Comparison of Degradation of Refinery Biomass Through Aerobic and Anaerobic Digestion

by

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Dissertation submitted in partial fulfilment of
the requirements for the
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(Civil Engineering)
Dr. Shamsul Rahman B M Kutty
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CERTIFICATION OF APPROVAL

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Approved by,

_____

(DR. SHAMSUL RAHMAN B M KUTTY)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
SEPT 2013

CERTIFICATION OF ORIGINALITY

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

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AHMAD ALIF ADLI B MOHD SUHAIMI

ABSTRACT

This research aims to monitor the pattern of organic degradation of biomass from effluent treatment system by utilizing two distinct methods which are aerobic and anaerobic system. In the wastewater treatment system, the sludge that is used in the treatment will be settled inside the clarifier tank. Some of them will be return as return activated sludge and some of them will be treated either by aerobic system or anaerobic system before being disposed. The organic contents that will be measured are Chemical Oxygen Demand (COD), mixed liquor suspended solid (MLSS) and mixed liquor volatile suspended solid (MLVSS). The sample was obtained from PETRONAS Penapisan Melaka Sdn Bhd (PPMSB) and the experiment is conducted using Anaerobic Sludge Digester. The scope of study will include the characterization of the biomass, the determination of COD, MLSS and MLVSS and the comparison between the aerobic system and anaerobic system. The methodology will include the characterization of the sample, the separation process of supernatant and the sludge, Then the biomass was placed inside the Anaerobic Sludge Digester which is into aerobic and anaerobic reactor with different temperature. Sampling was conducted for the first 24 hours and then continued on daily basis. The final results have shown that there is 88 % of MLSS degradation and 91 % decrease of MLVSS concentration in 24 hours in both reactors and the degradation pattern is successfully obtained. It can be seen that the anaerobic reactor resulted in higher organic content value and also higher degradation rate compared to the aerobic reactor. A comparison will be made for the effectiveness of both methods so that it can be a guide for a better sludge treatment process in the industry.

ACKNOWLEDGEMENT

First and foremost, I would like to express my gratitude my utmost thankfulness to Allah S.W.T the Almighty whom had my Final Year Project I and II to be very meaningful and successful.

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1.1 Background of Study

Wastewater is the water we dispose of from our homes, offices and industry. It comes from toilets, sinks, showers, washing machines and industrial processes and was historically called sewage. The wastewater may contain different types of element depends on the type of activity being held in the area. As an example, in oil and gas industry, large volume of water is used during the refining process in petroleum refineries which subsequently generate large volume of wastewater. The refinery wastewater mostly contains high level of pollutant and each refinery is made up of different plants, which produce different wastewater characteristics that is generally unique and can vary periodically. All of this wastewater will certainly undergoing proper treatment before it can be discharged to the sea.

During the treatment process, the wastewater will be delivered to the clarifier tank. From there, the biomass inside the wastewater will be settled down and the effluent, which is believed already meet the policy requirements will be discharged from the clarifier to the sea. So, what is left is the biomass inside the clarifier tank. Some of them will be recycled back as return activated sludge to the aeration tank and some of them will be disposed of.

So, the study that are being conducted now is to actually get to know what is actually will happen to the biomass especially in terms of its organics contents by using the aerobic and anaerobic system. The sample is retrieved from the PETRONAS Penapisan Melaka Sdn Bhd and the experiment is conducted in the Anaerobic Sludge Digester. So, by doing aerobic and anaerobic system, the results then will be compared to determine which one is better in having the degradation of the biomass.

1.2 Problem Statement

1.2.1 Problem Identification

The Oil and Gas Industry in Malaysia is becoming more advance in term of technology and devices especially in obtaining the crude oil from the source origin. This advancement also leads to higher production of oil and gas to be exported to various countries around the world. In processing the crude oil to be converted into different types of oil, there are a lot of stages need to be undergo and all of these stages are producing the waste that contain a lot of harmful substances.

It is obviously that these wastewater need to be treated properly so that it would not exhibit negative effect to the people and environment when it is discharge into the sea later on. The PPMSB also comply to these rule where they treat their wastewater first before it is being discharged somewhere else, however we do not know what happens to the biomass that are being left inside the clarifier tanks after all the supernatant or effluent are already discharged. There are not so much studies that are being conducted in determining the behaviors and organic changes during the biomass degradation.

1.3 Objectives

The objectives of the research are:

- To determine the behavior and the pattern of the organic degradation of biomass using aerobic and anaerobic system.
- To investigate the effectiveness of both method, which is aerobic system and anaerobic system.

1.4 Scope of Study

Throughout the study, the scope of study will include the characterization of the biomass, the determination of COD, MLSS and MLVSS and the comparison between the aerobic system and anaerobic system.

1.5 Relevancy of the Project

The study is very relevant because from this study, the degradation rate of the biomass can be determined. So, it can be justify that how long time do it needs for the biomass to fully degenerate. We can also determine which system is more efficient in removing the biomass. So, in the future, any of these systems can be recommended to be practiced in the industrial world.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

Wastewater can be generally classified as used water. It includes substances such as human waste, food scraps, oils, soaps and chemicals. In homes, this includes water from sinks, showers, bathtubs, toilets, washing machines and dishwashers. Businesses and industries also contribute their share of used water that must be cleaned (Perlman, 2013).

The petroleum refining industry converts crude oil into more than 2500 refined products including liquefied petroleum gas, gasoline, kerosene, aviation fuel, diesel fuel, fuel oils, lubricating oils, and feedstocks for the petrochemical industry (Benyahia, n.a). Crude oil and condensate refineries generate a large amount of wastewater that has both process and non-process origins (Benyahia, n.a).

Wastewater is characterized in terms of its physical, chemical and biological composition. It should be noted that many of the physical properties and chemical and biological characteristics are interrelated (Tchobanoglous, et. al, 2003). One of the example is the temperature of the wastewater. The degree of the temperature will affect the amount of gases dissolved and the biological activity in the wastewater. In order to characterize the wastewater, proper sampling and analysis is very essential to be done.

2.2 Wastewater Treatment System

Wastewater collected from municipalities and communities must ultimately be returned to receiving waters or to the land or reused (Tchobanoglous, et. al, 2003). Here comes the role of wastewater treatment system. The major aim of wastewater treatment is to remove as much of the suspended solids as possible before the remaining water, called effluent, is discharged back to the environment (Perlman, 2013). The typical

treatment process will involve several steps before the effluent can be allowed to be discharged into the river. The steps are:

1. Preliminary treatment

   During this stage, Coarse and big solids such as rocks, plastics and other big material are being screened out..

