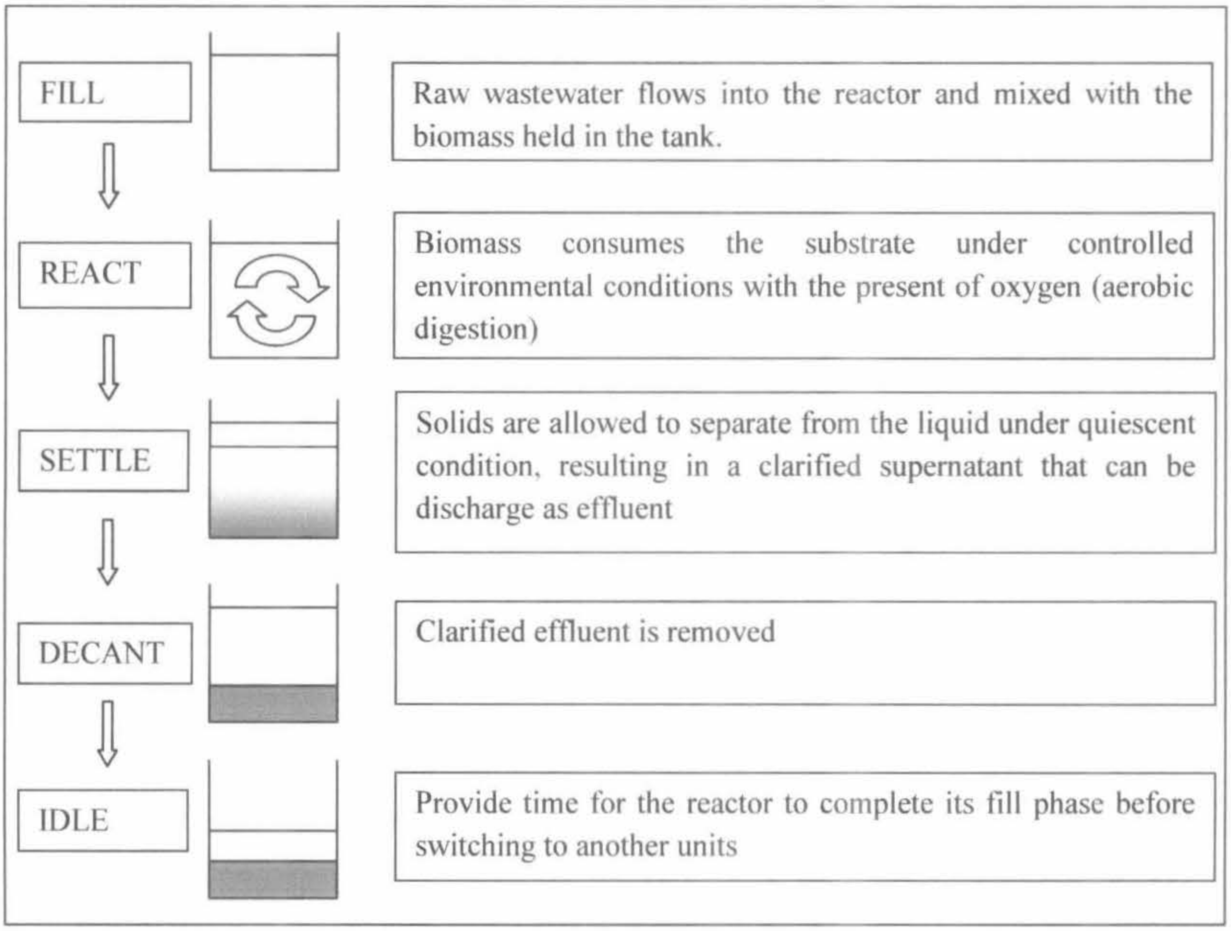


Figure 3.2: SBR system operations

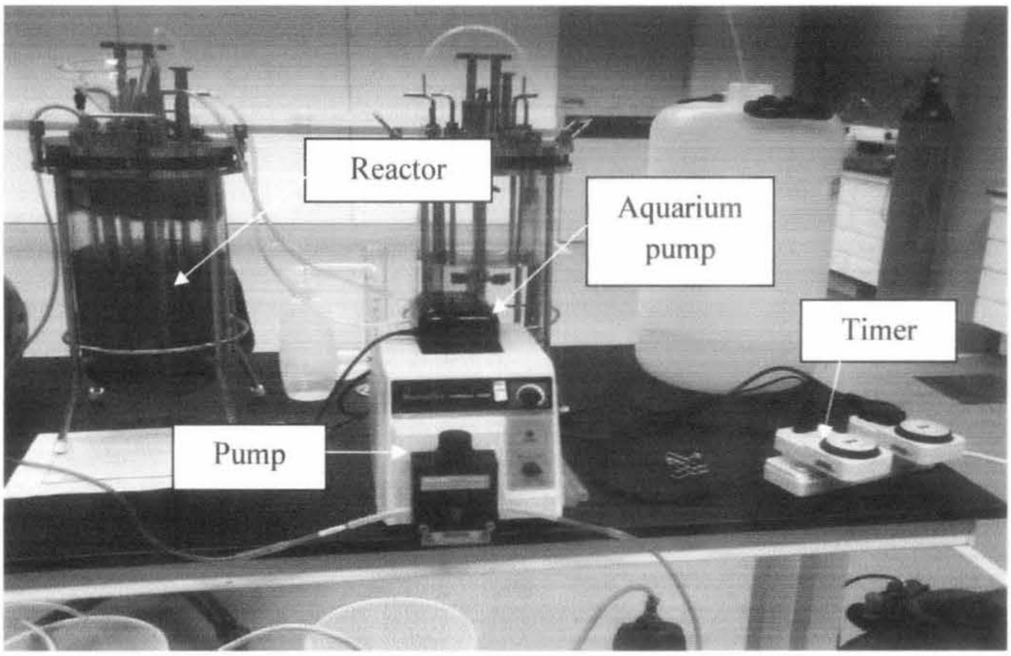


Figure 3.3: Laboratory reactor setup

3.2 Analytical methods

3.2.1 Biological oxygen demand (BOD)

BOD was analysed according to the analytical methods 8043 of Standard Methods (APHA, 1998)

The BOD was determined by measuring the dissolved oxygen by the microorganism in the biochemical oxidation of organic matter. The sample was poured into the BOD bottles and seeded with the activated sludge or influent. Then the BOD bottles were placed in the refrigerator at 20°C for 5 days. The initial and final dissloved oxygen (DO) are measured by using DO probe.

