“Enhancement of Organic Removal of Compact Extended Aeration Reactor (CEAR) by using Attached Growth System”

By:

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Dissertation submitted in partial fulfilment of

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Universiti Teknologi PETRONAS

Bandar Seri Iskandar

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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible to 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 and person.

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(Anis Dalila Binti Dawam)

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ABSTRACT

Compact Extended Aeration Reactor (CEAR) is a system that practices the concept of integration of wastewater treatment system in which the reactor comprises of aeration tank, anoxic tank and clarifier and one of the challenge of the CEAR system is to improve the treatment system efficiency. Extension to that, enhancement on the reactor has been made by implementing attached growth system in addition to the existing suspended growth system and it makes the purpose of this project which is to evaluate the performance of CEAR in removing organic from wastewater before enhancement and also evaluation after enhancement on the CEAR. For the enhancement of CEAR, a packing medium for attached growth known as Aero-Packer has been designed and installed in the aeration tank as well as Bio-Balls in the anoxic tank. This Aero-Packer helps to increase the capacity of the activated sludge systems in the same tank volume. The project is using a reactor model with total volume of 0.176 m^3. The reactor has been operated with real biomass obtained from UTP STP aeration tank and been fed with synthetic wastewater made from dog food with flowrate of 15 L/day. As for experimental purpose, samples are taken from the influent, aeration tank, anoxic tank and effluent before test on BOD, COD, TSS and MLSS can be conducted. The result shows that the reactor performance before enhancement is at average level with reduction percentage of 67% of BOD, 64% of COD and 75% of TSS with MLSS average value of 6500 mg/L. With the installation of Aero-Packer inside the aeration tank, the reduction percentage increases with 77% for BOD, 80% for COD and 85% for TSS with average MLSS reading of 7556 mg/L. This shows that the performance of the reactor has been better with the implementation of attached growth system. However, as the process of activated sludge with fixed-film packing is very complex and there are issues regarding to understanding of the biofilm area and activity, the process designs are empirical and based on lab-scale results.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Wastewater treatment has started since 1900's with objectives of removal of colloidal, suspended and floatable material; treatment of biodegradable organics and elimination of pathogenic organism (Metcalf & Eddy, 2004). However, as more extensive research into the wastewater has been done as well as more comprehensive techniques of assessing the specific constituents and their potential health and environmental effects, many of new treatment method has been developed to deal with the health and environment concerns. Nowadays, treatment of wastewater is mainly focusing on producing effluent that complied with discharge limit appointed by the respective authority.

Wastewater is defined as a combination of liquid or water carried wastes removed from residence, institutions and commercial and industrial establishment, together with such groundwater, surface water and stormwater that may be present (Metcalf & Eddy, 2004). Wastewater produced nowadays contain more substrate element and harmful substances then it was decades ago. Due to that, wastewater treatment development needs to be improvised from time to time. Current treatment system is focusing on removing the quantities of nitrogen, phosphorus, organic matter and solids matter in suspension (Caraman S. & Barbu M., 2008) by going through several treatment process.

Other than concern on the effluent quality produced by a wastewater treatment plant, another concern come into mind is the space required for the construction of the WWTP structure. Current trend shows that every highly populated area will usually have their independent wastewater treatment plant. As we all know, a sewage treatment plant requires a huge space of area, even a small WWTP will need area space as large as 3-10 acres of land dependent on the population rate. With the development of integrated treatment reactor system, the space used for WWTP structure could be greatly reduced but still with the same level of treatment performance of conventional treatment plant. This is very beneficial for the developers as that reduced area could be used for other purpose that could bring more profit to them.

This concept is adapted in the project where aeration tank, anoxic tank and clarifier is built and has been operated together inside a batch reactor. This project is divided into two phases in which the first phase is wastewater treatment without Aero-Packer (before enhancement) and wastewater treatment with Aero-Packer (after enhancement) for the second phase. Although the concept of compact reactor is still on research level and there is not much information available, the development of batch reactor of this project has been done carefully to make sure that it has been able to produce effluent that meet the discharge standard limit.

1.2 Problem Statement

A major problem regarding conventional WWTP is the requirement for a huge space of area for their structure. This is because all of the treatment process is done separately in different tanks (example: aeration tank and clarifier) and this matter gets worse by the large area required for each tank. However, with the application of CEAR this problem can be solved.

The application of CEAR that uses several tanks which is aeration, anoxic and clarifier tank faces another problem of enhancing the wastewater treatment system with the same tank volume. Aeration tank for example needs enhancement to increase the rate of organic matter removal. The enhancement of the system in necessary in order to produce better quality effluent that complies with the discharge limit appointed by DOE such as Standard A or Standard B the least.

1.3 Objective

The main objective of this study is to evaluate the performance of the CEAR before and after enhancement. The enhancement involves designing and installing Aero-Packer inside the aeration tank to increase the rate of organic removal from the wastewater.

1.4 Scope of Study

The scope of study for this project was includes operation and evaluation of the CEAR performance. The reactor has been operated with real biomass obtained from the UTP STP. As for the feeding of influent, synthetic wastewater made from dog food was used in this project because the synthetic wastewater has constant amount of organic loading.

The scope of study of this project was also include the desig and installation of Aero-Packer in the aeration tank. The purpose of the Aero-Packer installation is to enhance the organic matter removal in the aeration tank. This is a part of the process of enhancing the whole wastewater treatment of the reactor.

For the evaluation of the CEAR performance, test has been done on several parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS) and Mixed Liquor Suspended Solid (MLSS). The test on MLSS concentration is to ensure that the aeration tank always has sufficient biomass concentration for the success of substrate degradation process. As for other three parameters which are BOD, COD and TSS; this is to calculate and evaluate the percentage of reduction of these parameters in the produced effluent of the reactor. BOD, COD and TSS test was also conducted on every tank to evaluate the rate of substrate reduction in every tank. All in all, the test done is to evaluate the quality of effluent and to check whether it is in compliant with the DOE's effluent discharge standard.

1.5 Relevancy of the Project

This project is relevant to the society as the development of innovative Compact Extended Aeration Reactor (CEAR) will give big impact to the wastewater treatment industry in overall. With the implementation of the innovative CEAR system, wastewater treatment plant will no longer need a huge space of area but with the same treatment system performance with the conventional system.

This project is also covered the theory and knowledge learnt by the student during the study period. This project is all about the application of theory learnt during in class into a real application. Besides that, the concept of integrated batch reactor is currently in a rapid phase of research done by other researches all over the world. With the successfulness of the project, it will contribute to the development of a new wastewater treatment technology.

1.6 Feasibility of the Project within the Scope and Time Frame

Time period given to the student for completion of the project is approximately 8 months for which is sufficient for the completion of project. Besides that, with the preparation of Gantt chart it was surely help the student to be in track towards the completion of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Extended Aeration Activated Sludge Concept

One of the most important parts of domestic wastewater treatment is the BOD removal which can be done through biological process such as suspended growth treatment. This biological process is an aerobic process and takes place in the aeration tank where the wastewater has been aerated with oxygen. With good environment, it will help to boost the growth of bacteria that will eventually help in treating the wastewater (Lenntech B.V, 2008). The bacteria function is as to degrade the substrate before the bacteria itself creates floc and gases which finally has been removed to clarifier. After that, the primary effluent is mixed with return activated sludge to form mixed liquor which is known as activated sludge. Activated sludge processes play important roles in the biodegradation of organic materials, transformation of toxic matters into harmless product, and the removal of nutrients (Kwon et. al., 2010). The mixed liquor is aerated for a specified length of time. Suspended solids are produced by the process and the additional organisms become part of the activated sludge. Periodically the excess solids and organisms are removed from the system (waste sludge). This whole process is called activated sludge process where the schematic diagram is shown in **Figure 1**.