2. Primary treatment

   Primary treatment screens wastewater to remove crude solids and skim off grease, oil and fat. It will also enhance the removal of remaining suspended solids and organic matter.

3. Secondary treatment

   Secondary treatment removes biodegradable organic matter by using bacteria to convert degradable organic matter into bacterial cells. The wastewater is then clarified by separating treated liquid from grown bacterial cells using gravity. Bacteria and sludge is then either processed onsite or sent to a separate solids treatment facility.

4. Tertiary treatment

   Further treats effluent to remove nitrogen, phosphorus, fine suspended particles and microbes, and to kill or disable disease-causing organisms and viruses. It is possible to treat effluent in this phase, resulting in a non-potable reclaimed water source, which can be reused in a variety of ways.

2.3 Aerobic and Anaerobic Digestion

Many sludge are treated using a variety of digestion techniques, the purpose of treating these sludge is to reduce the amount of organic matter and the number of disease-causing microorganisms present in the solids. There are a lot of treatment methods that are being implemented nowadays. The most common treatment options include anaerobic digestion, aerobic digestion, and composting.

2.3.1 Anaerobic digestion

Anaerobic digestion is a bacterial process that is carried out in the absence of oxygen. The process can either be thermophilic digestion in which sludge is fermented in tanks at a temperature of 55°C or mesophilic, at a temperature of around 36°C (Mittal, 2011). Though allowing shorter retention time, thus smaller tanks, thermophilic digestion is more expensive in terms of energy consumption for heating the sludge (Mittal, 2011).

Anaerobic digestion generates biogas with a high proportion of methane that may be used to both heat the tank and run engines or microturbines for other on-site processes (Nazaroff, n.a). In large treatment plants sufficient energy can be generated in this way to produce more electricity than the machines require (Nazaroff, n,a). The methane generation is a key advantage of the anaerobic process. However the disadvantage is the production of methane took quite a long time and the capital cost also is high.

Under laboratory conditions it is possible to directly generate useful amounts of electricity from organic sludge using naturally occurring electrochemically active bacteria (Mittal, 2011). Potentially, this technique could lead to an ecologically positive form of power generation, but in order to be effective such a microbial fuel cell must maximize the contact area between the effluent and the bacteria-coated anode surface, which could severely hamper throughput (Mittal, 2011).

2.3.2 Aerobic digestion

Aerobic digestion is a bacterial process occurring in the presence of oxygen. Under aerobic conditions, bacteria rapidly consume organic matter and convert it into carbon dioxide (Ward, n.a). Once there is a lack of organic matter, bacteria die and are used as food by other bacteria. This stage of the process is known as endogenous respiration (Mittal, 2011). Solids reduction occurs in this phase as the bacteria needs to eat each other to survive. Based on the research, aerobic digestion occurs much faster than the anaerobic digestion, hence it helps to reduce the capital cost. It also can produce

high quality supernatant, the process is safer as no methane is produced and easy to operate. However, the operating cost will be much higher because more energy is required to supply the aeration as oxygen is needed for the process and the digested sludge becomes more difficult to dewater. Below is the reaction that happens during aerobic digestion. We can see that because of the absence of microorganisms, the biomass need to eat each other to survive and there will be expected increase of ammonia during the process.

$$\text{Biomass} + O_2 = \text{Less Biomass} + CO_2 + H_2O + NH_3$$ (Gallert, 2005).

2.4 Biomass degradation

Sludge collected during the treatment process contains a large amount of biodegradable material making it amenable to treatment by a different set of micro-organisms, called anaerobic bacteria, which do not need oxygen for growth (David, 2004). It also can be treated by the means of aerobic digestion.

In a biological system microorganisms are known to die and decay. This results in a reduction in active volatile organism mass with time. Two approaches have developed to describe the process of organism decay in a biological wastewater treatment system (Marais, 1980).

- Endogenous respiration approach
- Death-regeneration approach

Endogenous respiration has been attributed to an energy requirement for organism maintenance, where a fraction of the active organism mass is oxidized to provide energy for the maintenance of the mass remaining (Marais, 1980). The mass of organisms that ‘disappear’ is directly equated to the oxygen consumption for endogenous respiration (Marais, 1980). Here, there will be a huge reduction of volatile solids as some die and become food for each others.

Particularly in systems with a longer solid retention time (SRT), growth antagonistic processes play an important role. These processes are generally described as

lysis or decay of active biomass and slow degradation of other organic material (Henze et al., 2000).

Experimentally it is common practice to use aerobic batch digestion experiments to gain information about the processes that are involved in degradation of activated sludge (Spanjers and Vanrolleghem, 1995 and Spanjers et al., 1996). The assumption is that this information is representative to describe decay in an environment where decay and growth takes place simultaneously. The metabolic explanation of these processes is expressed in concepts like endogenous respiration (Gujer et al., 1999), death-regeneration (Dold et al., 1980), maintenance (Loosdrecht van and Henze, 1999) or predation (Moussa et al., 2005). All these concepts are based on the assumption that organic material in activated sludge consists of a biodegradable fraction and an unbiodegradable fraction.

2.5 The degradation pattern

The pattern of the degradation of biomass will be different in different conditions and also depend on the type of the biomass. Generally, what will differ them is the solid retention time and the percentage of volatile solid reduced by time. Typically, when the biomass is undergoing endogenous situation, it will certainly be reduced. Figure below is the degradation pattern based on the information given by Marmara University.

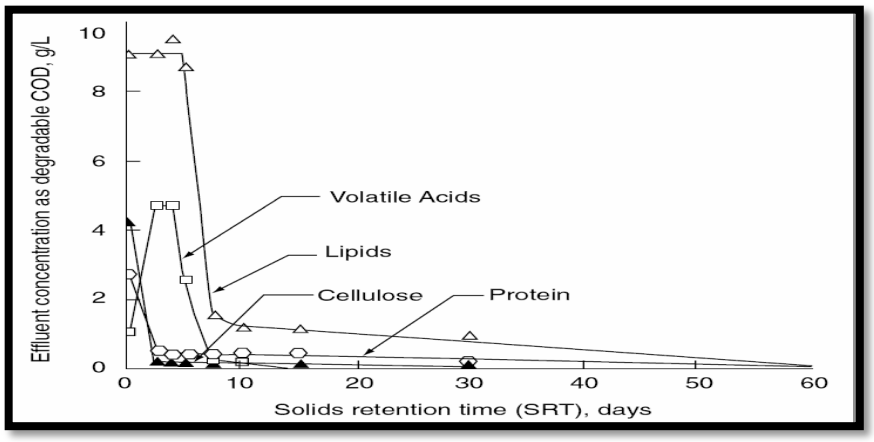

Figure 1: The reduction of organic nutrients against time

It is usually assumed that solids reduction takes place only in the volatile portion of the sludge solids. Therefore, usually we will monitor the amount of volatile solids inside the biomass. In the reduction, it depends on the characteristic of the sludge itself and also the parameter that have been setting up for the specific system.