The value of BOD is measure using the equation of;

To determine the BOD value without seed correction:

$$= \frac{(Initial\ dissolved\ oxygen) - (Final\ dissolved\ oxygen) - (Blank\ correction)}{\frac{Sample\ size}{300}} \quad (Eq. 1)$$

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

$$= \frac{(Initial\ dissolved\ oxygen) - (Final\ dissolved\ oxygen) - (Seed\ \&Blank\ correction)}{\frac{Sample\ size}{300}} \quad (Eq. 2)$$

To determine the BOD value with seed correction and blank correction

as well as dilution:

$$= \frac{(Initial\ dissolved\ oxygen) - (Final\ dissolved\ oxygen) - (Seed\ \&Blank\ correction)}{\frac{Sample\ size}{300}} \quad (Eq. 3)$$

3.2.2 Chemical oxygen demand (COD)

Total and soluble chemical oxygen demand was analysed by adapting the analytical method of HACH, method 10212.

The COD was determind by an oxidationof a boiling mixture of chromic and sulphuric acids. The sample was refluxed in a strong acid solution with an excess of potassium dichromate ($K_2Cr_2O_7$). After two hours of digestion, the oxidizable matter was calcuted in terms of oxygen equivalent.

3.2.3 Soluble chemical oxygen demand (sCOD)

The sCOD is analysed according to the Standard Methods. The sample was first centrifuged at 2332g for 15 minutes. The supernatant from the centrifuge process being filter through a 0.45 μm membrane filter. The value of sCOD were determined using the colorimetric method in Hach COD vials and reactor. The Hach spectrophotometer DR/2000 is used to show the value.

3.2.4 Total suspended solids (TSS)

TSS was analysed according to the analytical methods 2540B of Standard Method (APHA, 1998). An amount of well-mixed sample was put in a filter paper and dried overnight to a constant temperature at 103-105°C. The weight of filter paper and the filter paper with the dried residue was determine and used to calculate the TSS in mg/L. The TSS is measured by the following formula;

$$= \frac{(Weight\ of\ pan + filter\ paper\ after\ drying) - (Weight\ of\ pan + filter\ paper\ before\ drying)}{(Sample\ size\ (L))} \qquad (Eq. 5)$$

3.2.5 Mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS)

MLSS and MLVSS were analysed according to the analytical methods 2540D and 2450E of Standard Methods (APHA, 1998).

For MLSS determination, a well mixed sample was filtered through a weight standard glass-fiber filter (GF/C 47mm) and the residue retained on the filter was dried an hour to a constant temperature at 103-105°C. The weight if the filter and the dried residue was determined and used to calculate the MLSS in mg/L.

MLVSS was determined by the combustion of the MLSS filter in a furnace at a temperature of 550°C for 15-20 minutes. Then, partially cooled in the air until most of the heat had been dissipated and transfer. The weight of the dried residue and the combustion residue was used to calculate the MLVSS in mg/L.

The determination of MLSS and MLVSS by using the following formula;

To determine the MLSS of the sample:

$$= \frac{(Weight\ of\ pan + filter\ paper\ after\ drying) - (Weight\ of\ pan + filter\ paper\ before\ drying)}{(Sample\ size\ (L))} \quad (Eq.6)$$

To determine the MLVSS of the sample:

$$= \frac{(Weight\ of\ pan + filter\ paper\ after\ furnace) - (Weight\ of\ pan + filter\ paper\ before\ furnace)}{(Sample\ size\ (L))} \quad (Eq.7)$$

3.3.6 pH determination

pH of the wastewater sample was determined using a digital pH meter based on the HACH method, pH method 8156.

3.3 Experimental procedure

The parameters used to evaluate the performance of the SBR in treating the anaerobically treated POME is COD, sCOD, MLSS, MLVSS, TSS, Temperature and pH. 5 stages were introduced in this research. The 5 stages was the different stages introduce to get the better and improved the results. The 5 stages as shown in the **Table 3.1** below.

Table 3.1: Description of the 5 stages

	Dilution factor	**MLVSS (mg/L)**	**Aeration Time (hour)**	**HRT (hour)**	**Cycles**
Stage 1	1:3	530 – 630	9.75	2.08	12-h
Stage 2	1:1	5500 – 8000	9.75	2.08	12-h
Stage 3	1:1	29000 – 38000	9.75	2.08	12-h
Stage 4	1:1	29000 – 38000	20	2.08	24-h
Stage 5	1:1	11000 – 14000	20	4.17	24-h

The dilution factor was introduced to reduce the influent concentrations. The influent was dilute only at the stage 1 because to acclimatize between the sample (anaerobic treated POME) and the microorganism used in the reactor. In this stage the influent is dilute with the 3 factor of dilution, meaning 2 ml of distilled water was added to 1 ml of sample. Then, the other stages used the raw influent without any dilution.

Different value of MLVSS in every stages showing the different concentration or amount of microorganism used in the reactor. the critical point in this research was to find the right concentration of microorganism to treat the anaerobic treated POME effectively. Low value of MLVSS showing the low concentration of microorganism exist and vice versa.

The aeration time was related to the cycles. The different cycles introduces in this research, 12-h cycles and 24-h cycles. different type of cycle can contribute to the different time of every phases in the SBR system. The main chages in the phases of the cycle was the aeration time. Instead of using 9.75 hour in the 12-h cycle, the 20 hour of aeration time introduced in the 24-h cycles.

HRT relate to the amount of effluent taken out from the reactor. Stage 1 to 4 used 600 ml and stage 5 used 300 ml as the effluent.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 POME characteristics

Several type of test is conducted for the POME before the treatment started in order to find the characteristics of the sample. The resulting operating parameters of COD, sCOD, TSS, temperature, pH, MLSS concentration, MLVSS concentration and F/M ratio were observed throughout the experiment and their value summerized in **Table 4.1.** This initial value would be the base of this research and also the parameters limit and to be reduce after the treatment.

Table 4.1: Characteristics of anaerobic treated POME

Parameters	Concentrations
Temperature (°C)	22-27
pH	8.63 ± 0.008
COD (mg/L) without dilution	682 ± 14
COD (mg/L) 1:3 dilution	211 ± 2
sCOD (mg/L)	589 ± 2
sCOD (mg/L) 1:3 dilution	182 ± 1
BOD (mg/L)	367 ± 15
TKN (mg N/L)	186 ± 44
TSS (mg/L)	29 ± 7

The characteristics of the anaerobic treated POME in this research as in **Table 4.2** and the characteristics from another research as in **Table 1.1** was different in value. Compare to other research the COD and BOD concentration in this research is much lower than the others. This research focused more on the sCOD parameter rather than the COD. The other research did not state the characteristic of the sCOD parameter of the anaerobic treated POME.