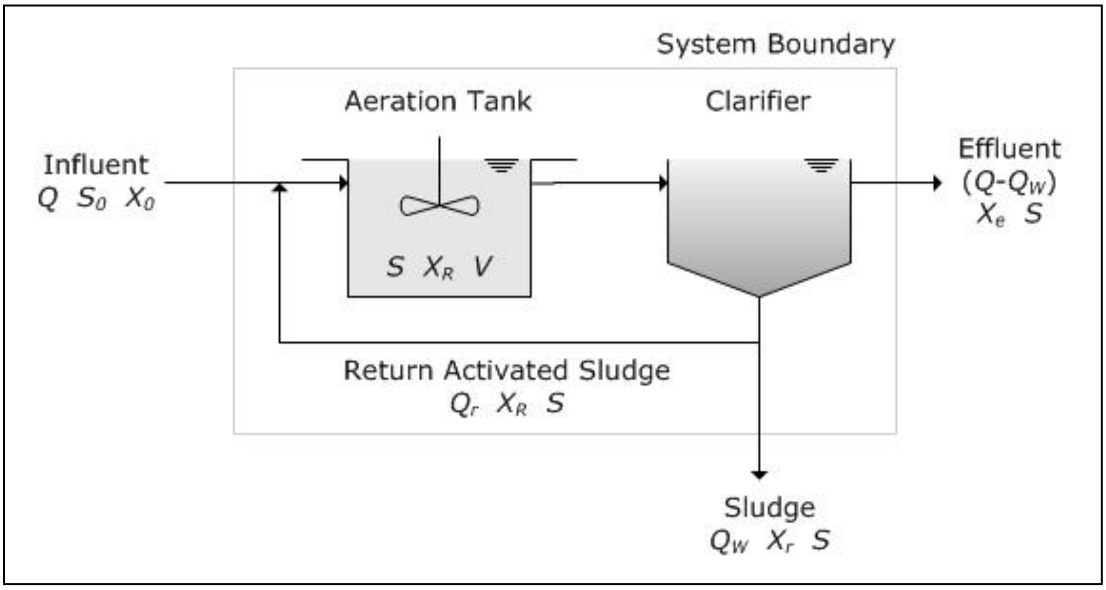


Figure 1: Activated Sludge Process Schematic Diagram (Lenntech B.V, 2008)

The performance of activated sludge treatment system is affected by several factors such as temperature, sludge return rates, amount of oxygen available, amount of substrate/organic matter available, pH, sludge waste rate, aeration time and wastewater alkalinity (Metcalf & Eddy, 2004).

Extended aeration concept is used in this project where are many researches been done on this field. Extended aeration is a concept where an activated sludge system operates at a sufficiently long sludge age and low food to microorganism (F/M) ratio. With this system, the excess sludge production can be greatly reduced as a result from the lower observed biomass yield which depends by sludge retention time (SRT) (Foladori et. al., 2010). Compared with conventional activated sludge system, extended aeration system is the most widely used in the treatment of domestic wastewater as it is proven to have more advantages (Foladori et. al., 2010) such as conventional process applied at full scale, high quality of effluent, better stability of sludge, lower odour potential and improvement of sludge dewaterability.

Basic process and equation involve in the process are (Metcalf & Eddy, 2004):

Oxidation:

COHNS + O_2 + bacteria $\rightarrow$ CO_2 + H_2O + NH_3 + other end products + energy

Synthesis:

COHNS + O_2 + bacteria + energy $\rightarrow$ $C_5H_7NO_2$

Endogenous respiration:

$C_5H_7NO_2 + 5O_2 \rightarrow 5CO_2 + NH_3 + 2H_2O$

All of the oxidation, synthesis and endogenous respiration process has been in an aeration tank for a successful substrate removal. In aeration process, several parameters need to be monitored closely to prevent any errors while treating the wastewater.

Aeration process can be operated in several ways which are suspended growth, attached growth and hybrid growth (combined suspended and attached growth processes) (Metcalf & Eddy, 2004). However, in both of the system it is important to provide a conducive environment for the growth of bacteria. For growth to take place, bacteria must be able to replicate their genetic material and carry-out chemical transformations which allow the synthesis of all the constituents from various precursors and energy (Mogens H., Mark C.M., George A.E., Damir B., 2008). In order for this to happen, energy is needed by bacteria which can be obtained from the carbon sources, energy sources as well as sufficient nutrients.

2.2 Operating Condition Requirement in Wastewater Treatment

Carbon source for cell growth of microorganisms can be obtained either from organic matter or carbon dioxide. There are two types of microorganisms which are heterotrophs (use organic carbon for the formation of new biomass) and autotrophs (derive cell carbon from carbon dioxide). As for energy sources, bacteria are able to oxidize organic or inorganic compounds to gain energy in which the energy needed for cell synthesis may be obtained either from light (phototrophs) or by a chemical oxidation reaction (chemotrophs). Chemical oxidation reaction is somehow the most common process in municipal and industrial wastewater treatment where the reaction involves the transfer of electrons from an electron donor to an electron acceptor. The electron donor is oxidized and the electron acceptor is reduced. Other than carbon or energy sources, another limiting factor for bacteria cell synthesis and growth is the limited nutrient. The principal inorganic nutrients needed by microorganisms are N, S, P, K, Mg, Ca, Fe, Na and Cl (Metcalf & Eddy, 2004) while minor nutrients of importance include Zn, Mn, Mo, Se, Co, Cu, and Ni (Madigan et. al., 2000). Besides that, the three major classes of bacteria growth factors are amino acids, nitrogen bases and vitamins. All of these nutrients presence are abundant in municipal wastewater but somehow is less in industrial wastewater.

Another important parameter during the aerobic process is the alkalinity of the wastewater. Alkalinity is defined as the ability to buffer acids determined by titrating with sulphuric acid to a select endpoint of 4.5 pH (Davis et. al., 1992). pH is used in expressing both acid and base activity where a value of 7 represents neutrality, values less than 7 are increasingly acidic and values greater than 7 increasingly alkaline. Alkalinity in wastewater results from the presence of the hydroxides, carbonates and bicarbonates of elements such as calcium, magnesium, sodium, potassium and ammonia (Metcalf & Eddy, 2004).

However there are two most common elements of all other elements which are calcium and magnesium bicarbonates. The alkalinity in wastewater role is to resist changes in pH caused by the addition of acid during the treatment process. The process of nitrification will release the H^+, which will increase the concentration of H^+ in mixture, make the pH value drop. The optimum pH value of nitrification is 8.0 to 8.4. Nitrifying bacteria is sensitive to the changes of pH thus in order to maintain the suitable pH, the sufficient alkalinity should be maintained to cushion the change of pH (Liang M., Su L., 2008)

Besides that, another important parameter that needs most concern is the temperature during the wastewater treatment process. Temperature will affect the biological reaction-rate and eventually will determine the overall efficiency of biological treatment process. Optimum temperatures for degradation activity to take place are between 25 to 35^{o}C (Honjun H. et. al., 2004). When the temperature rises up to 50^{o}C, the process of aerobic digestion and nitrification will immediately stop. Not only affecting the microbial activity, abrupt change in temperature will also affect the gas-transfer rate and the settling characteristics of the biological solids. All in all, equilibrium constants, solubility product constants and specific reaction-rate constants are all dependent on temperature (Metcalf & Eddy, 2004).

Dissolved oxygen (DO) is required for the respiration of aerobic microorganisms as well as all other aerobic life forms. Unfortunately, oxygen is only slightly soluble in water where the actual quantity that can be present in solution is due to the solubility of the gas, the partial pressure of the gas in the atmosphere, the temperature and the concentration of the impurities in the water. The presence of dissolved oxygen in wastewater will also help to prevent the formation of noxious odour.

2.3 Medium for Bacteria Growth

In aeration system, there are two approaches for the growth of bacteria that is suspended growth or attached growth. As for attached growth, the bacteria are attached to an inert packing material for their growth and then react for the conversion of organic material or nutrients. Bacteria growth medium could be made from rock, gravel, slag, sand, redwood, wide range of plastic and other synthetic materials (Metcalf & Eddy, 2004). After certain time and the process of degradation of organic material and nutrient has completed, it will then be removed from the system in which it is known as biofilm. The packing could be fully submerged or half submerged in the wastewater and can be operated as aerobic or anaerobic system. For the maximum thickness of the biofilm, it depends on the growth conditions and hydrodynamics of the system, the biofilm thickness may range from 100 µm to 10 mm (WEF, 2000). The dense level of biomass can sometimes be very high in biofilm but somehow it still varies in density and depth while the VSS concentrations may range from 40 to 100 g/L (Metcalf & Eddy, 2004). Hinton and Stensel (1991) also reported that in practical application, it is impossible to obtain uniform packing across the packing because of the occurrence of periodic sloughing as well as due to the hydrodynamics and media configuration.

2.4 Ammonia Removal

The traditional biological nitrogen removal process involves two process which is nitrification and denitrification in which it is the limiting step in the whole process of wastewater treatment due to the relatively lower proportion and specific growth ratio of nitrifying bacteria (Henze et. al., 1995; Jubany et. al., 2005; Rittmann and McCarty, 2001). Nitrification is defined as the oxidation of ammonia (NH_4-N) to nitrite (NO_2N) and nitrite to nitrate (NO_3-N). Nitrification in wastewater treatment is due to several concerns such as the effect of ammonia on receiving water with respect to DO concentrations and fish toxicity, the need to provide nitrogen removal to control eutrophication and finally the need to provide nitrogen control for water-reuse applications including groundwater discharge.

For activated-sludge system with bacteria growth medium, it is important to focus on the dissolved oxygen (DO) concentration level of the wastewater as the focus of aeration process in this project is for organic matter and ammonia removal only. This is because denitrification might occur in the presence of low bulk liquid DO concentrations. Skerman and Macrae (1957) and Terai and Mori (1975) states that a dissolved oxygen concentration of 0.2 mg/L and above has been reported to inhibit denitrification for a Pseudomonas culture and by Dawson and Murphy (1972) for activated-sludge treating domestic wastewater.