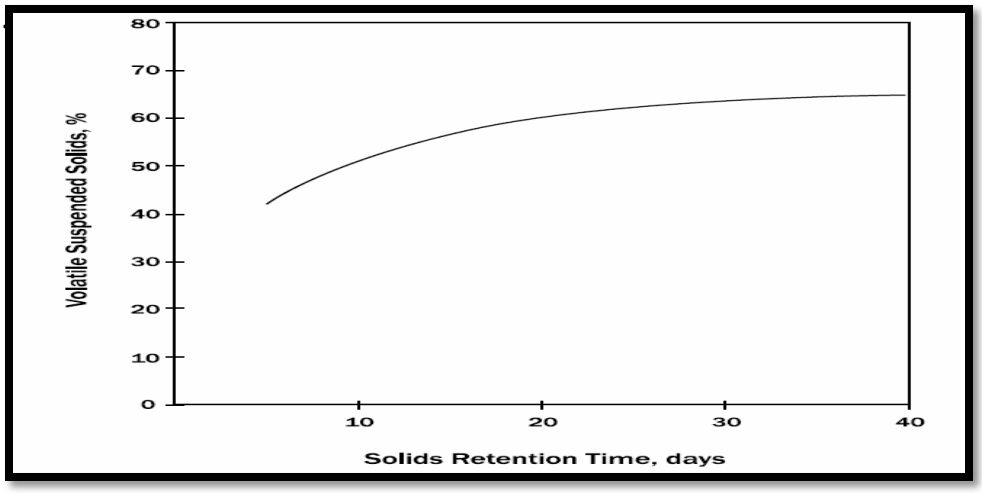

Figure 2: Volatile solids reduction as function of solids retention time

There are also some research that have been conducted to study the rate of decay and also the degeneration of the biomass. Figure below shows the results and pattern of a study that evaluated the potential biodegradability of the endogenous residue in activated sludge subjected to batch digestion under either non-aerated or alternating aerated and non-aerated condition by Abdellah Ramdani from Ecole Polytechnique of Montreal in 2010.

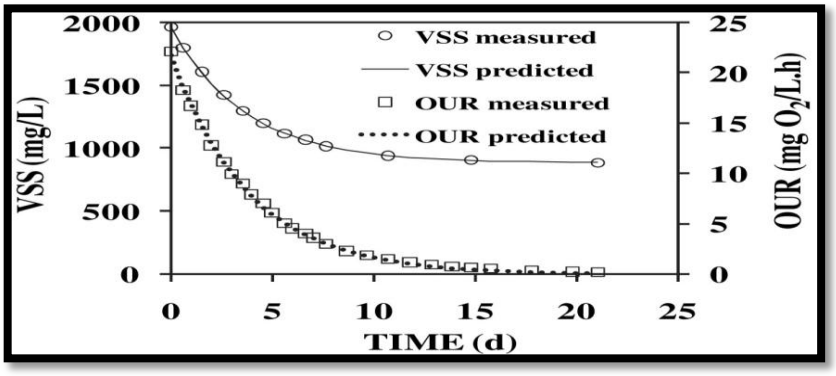

Figure 3: Typical example of fitting predicted and measured VSS and OUR

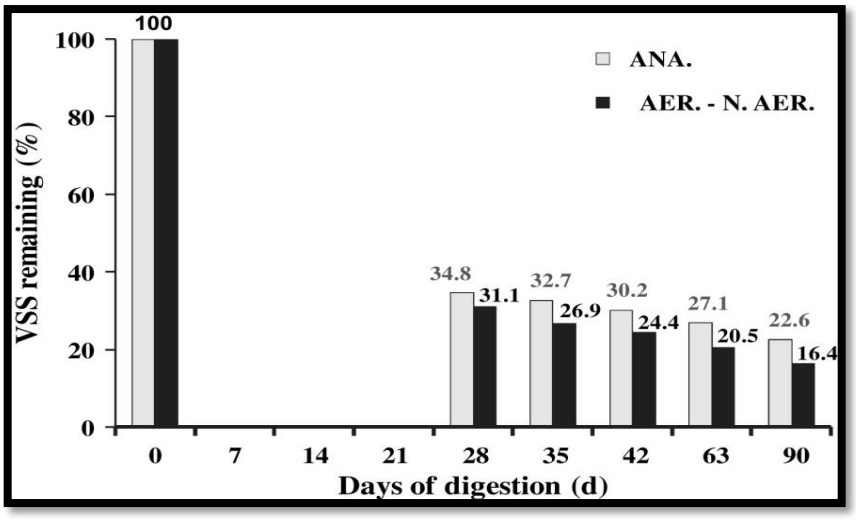

Figure 4: Evolution of the %VSS remaining in the two digestion units

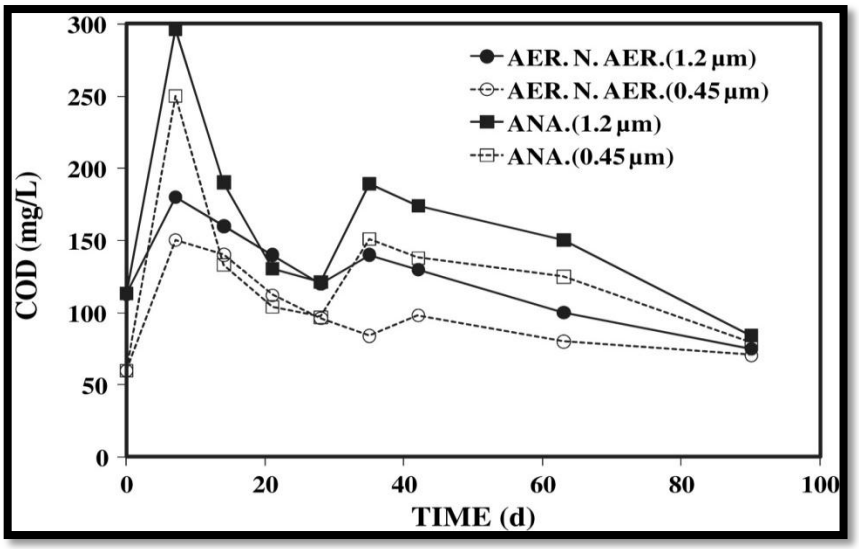

Figure 5: Filtered COD evolution

One more research also has been conducted by M. Friedrich in his study in 2013 which entitled ‘A new interpretation of endogenous respiration profiles for the evaluation of the endogenous decay rate of heterotrophic biomass.