The effluent of each cycle for the SBR treatment was collected and tested as the parameters in **Table 4.1**. The results of the effluent compared with the characteristics of POME in order to evaluate the SBR performance in treating the anaerobic treated POME.

4.2 sCOD

The sCOD is the main parameter use in this research to evaluate the SBR performance. The sCOD used to measure the oxygen equivalent of the soluble organic material in wastewater. The value for the sCOD normally lower than the value of COD. The sCOD is just like the fraction from the COD. The effluent is filter first to get the soluble organic material and test with just like the COD. The sCOD was used in this research rather than the COD because the COD value is too high. The COD value being effected by the high concentration of the suspended solids exists in the effluent. The set of data for the COD and the sCOD can be reviewed at the **appendix**. **Figure 4.1** shows the graph of the sCOD result of the effluent for every stages. The removal efficiency of the sCOD also can be reviewed at the **appendix.**

Figure 4.1 showing the result of the sCOD concentration for the effluent. The graph is divided into 5 stages accordingly. This 5 stages were the time frame used in this research and for every stages, different parameters or factors being changes as shown in the **Table 4.1**. The overall result of the graph showing the decreasing of the sCOD concentration happened for each of the stages except in the stage 2 where the value is increasing. The decreasing value of the sCOD showed the SBR working actively in treating the wastewater.

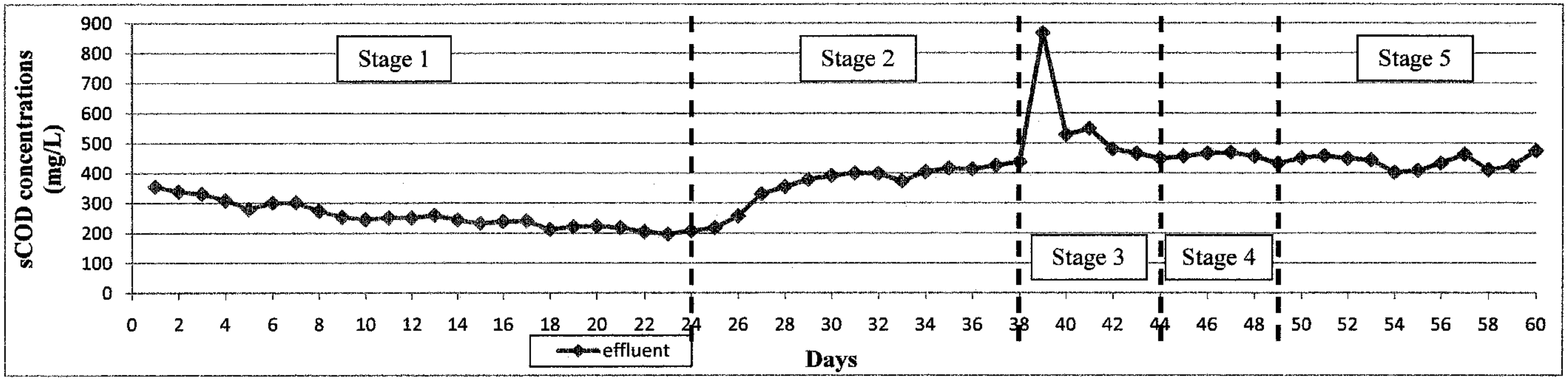


Figure 4.1: Graph of sCOD concentations

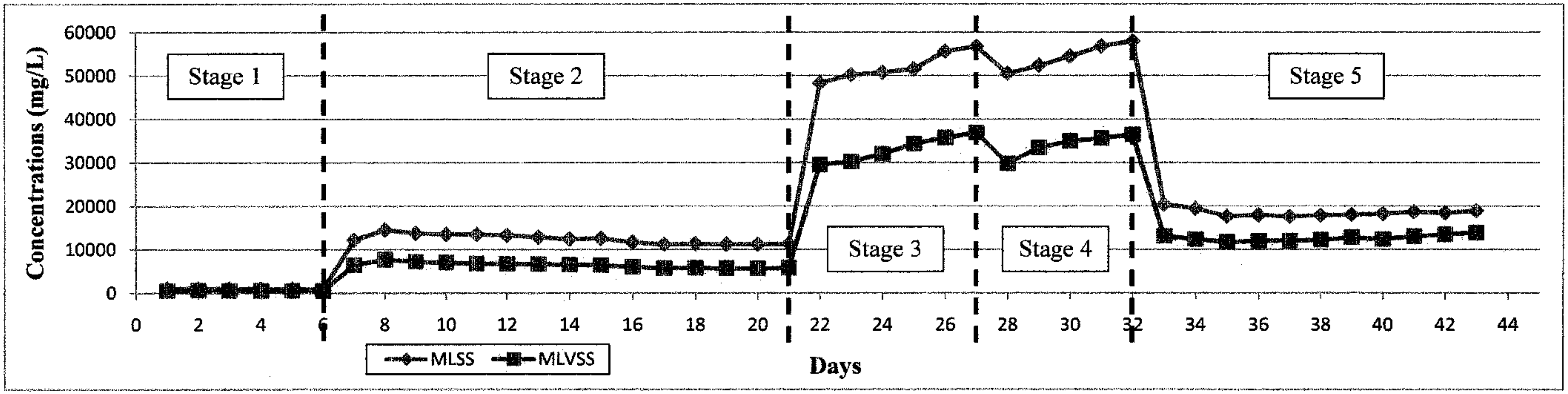


Figure 4.2: Graph of MLSS and MLVSS

The sCOD for every earlier stages showing much higher value and unstable due to the reactor is acclimatize with the situation. The microorganisms need some time for adapting with the new environment before can working effectively. At the stage 3, the first value is obviously high that can reach up to 866 mg/L more than the influent value. Happened because of the microorganism shocked and try to adapt with the new environment.