2.5 Submerged Attached Growth Processes

There are three main element included in an aerobic submerged fixed-film processes which are a packing, biofilm and liquid. In an attached growth process, the performance and operation characteristic is highly dependent on the type and size of packing. Several major advantages of this system are their small space requirement, the ability to effectively treat dilute wastewater, no sludge settling issues for activated-sludge process and their high aesthetic value (Metcalf & Eddy, 2004). This system however also several disadvantages such as more complex system in terms of instrumentation and controls, limitations of economies of scale for application to larger facilities and finally a higher capital cost than activated-sludge system.

Yeon et. al. (2011) also states that increment of packing ratio inside aeration tank does not only help increasing the attached biomass ratio but also the capacity of total biomass which can increase the possibility of denitrification to occur. From that, the author concludes that attached growth process has more possibility for capacity of biomass and nitrogen removal than suspended growth process. Other than that, Yeon et. al. (2011) also agreed that media packing can provide anoxic zone inside the media which promotes simultaneous nitrification-denitrification process. Based from that, the author concluded that attached growth process can reduce requirement for area and increase removal rate of nitrogen with small area.

In addition to that, formation of biofilm in attached growth helps biomass to be retained in a reactor at a flow rates greater than the washout flow rate (Gavrilescu et. al., 2000). Gavrilescu also suggested new design of packed bed bioreactors that proposed construction provides a large surface area of the biofilm carrier per unit volume of the apparatus, as well as the possibility for an easy removal of the biomass after reaching certain thickness of the biofilm increasing the gas velocity.

2.6 Integrated Fixed Film Activated Sludge (IFAS)

The IFAS system is a variation of the activated sludge process in which biomass support material or media are incorporated into suspended growth bioreactor. The biomass support materials are typically suspended plastic pieces or fixed synthetic mesh, which provide a large surface area for the attachment of microorganisms (Kwon et. al., 2010). The purpose of this mechanism is to provide greater biomass concentration in the aeration tank with lesser requirement for basin size that will help to enhance the activated-sludge process.

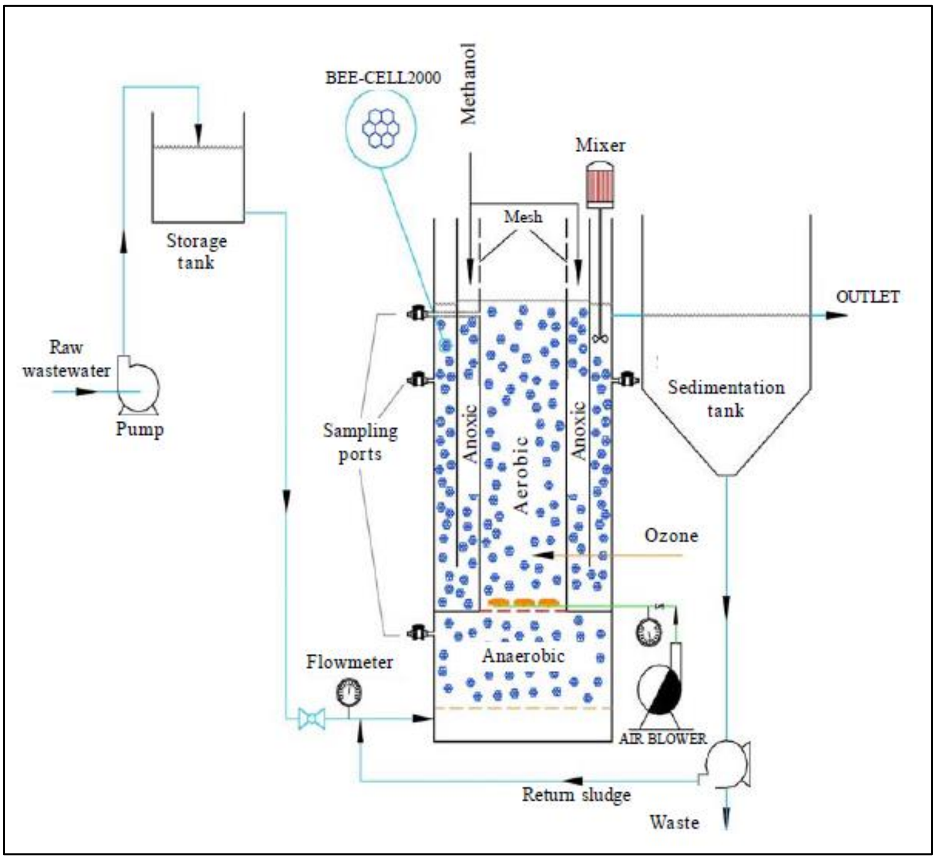


Figure 2: Schematic Diagram of the IFAS Pilot-Plant (Mehrdadi et. al., 2006)

A unique feature of this system is the tremendous surface area of the media that allows for attachment and growth of microorganisms. The fixed-film system has four principal advantages over the other currently available systems which are; simpler to operate, better handle to shock loads, less formation of solid sludge wastes and more energy efficient as it requires less power to operate (Chih-Ju G. et. al., 2002). IFAS system also promote better microorganism settling characteristics and it is frequently used to retrofit or upgrade wastewater treatment plant (WWTP) without increasing the bioreactors and settling tank volumes (Kwon et. al., 2010).

Activated sludge systems can be operated at high sludge recycle ratios to achieve both high biomass concentrations within the reactor, and minimize biological solids formation. The effectiveness of sludge recycling is however limited by the efficiency of the clarification step. For instance, the sludge age is similar to the hydraulic retention age without the clarification step. Difficulties are often encountered in activated sludge plants that attempt to lower sludge production by increasing sludge age. Two of the main problem due to this process is the inability to settle the sludge, and the excess formation of scum foam (Chih-Ju G. et. al., 2002). Soddell and Sevious (1990) also reported that high sludge recycling often leads to the growth of filamentous bacteria such as *actinomycete Norcardia*, which promotes sludge bulking, scum formation and increased sludge wasting. However, with the implementation of IFAS, the biomass is fixed in immobilized systems thus they will not have this disadvantage. Besides that, although the MLSS concentration can reach up to 6000 mg/L or more, the attached growth will not cause solids loading rates on final clarifiers because it remains in the aeration basin (Azimi et. al., 2007).

As for the removal of organic matter and ammonia (nitrification), Azimi et. al. (2007) reported that IFAS system offers the achievement of high biomass age that is very important for the nitrification process. Azimi et. al. (2007) also reported that nitrification in IFAS system is clearly oxygen limited at higher ammonia concentrations and as for the unlimited conditions the dissolved oxygen/ammonia ratio in the reactor should be at least 4. With increasing air supply the concentration of oxygen and air velocity in the reactor increased and external mass transport resistance decreased. Higher concentration of organic compounds in the nitrification zone leads to a competition for oxygen in the biofilm between heterotrophic (COD elimination) and autotrophic (nitrification) organisms. In short, optimum range of nitrification rate can be obtained by using a well-designed media with a high specific surface area (Azimi et. al., 2007).

The implementation of IFAS system will promote the growth of biofilm on the packing medium. Basuvaraj et. al. (2012) states that the biofilm structure plays an important role in overall treatment performance. The external mass transport could greatly affect the rates of aerobic carbon oxidation and nitrification. In addition, the mass transfer resistance is assumed to be located in a stagnant liquid layer with a certain thickness through which the mass transfer takes place by diffusion. A biofilm also can be fully or partially penetrated by oxygen, depending on the biofilm thickness, concentration of oxygen at the biofilm boundary and the rate of substrate utilization. A partially penetrated biofilm will have aerobic, anoxic and anaerobic growth zones; whereas, a penetrated biofilm has been completely aerobic in which the complete penetration could only occur with biofilm with a thickness of 20 µm or less. Basuvaraj et. al. (2012) also concluded that physiochemical and microbial properties of the biofilm are distinct from the floc and potentially contribute to better sorption and removal mechanisms of contaminants.

However, as the process of activated sludge with fixed-film packing is very complex and there are issues regarding to understanding of the biofilm area and activity, the process designs are empirical and based on prior pilot-plant or limited full-scale results (Metcalf & Eddy, 2004).

2.7 Wastewater Effluent Discharge Limit

SECOND SCHEDULE
(Regulation 7)
ACCEPTABLE CONDITIONS OF SEWAGE DISCHARGE OF STANDARDS A AND B

(i) New sewage treatment system

	Parameter	Unit	Standard A	Standard B
	(1)	(2)	(3)	(4)
(a)	Temperature	°C	40	40
(b)	pH Value	-	6.0-9.0	5.5-9.0
(c)	BOD5 at 20°C	mg/L	20	50
(d)	COD	mg/L	120	200
(e)	Suspended Solids	mg/L	50	100
(f)	Oil and Grease	mg/L	5.0	10.0
(g)	Ammonical Nitrogen (enclosed water body)	mg/L	5.0	5.0
(h)	Ammonical Nitrogen (river)	mg/L	10.0	20.0
(i)	Nitrate – Nitrogen (river)	mg/L	20.0	50.0
(j)	Nitrate – Nitrogen (enclosed water body)	mg/L	10.0	10.0
(k)	Phosphorous (enclosed water body)	mg/L	5.0	10.0

Note : Standard A is applicable to discharges into any inland waters within catchment areas listed in the Third Schedule, while Standard B is applicable to any other inland waters or Malaysian waters.