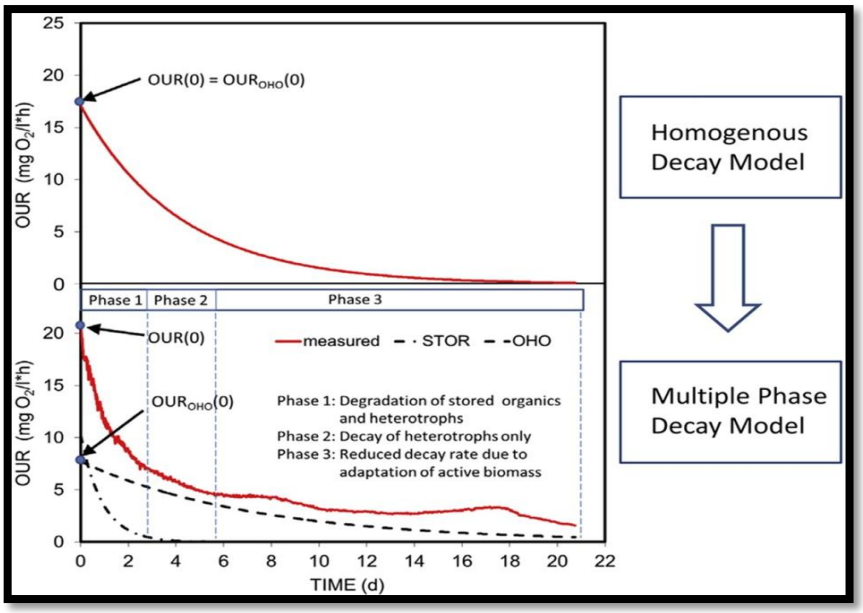

Figure 6: Decay model of a biomass

Based on the research that have been conducted by the others, it can be seen that the degradation process will happens when there is no supply for the biomass, hence they will consume each other. For the degradation and decay process, it can be seen that it depends on the type of biomass that are being experimented. Each of them exhibit different pattern of degeneration and also time of degeneration taken. So, it can be forecast in this study that the degradation of the effluent biomass will be decayed.

CHAPTER 3: METHODOLOGY

The essence of this chapter is to define the entire method adopted in this research work. It describes the procedure followed in realizing the goals and objectives in this research. This involves the adequate description of the research are stressing on the inclusiveness of the research regarding the topic of study, the work of characterization of the sample, collection of data and the results.

3.1 Literature Review

This is the early stage of research to get the overall overview of the proposed topic. At this stage research will be implemented only by documentation research such as books, journals, conference texts, agencies bulletin, project papers, internet and others. This stage is very important in order to find out the related matters that will help to cover the scope of research.

3.2 Characterisation of the sample

Sample will be collected from the PETRONAS Penapisan Melaka Sdn Bhd (PPMSB) prior to the permission given by the officer there. Based on the sample, various experiments will be carried out to determine the characteristic of the treated effluent biomass there. This is very important as it will the base of the experiment.

Some of the essential elements that will be determined are:

- Chemical Oxygen Demand (COD)
- Mixed Liquor Suspended Solid (MLSS)
- Mixed Liquor Volatile Suspended Solid (MLVSS)

All of the test will be carried out in the lab and all the sample is diluted before experiment is being conducted. For measuring COD, a dilution of 1:10 is applied while for measuring the volatile solid, a dilution of 1:50 is applied. This will be applied throughout the whole experiment.

For the raw sample, the reading is as shown below:

Parameter	Concentration (mg/L)
COD	410
MLSS	27133
MLVSS	601.7

3.3 Conducting the experiment

For this research, Anaerobic Sludge Digester machine will be used. Before that, the PPMSB treated effluent sample must be prepared first. The sample is being left for one day so that all the biomass will settle down and the sample will form two layer of supernatant and settled biomass. Then, the supernatant and the biomass are being separated into different container.

Two reactor of ASD will be used in this experiment. One will act as an aerobic system and the other one is anaerobic system. The sludge is filled inside the reactor until it reaches two liters. The aerobic reactor is supplied with continuous air pumped by the external pump and it operates at normal room temperature while for anaerobic process, there will be no air pumped and the temperature is 55 °C which is believed to be the effective temperature for anaerobic process to occur.

For the first phase, The biomass sample was collected at each hour for 24 hour. Then the experiment continued but the sample just need to be taken once for every 24 hour. For the amount of biomass that will be discharged, it will be replaced with the same amount of supernatant that will be put inside the reactor. Then, the sample is being brought into the laboratory to obtain its supernatant by putting it inside the centrifuge so

that further analysis of COD, MLSS and MLVSS can be done. All the experiment was conducted with 3 samples so that accurate results can be obtained.

3.3.1 Measurement of COD

Low range COD vials are being used since the sample is already a treated sample, so it is expected to have a lower value of COD. A blank is prepared first by using 2 mL of distilled water. After that, the sample is diluted at 1:10, and 2 mL of the diluted sample is retrieved and transferred into the COD vials. Then, the vials are digested for 2 hours under a temperature of 150 °C before it can be measured by using spectrophotometer.

3.3.2 Measurement of MLSS and MLVSS

Before the sample is being centrifuged in order to get the supernatant, some of the biomass is kept to measure MLSS and MLVSS. The sample is then diluted at 1:50. Filter paper is prepared first by putting it inside the 550 °C oven for 30 minutes after being through with distilled water. The filter paper is weighed and the results are recorded. Then, 25 mL of sample is filtered, then the filter paper is being dried in the 105 °C for one hour. After one hour, the sample is taken out and being weighed. The weight is the recorded. MLSS can be calculated from the data obtained. The sample is again being heat inside a 550 °C oven for 15 minutes. After that the sample is taken out the weight is measured and recorded. Finally MLVSS can be obtained.

3.4 Data Analysis

From the results collected, a graph for each element that is being observed such as the COD, MLSS and MLVSS will be constructed to see the pattern of the substance during the experiment. This methodology will include charts, tables, and textual write-ups of data. These methods are proposed to process and distill the data so that readers can assemble interesting information without needing to sort through all of the data on their own.