The sCOD concentration at the stage 1 is more lower than the other stages. The used of lower concentration of influent can reduce the concentration of the effluent. The influent is dilute with the 3 factor of dilution and fill into the reactor with the sludge or microorganisms. The graph showing the value keeps decreasing over time but it took longor times. Seems, the SBR system in stage 1 working properly but slowly in progress to reduce the concentration. But the lowest value of the stage 1, 197 mg/L also cannot reach to the influent concentrations as shown in **Table 4.2**, 182 mg/L. No removal of sCOD concentration happened at the stage 1. More time is needed to reduce the sCOD concentration in the stage 1 to a certain value lower then the influent concentration.

Stage 2 showing a bit different from the other stages. The earlier sCOD concentration is lower than the other but as time increases the concentration also increasing. Meaning the as the time past by the effeciency of the treatment become worst. The increasing of the sCOD concentration maybe due to the several reasons. The microorganism would not react actively or dying and the increase of the influent concentration, without dilution change the reactor performance. The microorganism maybe die in the stage 2 because the MLVSS concentration also decreasing as shown in **Figure 4.2**. The decreasing of the MLVSS value shows the reducing of the microoganism exist in the reactor. The stage 3 is introduce in order to improve the effluent results.

The high value of sCOD concentration at the early of the stage 3 due to the new changes in the reactor. The reactor is filled up with the raw influent without dilution and the sludge concentration is increase than stage 2 and the type of sludge also change. The microorganism took some time to adapt with the new environment before working as usual. The sCOD concentration in this stage reduce by the time. Showing the reactor is working properly.

For the stage 4 the sCOD concentrationis decreasing. The value of the stage 4 just likely continue from the stage 3. The different between the stage 3 and stage 4 is just the aeration time. The other parameters for this two stages were the same; influent concentration, sludge concentration, type of sludge, air flowrate and HRT. From the graph, the sCOD value did obviously not showing any particular different between this two stages. The sCOD concentration just slightly decrease over time, more likely being stable. The aeration time factor did not really had significant impact in the SBR system.

sCOD concentration in stage 5 also decreasing over time. The value can even reach to 402 mg/L that is 32% removal. The changes happened in this stage is the sludge concentration-sludge concentration is reducing from stage 4 and HRT.

4.3 MLSS and MLVSS

MLSS and MLVSS are both used to measures of the microorganism concentration in the system. MLSS included both the volatile and inert solids in the mixed liquor. MLVSS more closely approximates the biologically active portion of the solids in the mixed liquor, as microbial cellular material is organic and volatilizes or burns at 550°C [Y. J. Chan, 2010]. **Figure 4.2** showing the value of the sludge or microorganisms in the reactor of SBR treatment. The value of MLSS is higher than the MLVSS because of the MLSS included both the volatile and inert solids. The volatile fraction of the ratio of MLVSS:MLSS for the typical value is 0.85 [Metcalf, 2003] or 0.80 [Woodside and Kocurek, 1997]. In the present study, MLSS is measured more frequently than MLVSS, as the analytical test for suspended solids is quicker than the rest for volatile suspended solids. Hence, the MLVSS was approximated by using the ratio of MLVSS:MLSS [Y. J. Chan, 2010].

From **Figure 4.2** the graph also divided into the 5 stages. The stages are as shown in the **Table 4.1**. The overall graph showing the MLSS and MLVSS increasing over time except at the stage 2. The increasing concentration of both MLSS and MLVSS means the microorganism is actively working and multiple over time. The sludge concentration in the reactor is the most critical factor that contribute to the SBR performance. The most optimum sludge must be used in order to get the most effective treatment of the SBR system in treating the POME.

Stage 1 used the lowest concentration of the sludge in the reactor. Due to the dilution of the influent to the factor 3, the sludge concentration also reduce. The MLVSS is ranging between 530 mg/L to 630 mg/L. The sludge used in this stage taken from Sewage Treatment Plan (STP) in Universiti Teknologi Petronas (UTP).

For stage 2 the sludge concentration is increase a bit from the stage 1. After changing the influent from 3 dilution factor to raw influent without dilution, the influent concentration is increasing. Meaning the food for the microorganism also increases. To counter the increase food, the sludge also being increases. But after a while, the graph showing the value of the MLSS and MLVSS concentration is decreasing. Something happened to the microorganisms. The microorganism become less active or dying. Some factor contribute to the killing of the microorganism were the existance of the toxic material, temperature and pH.

For stage 3 and 4, the sludge concentration was increasing in order to find the optimum concentration of sludge in the reactor. The sludge was ranging between 29000 mg/L to 30000 mg/L. Because the high concentration of sludge used in the stage 3 and 4, the value of the sCOD also did not improve as much as the sludge concentration increases. In the stage 5, the sludge concentration being reduce from the stage 3 and 4 to a value ranging between 11000 to 14000 mg/L. Instead of increase the sludge concentration in the stage 5 but reduce sludge concentration in the reactor because another research shows the optimum sludge concentration for the SBR in treating the POME is ranging betwee 17500 to 20000 mg/L [Y. J. Chan, 2010]. The optimum sludge concentration is important in order to get the high quality of the result and make sure the SBR treatment is working effectively.

4.4 TSS

TSS is a parameter used to evaluate the concentration of the suspended solids exist in the effluent. High value of TSS represent the effluent is contain high concentration is suspended solids. The high performance of the SBR ia attributed to the appropriate acclimatization of the biomass which possesses good settling properties. The microorganisms are robust and able to purify the anaerobically digested POME effectively since proper environmental conditions are maintained in the SBR. In addition, the suspended matteris effectively removed by physical entrapment in the activated sludge floc and thereby appreciable TSS removal are attained [Y. J. Chan, 2010].

The attribute of the TSS concentration most influenced by the sludge concentration in the reactor. The high value of the sludge concentration produce more suspended solids after the treatment. The HRT also contribute to the TSS concentrations. The longer contact time given between the microorganism and the wastewater can generate more suspended solids. **Figure 4.3** showing the graph of the TSS concentration according to the stage respectively. The TSS concentration can contribute to the COD value. High suspended solids can increase the COD value.

From **Figure 4.3**, the value of the TSS concentration in the stage 1 is the most lower value attained in this research. Due to the lower concentration of the sludge used the suspended solids can be reduce. By time pass by the TSS concentration is decreasing. Showing the treatment can reduce the suspended solids exist in the reactor.

As the sludge concentration is increase in the stage 2, stage 3 and stage 4 the TSS concentration also increases. The sludge concentration in the reactor give the most effect to the TSS concentration. High amount of the sludge used for the reactor can produce high amount of the suspended solids. But as the treatment working the TSS concentration is reduce over time.