Figure 3: Acceptable Conditions of Sewage Discharge of Standard A and B (Department of Environment Malaysia, 2010)

FIFTH SCHEDULE
[Paragraph 11(1) (a)]

ACCEPTABLE CONDITIONS FOR DISCHARGE OF INDUSTRIAL EFFLUENT FOR MIXED EFFLUENT OF STANDARDS A AND B

	Parameter	Unit	Standard	
			A	B
	(1)	(2)	(3)	(4)
(i)	Temperature	°C	40	40
(ii)	pH Value	-	6.0-9.0	5.5-9.0
(iii)	BOD_5 at 20°C	mg/L	20	40
(iv)	Suspended Solids	mg/L	50	100
(v)	Mercury	mg/L	0.005	0.05
(vi)	Cadmium	mg/L	0.01	0.02
(vii)	Chromium, Hexavalent	mg/L	0.05	0.05
(viii)	Chromium, Trivalent	mg/L	0.20	1.0
(ix)	Arsenic	mg/L	0.05	0.10
(x)	Cyanide	mg/L	0.05	0.10
(xi)	Lead	mg/L	0.10	0.5
(xii)	Copper	mg/L	0.20	1.0
(xiii)	Manganese	mg/L	0.20	1.0
(xiv)	Nickel	mg/L	0.20	1.0
(xv)	Tin	mg/L	0.20	1.0
(xvi)	Zinc	mg/L	2.0	2.0
(xvii)	Boron	mg/L	1.0	4.0
(xviii)	Iron (Fe)	mg/L	1.0	5.0
(xix)	Silver	mg/L	0.1	1.0
(xx)	Aluminium	mg/L	10	15
(xxi)	Selenium	mg/L	0.02	0.5
(xxii)	Barium	mg/L	1.0	2.0
(xxiii)	Fluoride	mg/L	2.0	5.0
(xxiv)	Formaldehyde	mg/L	1.0	2.0
(xxv)	Phenol	mg/L	0.001	1.0
(xxvi)	Free Chlorine	mg/L	1.0	2.0
(xxvii)	Sulphide	mg/L	0.50	0.50
(xxviii)	Oil and Grease	mg/L	1.0	10
(xxix)	Ammoniacal Nitrogen	mg/L	10	20
(xxx)	Colour	ADMI*	100	200

ADMI- American Dye Manufactures Institute

Figure 4: Acceptable Conditions for Discharge of Industrial Effluent for Mixed Effluent of Standard A and B (Department of Environment Malaysia, 2010)

CHAPTER 3

METHODOLOGY

3.1 Research, Data Collection and Analysis

During the early phase of the project, the primary work done during that phase is based on theoretical knowledge and data gathering. The problem statement, objectives and scope of works are first justified before focusing on the literature review, data to be gathered and analysis that need to be done throughout the project.

Most of the data obtained for this project is obtained from several sources such as UTP IRC, UTP Wordpress website and also internet. All of the data collected that is relevant to the project is included in the report.

3.2 Experimental Methodology

3.2.1 Reactor Setup

Measurement on the Volume of Reactor

First of all, volume of the tank need to be first measured to determine the capability of the reactor to receive and treat wastewater. Measurement is done in two ways, in which the first one is by filling up water inside the tank and measure the volume and the second method is by measuring the dimension of the tank and then calculate the volume. Volume obtained from both of the method is compared to verify the accuracy of the data. The total volume of the tank measured is approximately 180 L. The volume for each tank is as shown at **Table 1**.

Table 1: Volume of Each Tank of the Reactor

Tank	Volume (L)
Aeration Tank	10
Anoxic Tank	20
Clarifier	150

Figure 5: Measurement Process of the Tank Volume

Assembling the Reactor

After the completion of tank volume measurement, the reactor is then been set up. The setup of the tank is done at ground floor of Block 13. The performance of the tank is first being tested by using tap water as the influent to make sure that there is no leaking and all of the compartments such as feeder pump, recycle pump, air diffuser and piping connection is working properly. For the operation of the tank, biomass obtained from aeration tank of UTP STP with MLVSS strength of 6000 mg/L is used and has been fed with synthetic wastewater made from dog food. The setup of the reactor is shown in **Figure 6** and **Figure 7.**

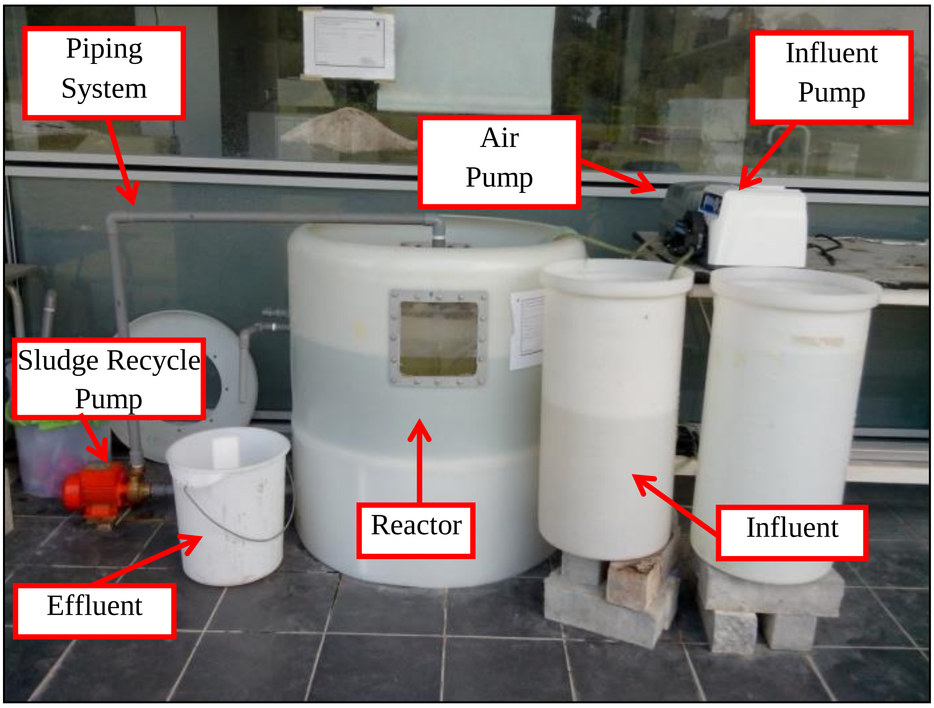


Figure 6: Setup Arrangement of the Reactor

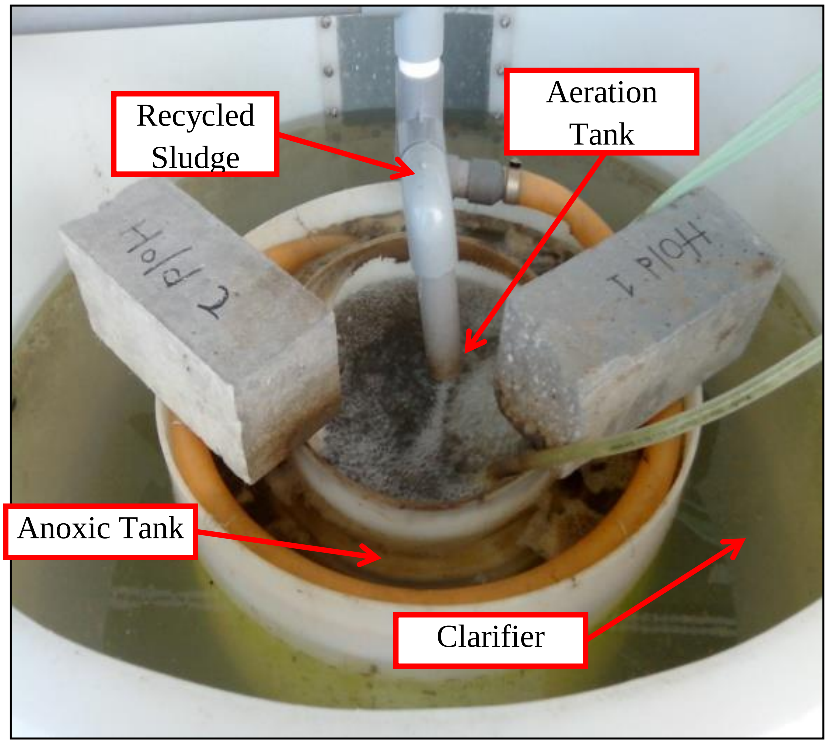


Figure 7: Top View of the Setup Arrangement of the Reactor

Calculation of Flowrate, Solid Retention Time (SRT) and Sludge to be wasted

Calculation for the flowrate, solid retention time (SRT) and sludge to be wasted is done based on the tank volume measured. From the guideline provided in Metcalf and Eddy (2004), the calculation for BOD removal and nitrification has been done based on the **Formula 1**. The excel formulation for the calculation is attached in Appendix section.

$$P_{X,bio} = \frac{QY(S_o - S)}{1 + (k_d)SRT} + \frac{(f_d)(k_d)Q(Y)(S_o - S)SRT}{1 + (k_d)SRT} + \frac{QY_n(NO_x)}{1 + (k_{dn})SRT}$$

(Formula 1)

SRT = Solid Retention Time (d)

Y, Y_n, S_o, S, f_d, k_d, k_n = kinetic coefficient for heterotrophic bacteria at 20 ^{O}C

NO_x = Nitrogen oxidised to Nitrate (mg/L)

Due to the lack of data, the formula has been used as basis for fix flowrate and SRT with assumption of $NO_{x\,=}$ 80% TKN as nitrogen balance cannot be done yet.