3.5 Key Milestones

Several key milestones for this research project must be achieved in order to meet the objective of this project:

Figure 7: Key Milestones

3.6 Gantt Chart

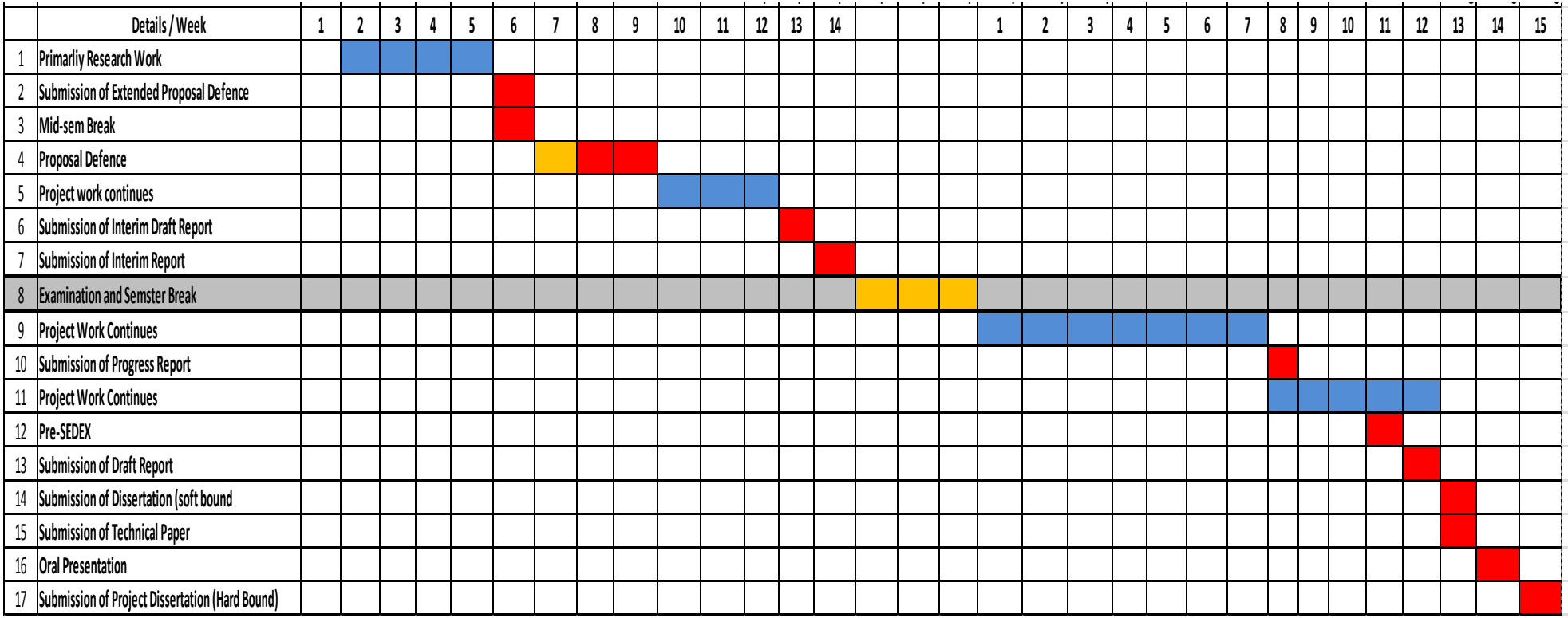

Figure 8: Gantt Chart

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Organic Content

Graph shown below is the results obtained from the analysis of the sample that has been taken for each hour for 24 hour and the analysis of sample for every 24 hour until 168 hours.

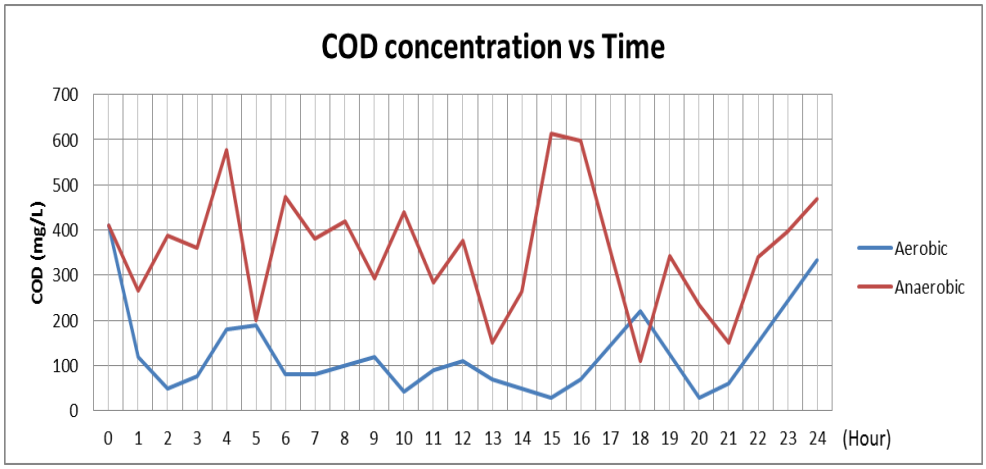

Figure 9: Concentration of COD versus time for each hour

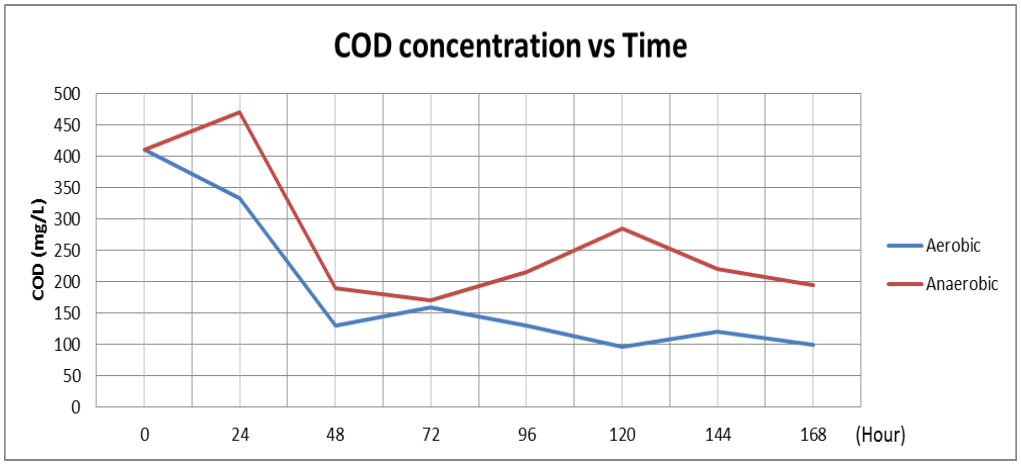

Figure 10: Concentration of COD versus time for every 24 hour

COD concentration in anaerobic reactor is mostly higher than the COD concentration in the aerobic reactor. This may be attributed to the presence of oxygen

inside the reactor that leads to a lower concentration of organic and inorganic solids inside the biomass.