For the stage 5, the TSS concentration is the most higher then the other stages. Although the sludge concentration is less then the stage 4 and stage 5 but the HRT in this stage is longer than the other stages. The contact time given for the treatment cn generates more suspended solids. But as the other stages, the TSS concentration is reducing over time because of the effective treatment occured.

4.5 Temperature and pH

Temperature and pH are other factors which significantly effect the performance of the SBR treatment [Y. J. Chan, 2010]. Because the temperature and pH are the environmental conditions that have an important effect on the selection, survival, and growth of the microorganisms. In general, optimal growth for a particular microorganism occurs within a fairly narrow range of temperature and pH, although most microorganism can survive within much broader limits [Metcalf, 2003].

Temperature affects the performance of treatment systems as a results of its impact on the rates of biological reactions. The optimum temperatures for bacterial activity are in the range of 25 - 35°C [Leslie Grady, 1999]. Temperature below the optimum typically have a more significant effect on growth rate then the temperature above the optimum. It has been observed that growth rate double with approximately every 10°C increase in temperature until the optimum temperature is reached [Metcalf, 2003].

Figure 4.4 showing the reactor temperature for the SBR treatment in this research. The overall temperature ranging between 22°C to 27°C for every stages. The temperature is still in the acceptable condition for the growth and operation of the microorganisms. The temperature ranging just in **Figure 4.4** because of the room temperature at the laboratory is lower that is ranging about 20°C to 25°C.

The pH in biological system has been known to affect microbial growth, but the quantative effects are unclear [Leslie Grady, 1999]. The pH is not the critical factor which determines the performance of SBR. However, this implies that the active growth of the microorganism can be sustained at the pH range of 7.5 – 9.2 [Y. J. Chan, 2010]. Most bacteria cannot tolerate pH level above 9.5 or below 4.0. Generally, the optimum pH for bacterial growth lies between 6.5 to 7.5 [Metcalf, 2003].

Figure 4.5 showing the graph of the pH in every stages of this research. The overall pH value is acceptable as the value ranging between 7.0 to 9.5. This indicates that the pH adjustment is unnecessary. Also reported a systematic increase in pH, from 7.5 to 8.5 in the aerobic treatment of bleached kraft pulp mill effluent [Tripathi, 1999].