To verify the result that has been calculated initially based on the **Formula 1**, result obtained from calculation based on **Formula 2** has been compared with previous result and this can only be done after the experiment has been done.

$$(X_{vss})(V) = (P_{x,bio})\ SRT$$

(Formula 2)

Where:

X_{vss} = Volatile Suspended Soilds (mg/L)

V = Volume of Aeration Tank (L)

$P_{x,bio}$ value is important to be calculated for determination of alkalinity and to be used as reference for sludge to be wasted daily. The typical value for all kinetic coefficient also has been obtained from Wastewater Engineering: Treatment and Reuse by Metcalf and Eddy (2004) textbook.

3.2.2 Study on Preparation of Synthetic Wastewater

The preparation of the synthetic wastewater is made with dog's food brand Purino Alpo High Protein Puppy Dog Meal as the main ingredient. Dog food is used for the synthetic wastewater to ensure constant influent concentration. The synthetic wastewater used represents the medium strength of domestic wastewater. The dog food was first grinded for few minutes until it turns into powder and then being sieved to obtained the finest powder. During the feasibility phase, several different weight of dog food such as 3.6 g, 1.5 g and 0.5 g has been prepared and mixed with 1 litre of tap water. Then several tests such as BOD, COD, TSS, Nitrate and Ammonia-Nitrogen tests has been conducted to measure strength of each prepared synthetic wastewater and the final chosen weight is 1.5 g of dog food in 1 litre of tap water.

The Ammonia-Nitrogen reading from the prepared synthetic wastewater however does not meet with the standard, thus Ammonium Chloride has been added into the mixture to increase the ammonia content. After several samples with different weight of Ammonium Chloride have been prepared, test was conducted and the most appropriate weight of Ammonium Chloride to be used is 150 mg for 1 litre of tap water. The constituent of the synthetic wastewater is shown in **Table 2**.

Table 2: Typical Medium Strength of Untreated Wastewater Composition (Metcalf & Eddy, 2004)

Parameter	Typical Medium Strength Wastewater Composition (mg/L)
COD	430
BOD_5	190
TSS	210
NH_3-N	25
NO_3	0
TKN	40
Total Phosphorus	7

3.2.3 Aero-Packer Design and Installation

Before designing the Aero-Packer, a lot of research on optimum design of packing medium has been done. From the research, it is concluded that there is no specific calculation needed for the design of packing medium. The main principal of a good packing medium is it should have ample susceptible surface area over total volume in order to provide enough space for the attachment of bacteria. The design was done by using AutoCAD software and the final design is as shown in **Figure 8** below.

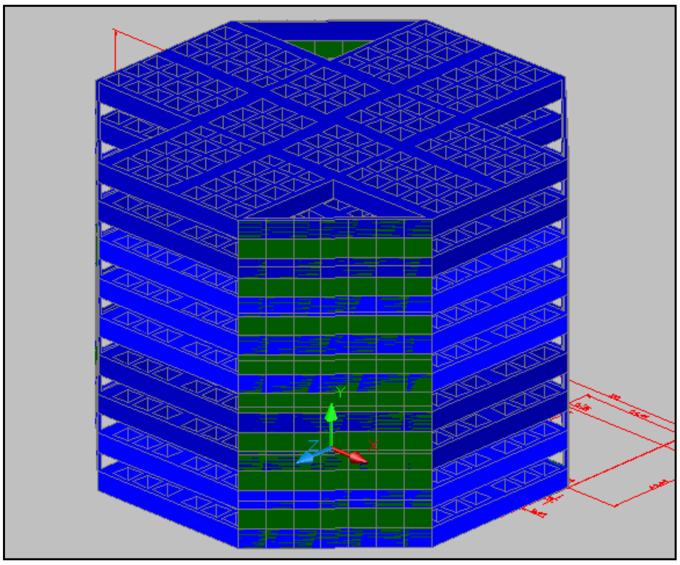


Figure 8: Final Design of the Aero-Packer Packing Medium

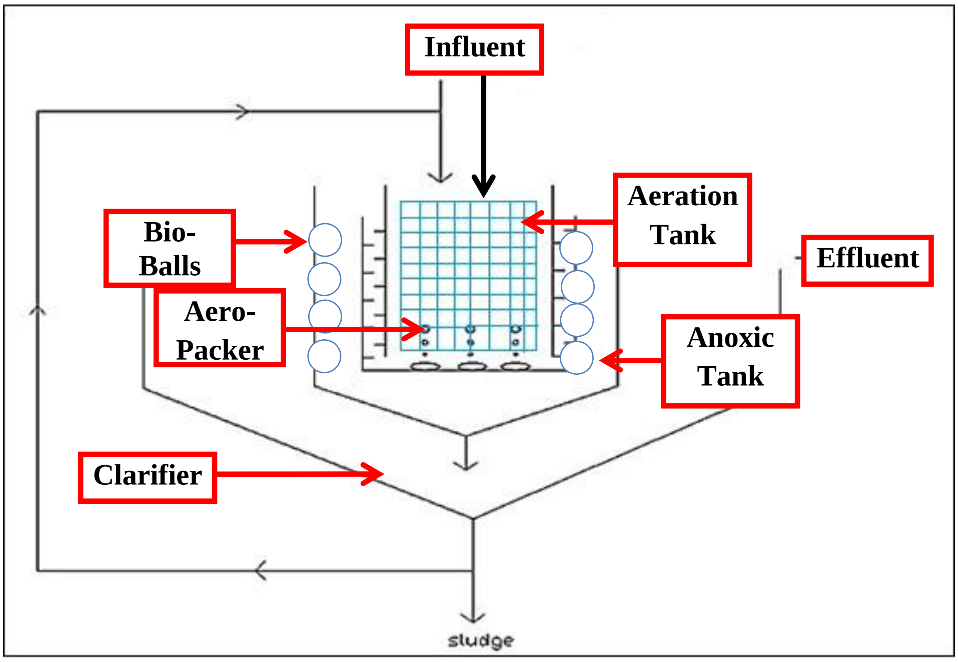


Figure 9: Schematic Diagram of the Reactor with Aero-Packer

The material used for the Aero-Packer is perspex with thickness of average 1 cm. The fabrication of the packing takes about one month and a half to be completed and the final product is as shown in **Figure 10**, **Figure 11** and **Figure 12** while **Figure 13** shows the Aero-Packer after it has been installed in the aeration tank.