As time pass by, we can see the pattern of the COD concentration in both reactors. Overall, the COD can be said in a constant value although there is up and down in the data, but it still move in a constant range. During the process, endogenous respiration occurs that yields to more products of ammonia. That is also one more reasons that can be related to the increase of the COD as ammonia can affect the COD concentration due to its oxidation in the presence of significant concentrations of free chloride ions.

4.2 MLSS and MLVSS

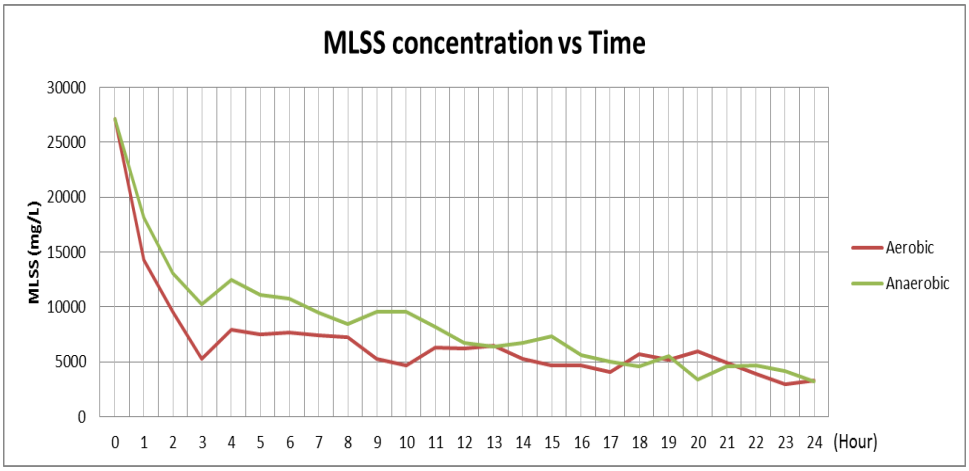

Figure 11: MLSS concentration versus time for each hour

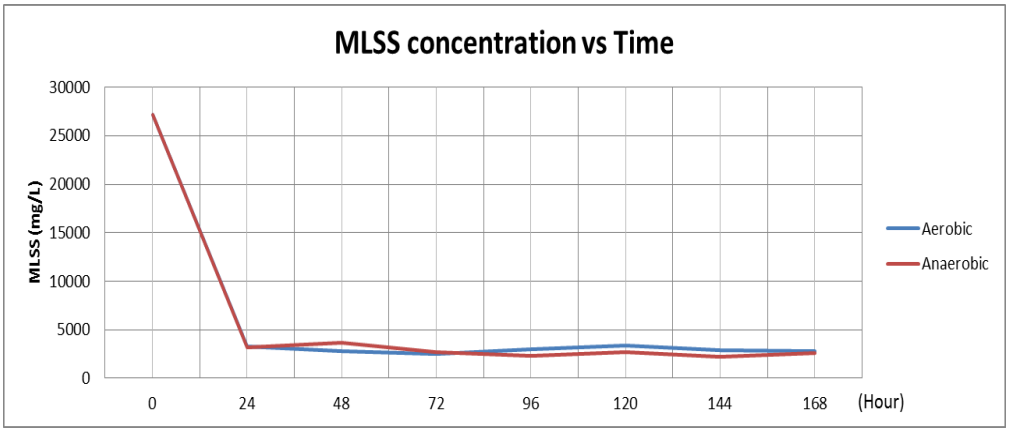

Figure 12: MLSS concentration versus time for every 24 hour

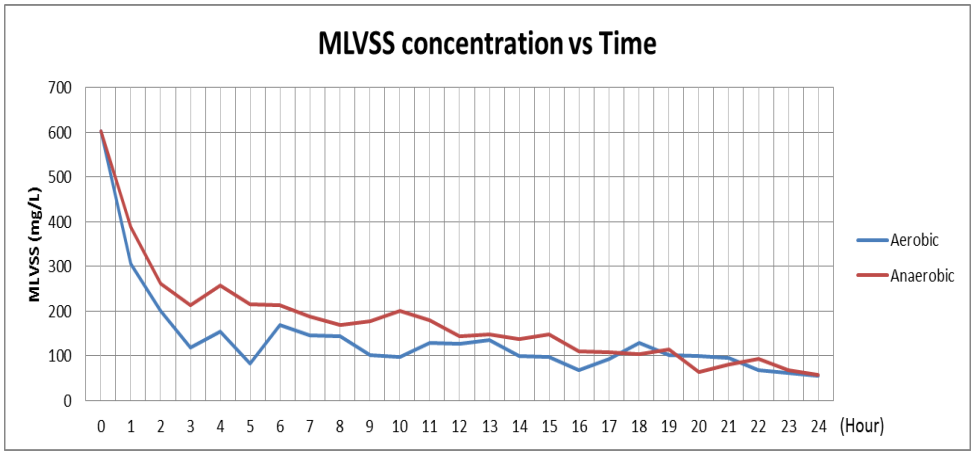

Figure 13: MLVSS concentration versus time for each hour

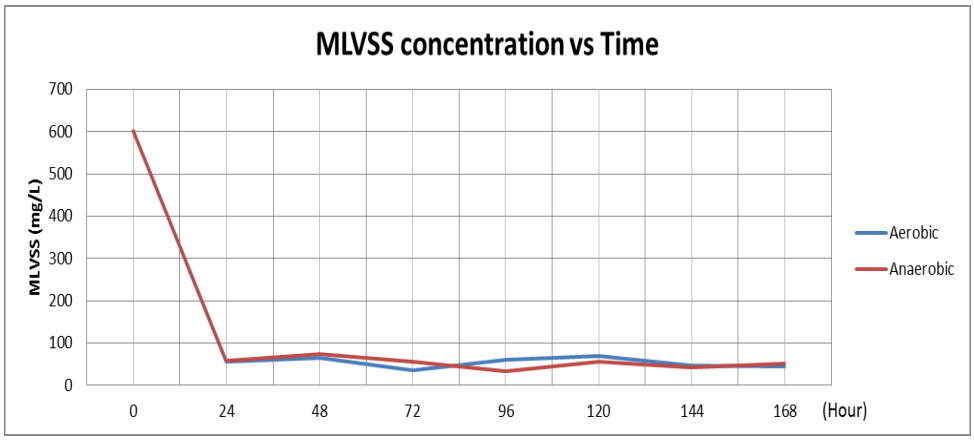

Figure 14: MLVSS concentration versus time for every 24 hour

For MLSS and MLVSS graph that had been shown above, for the hourly graph, it can be seen that at the first 3 hours, the degradation occurred very fast compare to the rest of the time. A structural analysis of degradation of the MLSS and MLVSS profiles can be stated that the endogenous decay during the first 3 hours is due to a faster reaction that degrades most likely stored substrate. Then at the rest of the hours we can see that the degradation pattern becomes slower and the amount of degradation also decrease, and there is even an increment temporarily. This behaviour is thought to be the consequence of proliferation of higher organisms and adaptation of active biomass to the conditions of severe starvation.