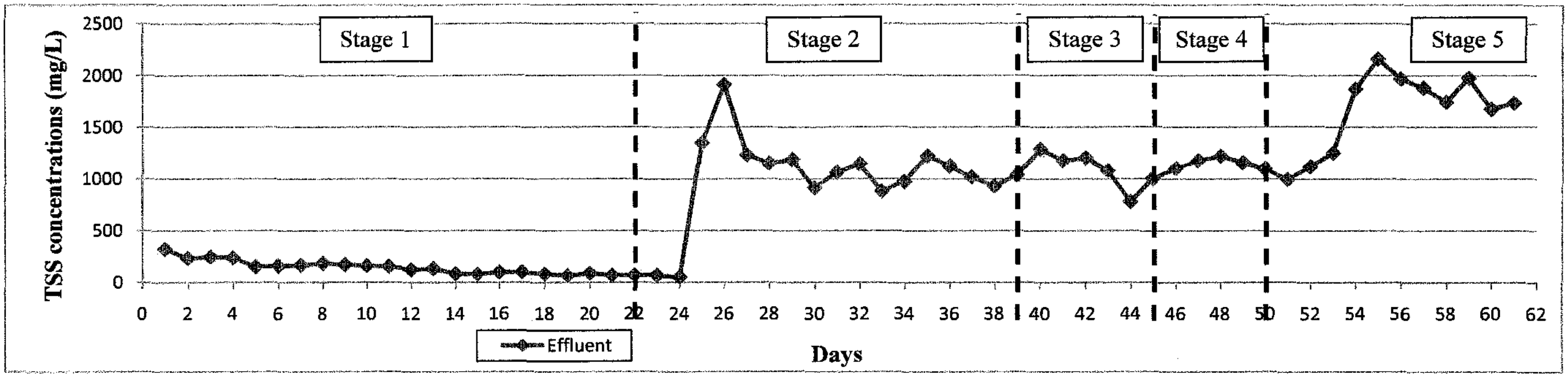


Figure 4.3: Graph of TSS concentrations

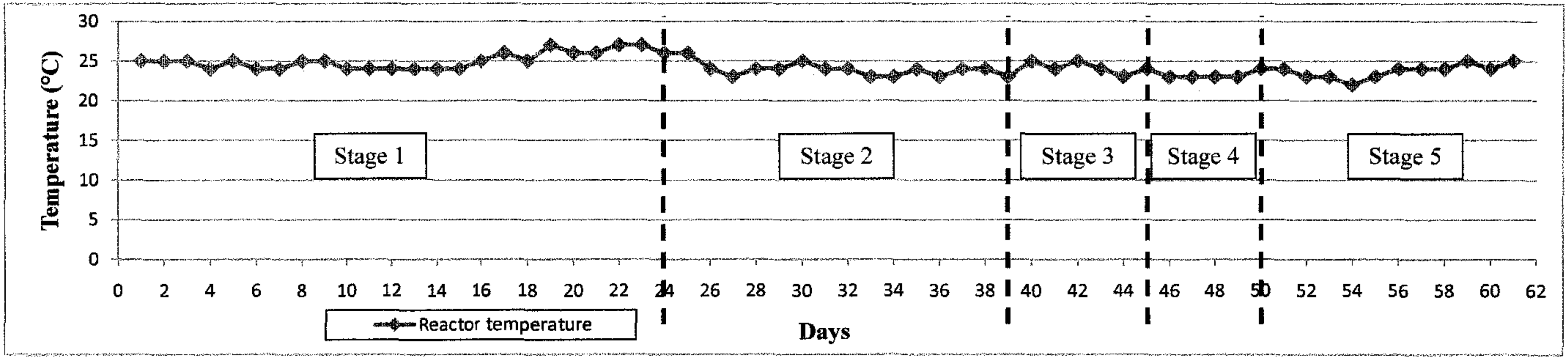


Figure 4.4: Graph of temperature

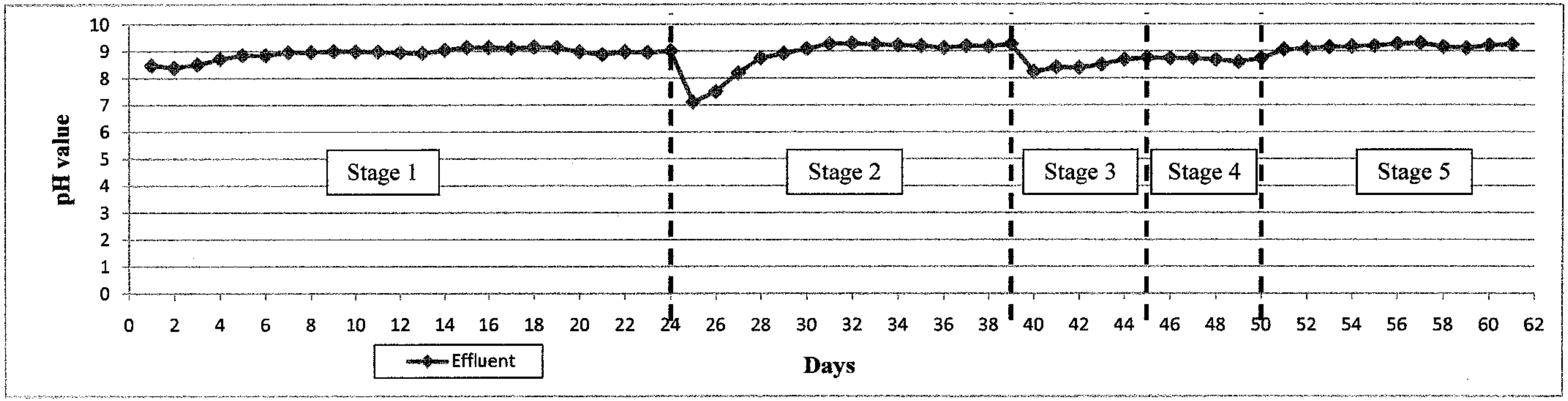


Figure 4.5: Graph of pH

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The SBR is an effective process for the post-treatment of anaerobically treated which can reduce the COD, sCOD and TSS concentrations. Although the value of COD did not reach up to the influent value, means no removal of COD but the COD concentration of the effluent continually decrease over time. It may take more time for the COD concentration to be reduce more than the influent value. The TSS also in same cases as the COD. The promising results show by the sCOD concentration. The percent removal of the sCOD can reach up until 32%.

The relatively high performance of the SBR were found to be attributed by several factors; adequate MLVSS concentration which is the amount of sludge or microorganisms and the development of good settling sludge. Temperature and pH were found to have slightly influences on the performance of the SBR.

It is recommend to research about the other factor that may influences the performances of SBR such as, type of microorganisms used, the optimum number of cycles, the optimum time for every phases in the SBR, the optimum flowrate of the oxygen given to the reactor and the other wastewater that can be treated by the SBR.

The treatment result using the SBR system as the biological treatment is not very effective because the optimum removal percentage of sCOD in this research can only up to 32%. The removal percentage is too low. So, another type of post treatment can be issued. Rather than using the biological treatment, the non-biological treatment can be introduced, such as physicochemical treatment.

CHAPTER 6

ECONOMIC BENEFIT

The SBR is most economical post-treatment of the wastewater and also produce high treatment efficiency. The SBR can save more money and energy compare to the other wastewater treatment because the SBR can be design according to the calculated of the capacity of influent and effluent used. For example;

Volume of waste production (influent) = 20 000 L per day

Influent for each cycle = 10 000 L (2 cycle provided per day)

Total volume of reactor for 600ml of influent is 5L. So, the total volume of reactor for 10000L influent is 83333L.

83333L of volume convert to meter is 83.33m^3

If the height of the reactor is 3m, so the area needed is 27.8m^2

The land that need to cover the reactor is 27.8m^2 or 0.00686953 acre.

This is the simple calculation for finding the land used for the reactor of SBR treatment. If the volume capacity of the influent is known, the calculation of land used can be estimated. The exact calculation can reduce the cost in term of land use, energy use and the cost for constructions. The design also can be calculated according to the volume and capacity of the influent. Means the reactor size is depend on the volume capacity of the influent.

Furthermore, the SBR is operated with simple tank with complete cycle like the activated sludge system. The land used for the SBR treatment is smaller rather than the treatment using the activated sludge system.

Compare to the physicochemical is seen to have less economical values compared to biological treatment because of the matters which are;

- The item like large crushers, mills, shredders and macerators can be expensive to purchase, particularly with associated material handling plant.
- Equipment capital costs are high and power consumption and maintenance contribute to high operating costs.

For example in chemical precipitation – Reagent very variable in cost – lime usually inexpensive but sulphide generation can be more costly.

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APPENDICES

sCOD data

No. of day	Date	Reading			Average (mg/L)	Standard deviation	Percent removal
		1	2	3			
1	12/2	360	358	344	354	9	0
2	13/2	340	335	340	338	3	0
3	14/2	335	332	322	330	7	0
4	15/2	313	306	308	309	4	0
5	16/2	284	286	268	279	10	0
6	17/2	302	289	309	300	10	0
7	18/2	288	289	327	301	22	0
8	19/2	280	275	266	274	7	0
9	20/2	256	250	253	253	3	0
10	21/2	243	239	254	245	8	0
11	22/2	256	248	250	251	4	0
12	23/2	243	255	254	251	7	0
13	24/2	263	249	266	259	9	0
14	25/2	240	246	246	244	3	0
15	26/2	234	232	231	232	2	0
16	27/2	231	243	241	238	6	0
17	28/2	240	246	235	240	5	0
18	1/3	224	217	194	212	16	0
19	2/3	225	223	216	221	5	0
20	3/3	229	208	232	223	13	0
21	4/3	220	212	222	218	5	0
22	5/3	200	210	202	204	5	0
23	6/3	209	197	184	197	13	0
24	7/3	208	210	204	207	3	0
1	9/3	224	211	218	218	7	63
2	10/3	258	276	236	257	20	56
3	11/3	332	327	333	331	3	44
4	12/3	358	351	355	355	4	40
5	13/3	373	383	379	378	5	36
6	14/3	393	390	392	392	2	33
7	15/3	397	404	399	400	4	32
8	16/3	395	399	401	398	3	32
9	17/3	370	375	375	373	3	37
10	18/3	398	408	405	404	5	31
11	19/3	413	419	417	416	3	29
12	20/3	408	418	412	413	5	30
13	21/3	434	419	425	426	8	28
14	22/3	445	429	436	437	8	26