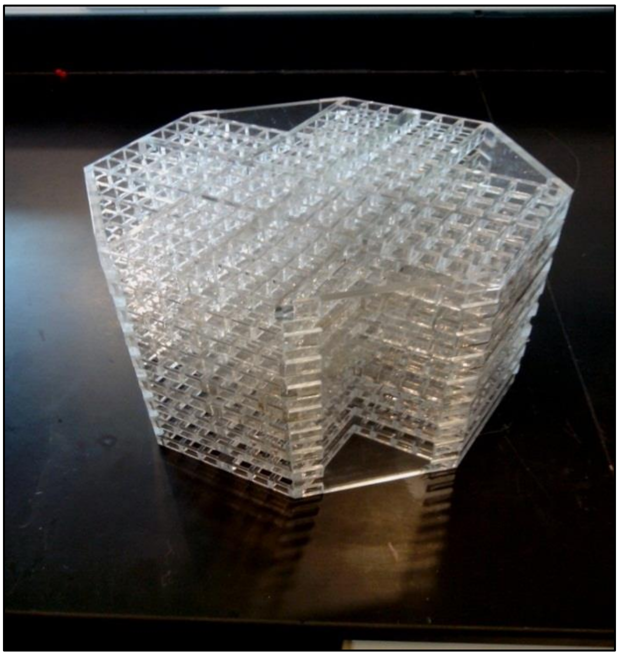


Figure 10: Isometric View of the Aero-Packer

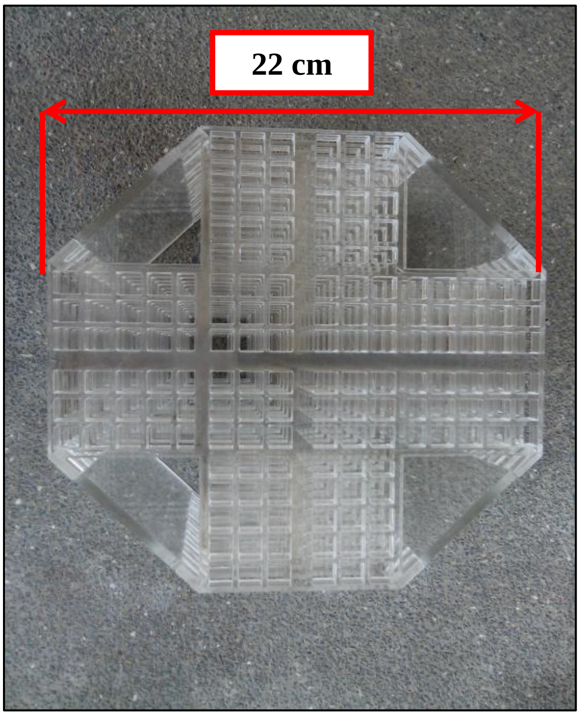


Figure 11: Top View of the Aero-Packer

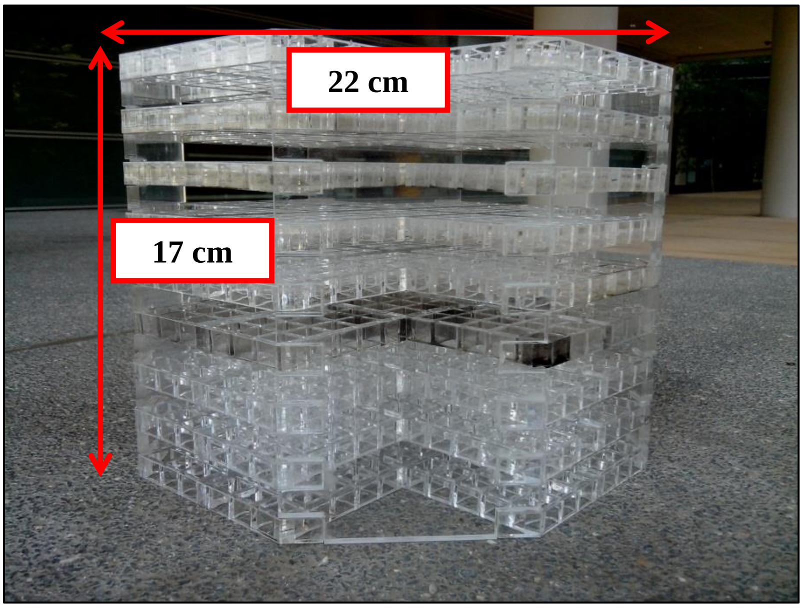


Figure 12: Plan View of Aero-Packer

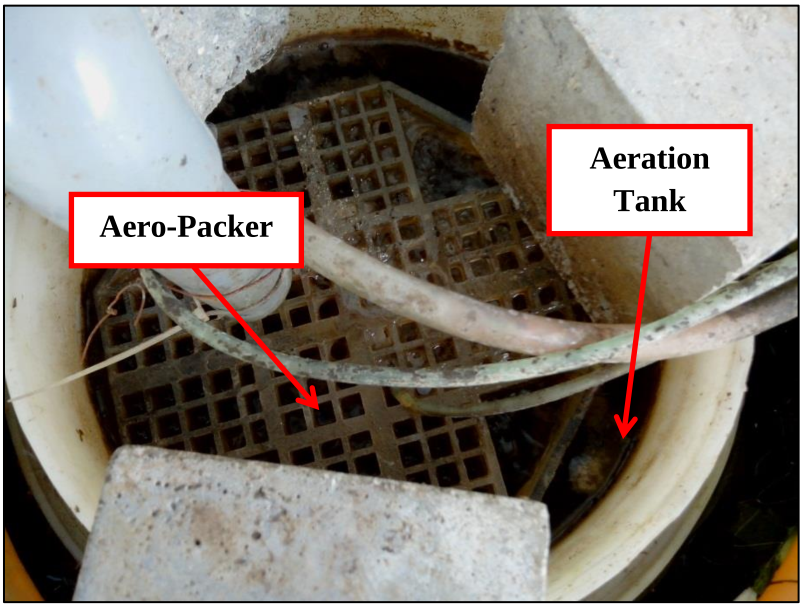


Figure 13: Top View of Aeration Tank after the Installation Aero-Packer

As the reactor has been operated and evaluated in 2 stages which are before enhancement and also after enhancement, the Aero-Packer has only been installed after the completion of the first stage.

3.2.4 Installation of Bio-Balls in Anoxic Tank

Other than installation of Aero-Packer inside the aeration tank, Bio-Balls have also been installed in the anoxic tank as part of the enhancement. The purpose of installing the Bio-Balls in the anoxic tank is as to enhance the denitrification process. **Figure 15** below shows the configuration of the Bio-Balls and **Figure 14** shows the Bio-Balls after it has been installed in the anoxic tank.

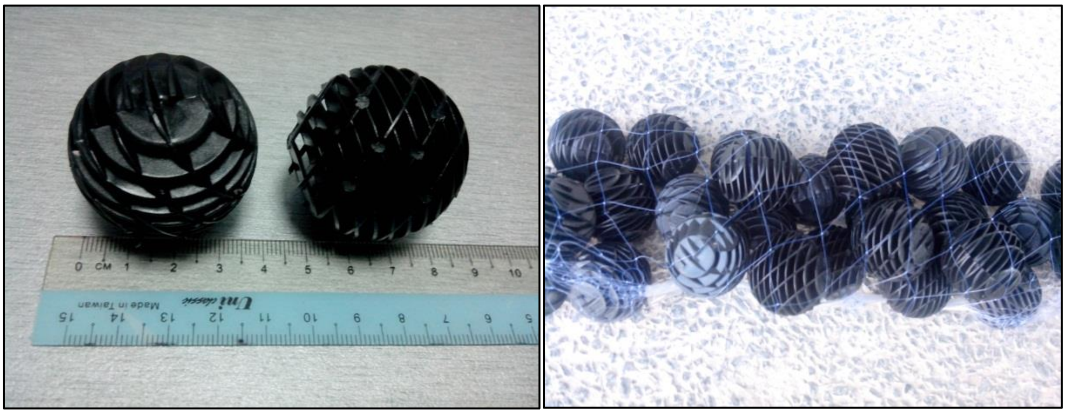


Figure 14: Configuration of the Bio-Balls

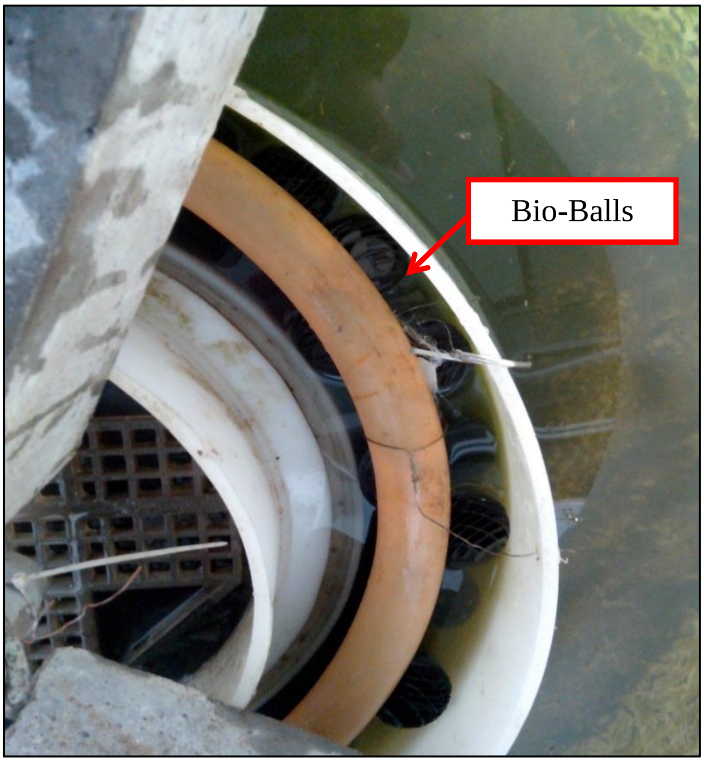


Figure 15: Installation of the Bio-Balls in the Anoxic Tank

3.2.5 Sample Collection for Performance Monitoring

As for the performance monitoring of the reactor, several tests has been done and samples were taken from four different points which are influent, effluent aeration, effluent anoxic and final effluent of the reactor. **Figure 16** below shows the points of sample were taken.