Apart from that, the faster degradation reaction at the first few hours also can be related to the adaptation of the biomass to a new environment. Before this, the biomass are being stored in the plant, then it is kept in the cool room and at last it was transferred into a 2 litre reactor. So, at the first few hours, it needs time to adapt to a whole new environment that actually leads to a higher rate of degradation. Because of that also we can see a constant degradation occur after the biomass is able to adapt themselves to the environment.

When the experiment continues until 168 hour, MLSS graph shows that the degradation had somehow become slower. This can be relate with the MLVSS graph as the value of active bacteria is very small compare to the vast amount of organic matter inside the biomass. Because of that small amount, it actually leads to a situation where it becomes an inert degradation. At this point of time, the bacteria cannot degrade anymore and that is why the experiment is stop at 168 hour.

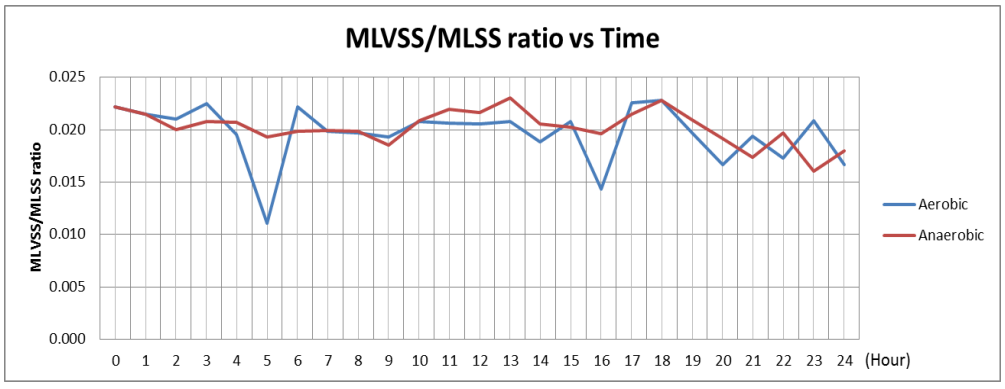

Figure 15 : MLVSS/MLSS ratio versus time for each hour

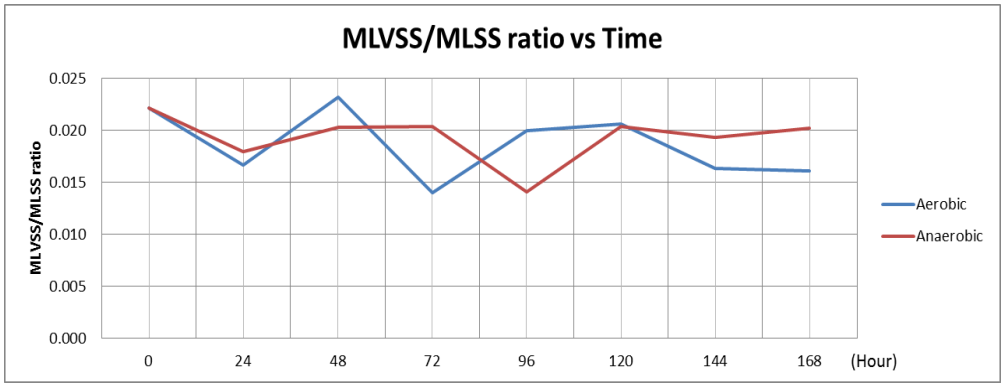

Figure 16 : MLVSS/MLSS ratio versus time for every 24 hour

As shown, the writer also calculated the MLVSS/MLSS ratio versus time. From the beginning, the ratio of MLVSS/MLSS is already very low which is 0.022. The typical ratio should be 0.65 to 0.85.This value keeps going in a constant range until the end of the experiment. This relates on why the process is only takes place for 168 hour to complete compared to any other studies conducted that sometimes it even take a month to finish the treatment as in this case the degradation process becomes inert faster due to low concentration of the active biomass.

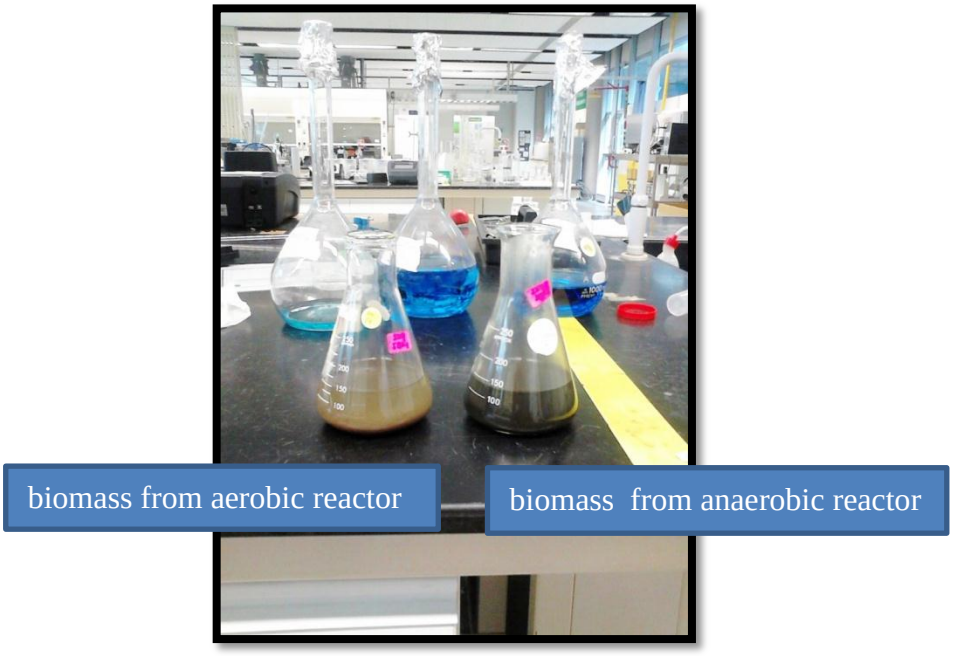

Figure 17: Sample taken from the aerobic and anaerobic sample after 144 hours

Figure above shows the difference in the physical appearance of the biomass after being discharged from the reactor. It can be seen that the biomass from the aerobic reactor exhibits lighter colour compared to the sample from anaerobic which has darker colour. This due to the continuous supply of oxygen in aerobic reactor that helps in the process of endogenous respiration. This also shows that in the anaerobic system, the biomass have a lot of suspended solid and this also can support the fact that it has higher COD value than biomass from aerobic system.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