1	25/3	613	1146	840	866	267	0
2	26/3	528	525	530	528	3	10
3	27/3	504	596	543	548	46	7
4	28/3	460	500	478	479	20	19
5	29/3	456	476	464	465	10	21
6	30/3	449	450	445	448	3	24
1	1/4	463	451	455	456	6	23
2	2/4	455	479	464	466	12	21
3	3/4	471	467	469	469	2	20
4	4/4	455	454	460	456	3	23
5	5/4	435	430	432	432	3	27
1	8/4	453	448	450	450	3	24
2	9/4	464	457	452	458	6	22
3	10/4	456	443	446	448	7	24
4	11/4	432	456	444	444	12	25
5	12/4	396	408	402	402	6	32
6	13/4	402	420	402	408	10	31
7	14/4	432	420	444	432	12	27
8	15/4	456	468	462	462	6	22
9	16/4	408	414	408	410	3	30
10	17/4	414	438	420	424	12	28
11	18/4	468	480	474	474	6	20

MLSS and MLVSS data

No. of day	Date	MLSS					MLVSS				
		1	2	3	Average	Stdr. Dev.	1	2	3	Average	Stdr. Dev.
1	2/3	970	960	980	970	10	550	520	600	557	40
2	3/3	950	900	920	923	25	530	550	790	623	145
3	4/3	920	900	970	930	36	530	570	540	547	21
4	5/3	940	910	930	927	15	560	640	500	567	70
5	6/3	950	880	900	910	36	510	550	570	543	31
6	7/3	890	870	800	853	47	480	610	510	533	68
1	8/3	12130	12220	12240	12197	59	6340	6410	6470	6407	65
2	9/3	14600	14740	14260	14533	247	7710	7860	7610	7727	126
3	10/3	13680	13920	13690	13763	136	7110	7250	7200	7187	71
4	11/3	13800	13430	13290	13507	264	7140	6980	6900	7007	122
5	12/3	13670	13340	13590	13533	172	6840	6800	6720	6787	61
6	13/3	13540	13310	13010	13287	266	6690	6710	6720	6707	15
7	14/3	12890	13070	12660	12873	206	6630	6590	6680	6633	45
8	15/3	12540	12280	12420	12413	130	6510	6580	6500	6530	44
9	16/3	12490	12660	12630	12593	91	6390	6450	6450	6430	35
10	17/3	11630	11640	11760	11677	72	5980	5930	6050	5987	60
11	18/3	11460	11060	11100	11207	220	5840	5650	5620	5703	119
12	19/3	11330	11200	11370	11300	89	5760	5790	5710	5753	40
13	20/3	11000	11390	11230	11207	196	5680	5630	5720	5677	45
14	21/3	11020	11270	11140	11143	125	5540	5690	5640	5623	76
15	22/3	11330	11210	11160	11233	87	5820	5730	5700	5750	62

1	25/3	48180	47960	48640	48260	347	29940	28900	29660	29500	538
2	26/3	49080	51940	49560	50193	1532	30580	31280	28660	30173	1357
3	27/3	48420	51700	52060	50727	2006	33740	31440	30860	32013	1523
4	28/3	46620	55460	52540	51540	4504	31100	35740	36220	34353	2828
5	29/3	54100	55080	57620	55600	1817	34300	35120	37800	35740	1831
6	30/3	58240	54930	56948	56706	1668	35670	37030	37970	36890	1156
1	1/4	51010	50550	49820	50460	600	28900	29560	30880	29780	1008
2	2/4	52470	52030	52520	52340	270	33230	33670	33450	33450	220
3	3/4	54890	54070	54390	54450	413	34730	35020	34980	34910	157
4	4/4	57050	56340	56950	56780	384	35690	35060	36140	35630	542
5	5/4	58120	57670	57970	57920	229	36390	36920	36040	36450	443
1	8/4	22340	16840	21980	20387	3077	13320	12140	13740	13067	830
2	9/4	18860	17580	21880	19440	2208	12200	11960	12900	12353	488
3	10/4	17740	18040	17020	17600	524	11440	12020	11660	11707	293
4	11/4	14720	22080	16960	17920	3773	11680	13220	10920	11940	1172
5	12/4	18100	16560	18040	17567	872	11800	11740	12420	11987	376
6	13/4	17780	17940	17809	17843	85	12005	12202	12423	12210	209
7	14/4	18180	17980	17900	18020	144	12890	12343	13047	12760	370
8	15/4	18290	18110	18296	18232	106	12830	12211	12069	12370	405
9	16/4	18540	18740	18742	18674	116	12890	13100	13130	13040	131
10	17/4	18650	18230	18416	18432	210	13248	13672	13430	13450	213
11	18/4	18990	18340	19340	18890	507	13654	14008	13975	13879	196

TSS data

No. of day	Date	Reading			Average (mg/L)	Standard deviation
		1	2	3		
1	12/2	330	316	316	323	8
2	13/2	258	254	188	233	39
3	14/2	244	238	260	247	11
4	15/2	298	190	178	238	66
5	16/2	150	154	152	152	2
6	17/2	156	168	166	161	6
7	18/2	174	204	126	168	39
8	19/2	184	178	190	184	6
9	20/2	168	154	178	173	12
10	21/2	166	154	160	160	6
11	22/2	174	150	142	155	17
12	23/2	124	134	122	123	6
13	24/2	144	136	122	134	11
14	25/2	74	92	90	85	10
15	26/2	78	82	78	79	2
16	27/2	114	86	98	99	14
17	28/2	96	106	102	101	5
18	1/3	84	92	82	83	5
19	2/3	62	68	70	67	4
20	3/3	92	86	88	89	3
21	4/3	52	60	86	69	18
22	5/3	48	98	68	71	25
23	6/3	76	66	68	70	5
24	7/3	42	52	60	51	9
1	8/3	1360	1344	1340	1348	11
2	9/3	1932	1924	1880	1912	28
3	10/3	1304	1068	1316	1229	140
4	11/3	1112	1296	1040	1149	132
5	12/3	1248	1200	1120	1189	65
6	13/3	968	972	808	916	94
7	14/3	1060	1072	1064	1065	6
8	15/3	1204	1112	1120	1145	51
9	16/3	932	900	816	883	60
10	17/3	1004	964	964	977	23
11	18/3	1220	1232	1216	1223	8
12	19/3	1152	1104	1120	1125	24
13	20/3	1016	1016	1028	1020	7
14	21/3	928	936	928	931	5
15	22/3	1076	976	1064	1039	55
1	25/3	1301	1270	1296	1289	17