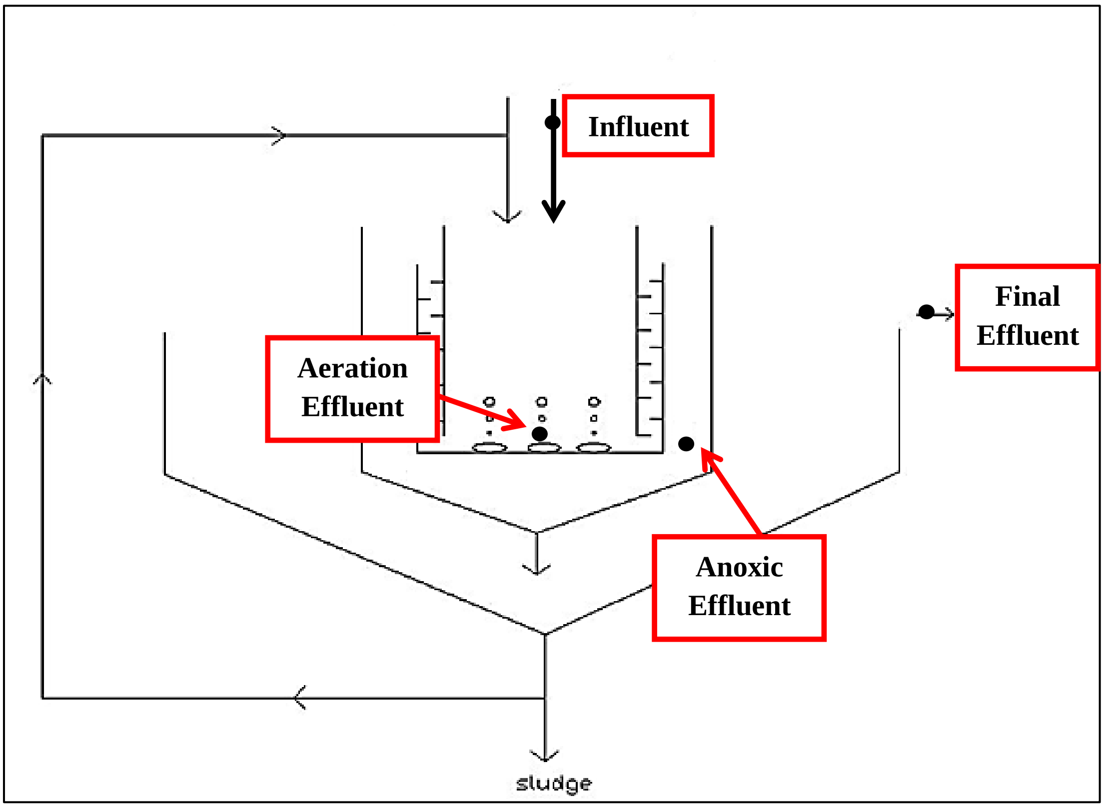


Figure 16: Sample Collection Points

Sample was obtained at it appointed point by using pipette with big bulb and total of 1000 mL of sample were taken each time. Samples have been taken at least three times a week to conduct the test. Tests that need to be conducted for each sample are BOD, COD, MLSS, Nitrate and Ammonia-Nitrogen. As for Total Phosphorus test, it only need to be done periodically as the purpose of this test is only to check the presence of nutrients in the tank while alkalinity test and TKN test need to be done at least once to check if additional alkalinity is needed.

3.2.6 Measurement of BOD, COD, TSS, MLSS, Ammonia-Nitrogen and Nitrate

To test the performance of the integrated batch reactor, several tests has been done to monitor the successfulness of the prototype.

1. **Measurement of BOD**

BOD test is important to assess the reduction of BOD of influent and effluent. In the standard BOD test, a small sample of the wastewater to be tested is placed in a BOD bottle. It is then filled up with aerated water and contain sufficient nutrient for bacteria growth. The usage of aerated water is to ensure that the amount of oxygen in the bottle is sufficient during incubation period. After incubation period of 5 days at 20°C, it is necessary to measure the dissolved oxygen concentration again. The difference in the dissolved oxygen concentration values (mg/L) divided by the decimal fraction of sample used is the BOD result of the sample. It is important to add microorganism seed for a low microorganism concentration wastewater before conducting the test.

2. **Measurement of COD**

The Chemical Oxygen Demand (COD) test measures the oxygen equivalent consumed by organic matter in a sample during strong chemical oxidation. The strong chemical oxidation conditions are provided by the reagents used in the analysis. The procedure starts with a 100 mL of sample was filtered by using filter pump and filter paper and the filtrate sample is taken for test. The DRB200 Reactor need to be turned on and preheat was set to 150^{0}C. The caps were removed from two COD Digestion Reagent Vials. A clean volumetric pipet was used to add 2 mL of sample to the vial. Another clean volumetric pipet was used to add 2 mL of distilled water to the vial for blank sample. Cap the vials were closed tightly and the vials were shook vigorously. The sample vials become very hot during mixing. Heat the vials for two hours by using DRB200 reactor. Then, the vial has been placed in rack and cooled to room temperature. The vials were wiped with a damp towel followed by a dry one. The blank vial sample was put into the spectrophotometer in order to set it to zero. Then the sample vial was put into spectrophotometer to record the COD reading in mg/L. Finally, all COD readings were recorded.

3. Measurement of TSS and MLSS

Both TSS and MLSS have the same method of test. The sample somehow is taken from different source; TSS sample for test is taken from influent and effluent of the wastewater treatment plant while MLSS sample is taken from the aeration tank only. For the test, filter disc is placed inside the filter holder. Well-mixed wastewater sample is then poured into the flask before applying the vacuum. The filter disc is then need to be in drying oven at 103°C to 105°C for an hour. The weight of filter disc before and after the drying shows the value of TSS and MLSS.