As stated before, the study that are being conducted is to actually to obtain and determine the behavior pattern of the degradation of the biomass when endogenous respiration occurs especially in term of its organics content. Based on the other research also, it has been shown that the biomass will certainly undergoes degradation, but the things that make the difference is the type of the treatment that we used and also the type of the biomass that we are dealing with.

Based on the results given, we can see that COD measurement acts as a monitoring tool only, as it can be seen that the COD range is always in a range that the difference is not too big, and there is no significant or fixed pattern that can be seen. The main focus here is the value of MLSS and MLVSS as it shows the amount of bacteria that is still active inside the biomass. So, based on the graph, it can be seen that there is actually a degradation pattern for both reactors and the degradation is fixed until the end of 168 hour. At 168 hour, it can be concluded that the biomass have already reach the inert stage as the MLVSS value is extremely low and with the value, the degradation process cannot be carried out anymore. For the effectiveness, it can be seen that anaerobic digestion process exerts higher rate of degradation. From the graph, initially the MLSS and MLVSS value for anaerobic system is higher than aerobic system, however as time goes by, the results is lower than the aerobic digestion, This shows that degradation occured very fast in this anaerobic system.

Last but not least, it can be conclude that the objective of the investigation can be met as the degradation pattern is determined and also we can see the difference in the degradation pattern between both reactors. It also can be concluded that biomass, which is a living things, surely will degrade as living things surely cannot live long enough without food to make up for their nutrients need.

5.2 Suggested Future Work for Expansion and Continuation

Lots of work can be done for this study to expand and creating a better results. Some of them are:

- For the anaerobic process, the study is using the thermophilic digestion where the sludge is being digested at a temperature of 55 degree celcius. So it is recommended for the future, the anaerobic process can be done in two types of anaerobic digestion which are thermophilic digestion and mesophilic digestion so that the difference between the results also can be determined.
- The study also can be conducted using different samples instead of one sample only so then we can get a variety of degradation pattern to be compared as different biomass will surely have different characteristic of degradation.
- For this study, it is only to monitor and observe the degradation pattern, so it is recommended next time that the decay rate also can be measured as from there we can get the exact information and answer regarding the degradation pattern that have been produced by the biomass. To make it possible, the oxygen uptake rate must be measured also, which did not being measured in the current study.

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CHAPTER 6: REFERENCES

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APPENDICES

Appendix 1: Table of COD concentration until 168 hours

Aerobic reactor	
Hour	Concentration (mg/L)
0	410
1	120
2	50
3	77
4	180
5	190
6	80
7	80
8	#N/A
9	120
10	43
11	90
12	110
13	70
14	#N/A
15	30
16	70
17	#N/A
18	220
19	#N/A
20	30
21	60
22	#N/A
23	#N/A
24	333
48	130
72	160
96	130
120	97
144	120
168	100

Anaerobic reactor	
Hour	Concentration (mg/L)
0	410
1	267
2	387
3	360
4	577
5	200
6	473
7	380
8	420
9	293
10	440
11	283
12	377
13	150
14	263
15	613
16	597
17	350
18	110
19	343
20	233
21	150
22	340
23	397
24	470
48	190
72	170
96	215
120	285
144	220
168	195

Appendix 2: Table of MLSS and MLVSS concentration until 168 hours

Aerobic reactor		
Hour	MLSS (mg/L)	MLVSS (mg/L)
0	27133	602
1	14307	307
2	9533	200
3	5267	118
4	7933	155
5	7533	83
6	7667	170
7	7400	147
8	7267	143
9	5300	103
10	4700	98
11	6300	130
12	6200	127
13	6500	135
14	5300	100
15	4700	97
16	4700	67
17	4100	92
18	5700	130
19	5200	102
20	6000	100
21	4900	95
22	3900	68
23	3000	63
24	3300	55
48	2800	65
72	2500	35
96	3000	60
120	3400	70
144	2900	48
168	2800	45

Anaerobic reactor		
Hour	MLSS (mg/L)	MLVSS (mg/L)
0	27133	602
1	18107	389
2	13067	262
3	10267	213
4	12467	258
5	11133	215
6	10733	213
7	9467	188
8	8467	168
9	9600	177
10	9600	200
11	8200	180
12	6700	145
13	6400	148
14	6700	138
15	7300	148
16	5600	110
17	5000	107
18	4600	105
19	5500	115
20	3400	65
21	4600	80
22	4700	92
23	4200	67
24	3200	57
48	3700	75
72	2700	55
96	2300	33
120	2700	55
144	2200	43
168	2600	52

Appendix 3: Table of MLSS and MLVSS ratio

Aerobic reactor	
Hour	MLSS/MLVSS ratio
0	0.022
1	0.021
2	0.021
3	0.022
4	0.020
5	0.011
6	0.022
7	0.020
8	0.020
9	0.019
10	0.021
11	0.021
12	0.021
13	0.021
14	0.019
15	0.021
16	0.014
17	0.023
18	0.023
19	0.020
20	0.017
21	0.019
22	0.017
23	0.021
24	0.017
48	0.023
72	0.014
96	0.020
120	0.021
144	0.016
168	0.016

Anaerobic reactor	
Hour	MLSS/MLVSS ratio
0	0.022
1	0.021
2	0.020
3	0.021
4	0.021
5	0.019
6	0.020
7	0.020
8	0.020
9	0.018
10	0.021
11	0.022
12	0.022
13	0.023
14	0.021
15	0.020
16	0.020
17	0.021
18	0.023
19	0.021
20	0.019
21	0.017
22	0.020
23	0.016
24	0.018
48	0.020
72	0.020
96	0.014
120	0.020
144	0.019
168	0.020