2	26/3	1100	1241	1190	1177	71
3	27/3	1237	1244	1128	1203	65
4	28/3	1124	1060	1060	1081	37
5	29/3	510	520	1310	780	459
6	30/3	1030	1100	890	1007	107
1	1/4	1098	1132	1076	1102	28
2	2/4	1128	1207	1199	1178	43
3	3/4	1267	1232	1164	1221	52
4	4/4	1198	1143	1127	1156	37
5	5/4	1104	1076	1114	1098	20
1	8/4	1520	730	750	1000	450
2	9/4	980	1150	1230	1120	128
3	10/4	1340	1040	1370	1250	182
4	11/4	2960	1290	1350	1867	947
5	12/4	2460	2450	1560	2157	517
6	13/4	2001	1867	2027	1965	86
7	14/4	1845	1902	1893	1880	31
8	15/4	1721	1778	1727	1742	31
9	16/4	1906	2045	1974	1975	70
10	17/4	1545	1698	1779	1674	119
11	18/4	1564	1746	1886	1732	161

Temperature data

No. of day	Date	Reactor temperature (°C)
1	12/2	25
2	13/2	25
3	14/2	25
4	15/2	24
5	16/2	25
6	17/2	24
7	18/2	24
8	19/2	25
9	20/2	25
10	21/2	24
11	22/2	24
12	23/2	24
13	24/2	24
14	25/2	24
15	26/2	24
16	27/2	25
17	28/2	26
18	1/3	25
19	2/3	27
20	3/3	26
21	4/3	26
22	5/3	27
23	6/3	27
24	7/3	26
1	8/3	26
2	9/3	24
3	10/3	23
4	11/3	24
5	12/3	24
6	13/3	25
7	14/3	24
8	15/3	24
9	16/3	23
10	17/3	23
11	18/3	24
12	19/3	23
13	20/3	24
14	21/3	24
15	22/3	23

1	25/3	25
2	26/3	24
3	27/3	25
4	28/3	24
5	29/3	23
6	30/3	24
1	1/4	23
2	2/4	23
3	3/4	23
4	4/4	23
5	5/4	24
1	8/4	24
2	9/4	23
3	10/4	23
4	11/4	22
5	12/4	23
6	13/4	24
7	14/4	24
8	15/4	24
9	16/4	25
10	17/4	24
11	18/4	25

pH data

No. of day	Date	Reading			Average	Standard deviation
		1	2	3		
1	12/2	8.54	8.46	8.44	8.48	0.05
2	13/2	8.39	8.39	8.40	8.39	0.01
3	14/2	8.51	8.51	8.51	8.51	0.00
4	15/2	8.71	8.71	8.71	8.71	0.00
5	16/2	8.88	8.88	8.79	8.85	0.05
6	17/2	8.84	8.85	8.85	8.85	0.01
7	18/2	8.96	8.96	8.96	8.96	0.00
8	19/2	8.96	8.97	8.97	8.97	0.01
9	20/2	8.99	9.00	9.00	9.00	0.01
10	21/2	9.00	8.98	8.99	8.99	0.01
11	22/2	8.98	8.98	8.98	8.98	0.00
12	23/2	8.94	8.95	8.95	8.95	0.01
13	24/2	8.92	8.92	8.92	8.92	0.00
14	25/2	9.04	9.04	9.04	9.04	0.00
15	26/2	9.13	9.14	9.14	9.14	0.01
16	27/2	9.13	9.13	9.14	9.13	0.01
17	28/2	9.10	9.11	9.11	9.11	0.01
18	1/3	9.11	9.16	9.17	9.15	0.03
19	2/3	9.12	9.13	9.13	9.13	0.01
20	3/3	8.96	8.98	8.98	8.97	0.01
21	4/3	8.86	8.87	8.88	8.87	0.01
22	5/3	8.95	8.96	9.03	8.98	0.04
23	6/3	8.94	8.96	8.96	8.95	0.01
24	7/3	9.01	9.01	9.01	9.01	0.00
1	8/3	6.95	7.17	7.18	7.10	0.130
2	9/3	7.48	7.49	7.51	7.49	0.015
3	10/3	8.15	8.21	8.21	8.19	0.035
4	11/3	8.74	8.75	8.75	8.75	0.006
5	12/3	8.89	8.91	8.95	8.92	0.031
6	13/3	9.06	9.09	9.09	9.08	0.017
7	14/3	9.26	9.27	9.27	9.27	0.006
8	15/3	9.27	9.27	9.28	9.27	0.006
9	16/3	9.25	9.25	9.25	9.25	0.000
10	17/3	9.21	9.22	9.22	9.22	0.006
11	18/3	9.19	9.19	9.19	9.19	0.000
12	19/3	9.09	9.12	9.12	9.11	0.017
13	20/3	9.17	9.20	9.20	9.19	0.017
14	21/3	9.18	9.23	9.10	9.17	0.066
15	22/3	9.25	9.26	9.26	9.26	0.006

1	25/3	8.20	8.25	8.24	8.23	0.026
2	26/3	8.39	8.40	8.40	8.40	0.006
3	27/3	8.37	8.37	8.38	8.37	0.006
4	28/3	8.43	8.57	8.49	8.50	0.070
5	29/3	8.67	8.69	8.69	8.68	0.012
6	30/3	8.75	8.75	8.75	8.75	0.000
1	1/4	8.73	8.73	8.73	8.73	0.000
2	2/4	8.74	8.74	8.74	8.74	0.000
3	3/4	8.68	8.67	8.67	8.67	0.006
4	4/4	8.59	8.61	8.61	8.60	0.012
5	5/4	8.72	8.73	8.75	8.73	0.015
1	8/4	9.07	9.04	9.04	9.05	0.017
2	9/4	9.11	9.10	9.10	9.10	0.006
3	10/4	9.14	9.15	9.15	9.15	0.006
4	11/4	9.17	9.17	9.17	9.17	0.000
5	12/4	9.20	9.18	9.18	9.19	0.012
6	13/4	9.27	9.26	9.26	9.26	0.006
7	14/4	9.30	9.29	9.28	9.29	0.010
8	15/4	9.15	9.16	9.16	9.16	0.006
9	16/4	9.10	9.11	9.11	9.11	0.006
10	17/4	9.21	9.20	9.23	9.21	0.015
11	18/4	9.23	9.24	9.24	9.24	0.006