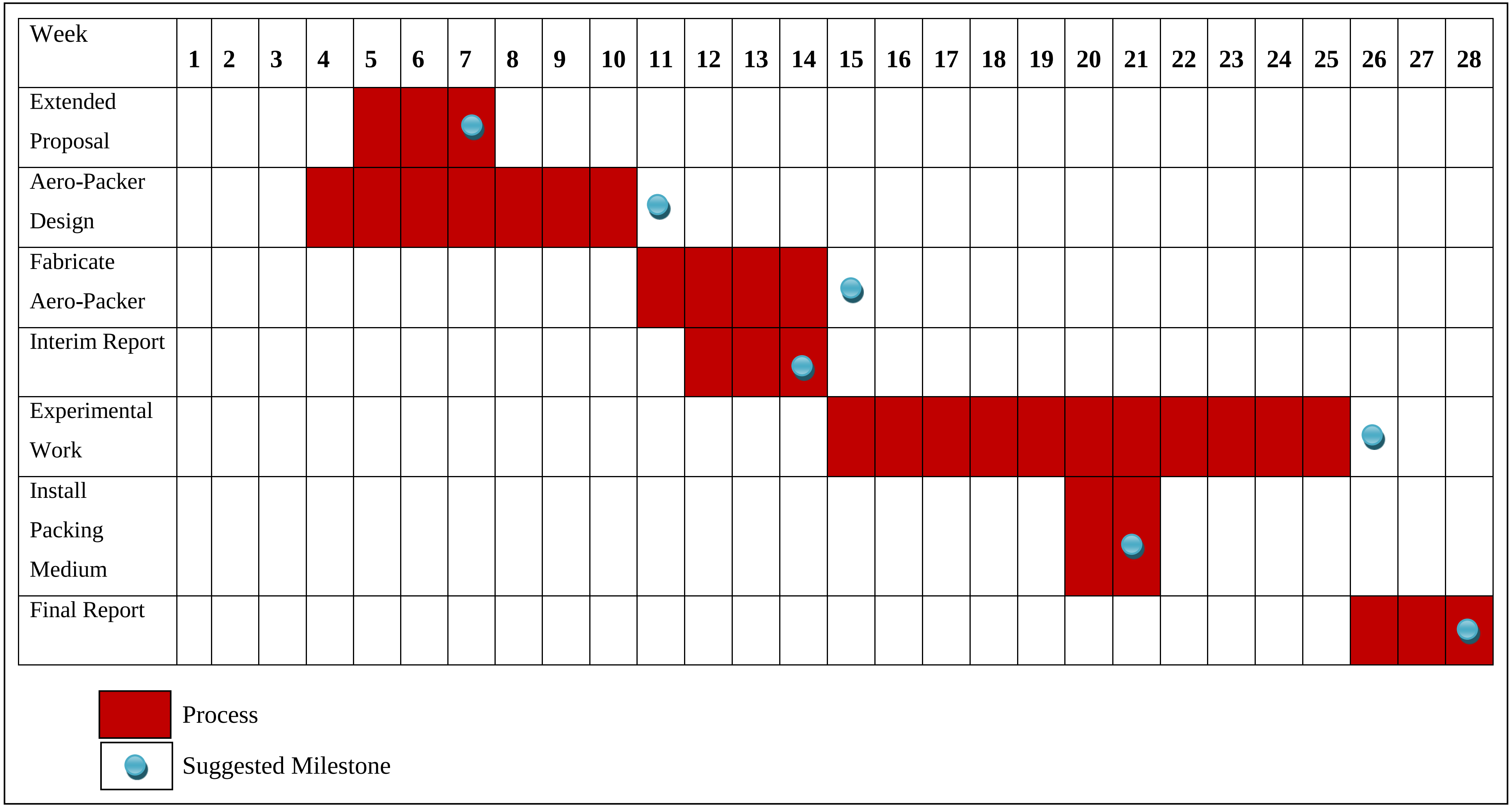
4. Measurement of Ammonia-Nitrogen

25 mL of sample and deionized water is poured into separate mixing cylinder as this is to prepare the sample and blank. Three drops of mineral stabilizer is then added to both mixing cylinders before they had to be shake vigorously for mixing. Then, add three drops of Polyvinyl Alcohol Dispersing Agent (to aid in colour formation in the reaction) into each cylinder and followed by 1.0 mL of Nessler Reagent. The solution is then being mixed well before being left for one minute reaction period. After that, 10 mL mixtures of each sample were poured into sample cell. The content of ammonia-nitrogen is then be measured by using Spectrophotometer.

5. Measurement of Nitrate

10 mL of sample is added into the sample cell before the content of one packet of NitraVer 5 Nitrate Reagent is added. After that, the mixture is being shaken well for one minute before being left for five minutes for reaction to take place. Formation of amber colour in the solution shows that there is presence of nitrate in the solution. For blank preparation, the sample cell is filled with 10 mL of similar sample. The content of the nitrate then can be measured by using Spectrophotometer.

3.3 Gantt Chart and Key Milestone



3.3 Tools

Table 3 below shows the software that has been used during the project of CEAR

Table 3: List of tools to be used for the completion of project

No.	Software/ Hardware	Description
1.	Microsoft Office • Microsoft Word • Microsoft Excel	This software is used for the documentation of paperwork, lab results and any calculations
2.	AutoCAD	This software is used for designing of Aero-Packer
3.	Existing integrated biological reactor	The reactor is used for the treatment of wastewater
4.	Laboratory apparatus and material	Apparatus and material are used for the experimental work such as COD , BOD, TSS and MLSS

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Preparation of Synthetic Wastewater

From the feasibility study done, the synthetic wastewater produced has almost the same properties as the typical medium strength of domestic wastewater as shown in **Table 4** and the quantity of raw material used to make the synthetic wastewater in 1 Litre of tap water is shown in **Table 5**:

Table 4: Typical Medium Strength of Wastewater Composition

Parameter	Synthetic Wastewater (mg/L)	Typical Medium Strength Wastewater Composition (mg/L)
COD	500	430
BOD_5	170	190
TSS	180	210
NH_3-N	27	25
NO_3	0.5	0

Table 5: Raw Materials used for the Synthetic Wastewater

Material	Gram per Litre of Tap Water
Purino Alpo High Protein Puppy Dog Meal	1.5
Ammonium Chloride powder	0.15

1.5 g of dog's food and 0.15 g of Ammonium Chloride in 1 Litre of tap water is used for the preparation of synthetic wastewater. 50 L of synthetic wastewater is prepared each time to ensure a constant loading is provided to the reactor. The mixture used for the preparation of synthetic wastewater consists of 75 g of dog's food and 7.5 g of Ammonium Chloride mixed well in the 50 L of tap water.

4.2 Calculation of the Flowrate, Solid Retention Time (SRT) and Sludge to be wasted

With the fixed design SRT, the calculation has been done with influent flowrate as the variable to be controlled. Typical value for extended aeration duration has been set as 35 days while other parameters have been taken from the typical value provided in Metcalf and Eddy (2004). The typical values adopted for the calculation are shown in **Table 6** while the $P_{x,bio}$ based on different flowrate assumed in shown in **Table 7**.

Table 6: Typical Values Adopted for the Coefficient Used

Coefficient	Value
Y	0.4 g VSS/g bCOD
Y_n	0.12 g VSS/g NO_x
K_d	0.088 g/g.d
K_{dn}	0.06 g VSS/g VSS.d
f_d	0.15
S_o	224 g bCOD/m^3
S	0.7 g bCOD/m^3

Table 7: Values of $P_{x,bio}$ Based on Different Flowrate for SRT of 35 Days

Flowrate (L/day)	$P_{x,bio}$ (g VSS/day)
50	1.655
25	0.827
15	0.496
10	0.331

During the first semester, the tank was initially run for 7 days (based on calculation made) with constant feeding of synthetic wastewater. After several days, it was observed that the production of biomass is very high that requires removal of sludge from the system regularly. As the objective of extended aeration system is to produce less sludge from reducing the F/M ratio, the flowrate was then reduced to 25 L/day and has been let run for another 10 days with recycle rate of every 2 hours. Changes is however been made during the second semester after several experiments have been done and has been further discussed in further sections.

4.3 Performance Monitoring

4.3.1 Before Installation of Aero-Packer and Bio-Balls (Before Enhancement)

During the second semester, the reactor has been operated with influent flowrate of 15 L/day. The performance monitoring is divided into two phases which are before the installation of Aero-packer in the aeration tank and after the installation. Several test such as BOD, COD, TSS and MLSS tests has been done to monitor the performance of the reactor in removing organic matter. To ensure the reliability of the results, each sample was tested 3 times and the final average value has been taken as the result. Samples have been taken from four different points each time which are influent, effluent aeration, effluent anoxic and finally the final effluent. Results below show the result of tests of reactor performance before the installation of Aero-Packer. The raw data is provided in Appendix section.

TSS Results

Based on the **Figure 17** (TSS for influent and effluent), the result shows that the TSS reading initially was 125 mg/L on day 1 before reducing on the consecutive days. During the first 10 days, the ingredient measurement used is 0.5 mg/L of dog food.

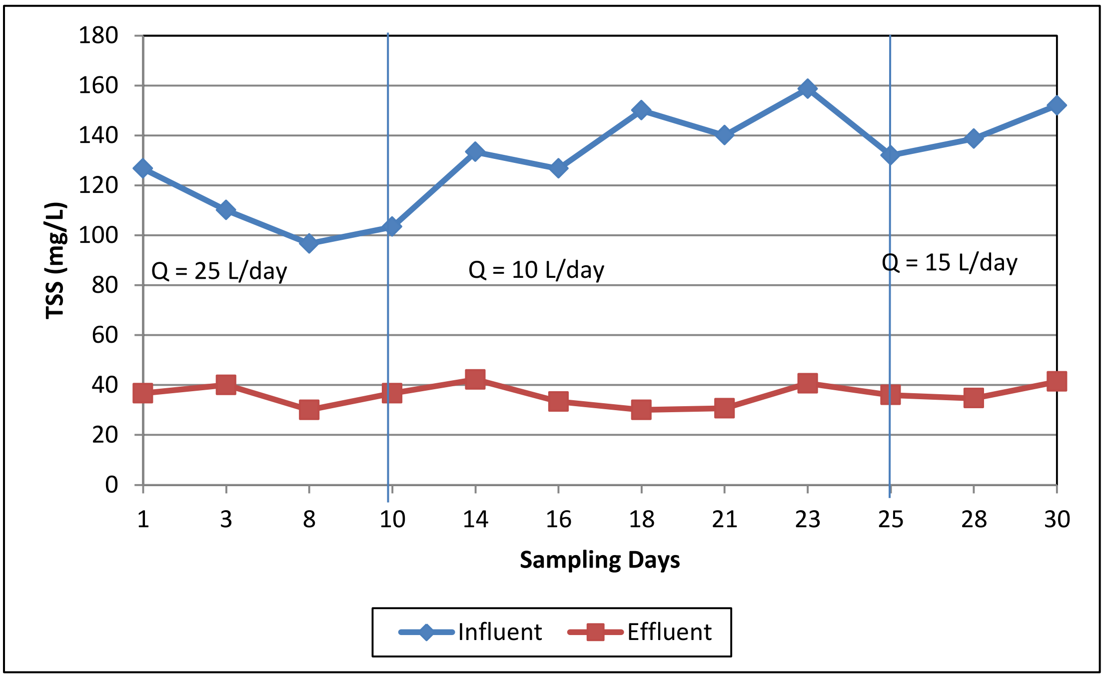


Figure 17: Graph of Total Suspended Solid (mg/L) vs Sampling Days

It is observed that the influent TSS is slightly lower than the typical domestic wastewater TSS, thus the loading was increased to 1.5 mg/L from day 10 up until day 30. From the changes made, the influent TSS increased with reading of 130 mg/L on day 14 and then alternately increased and decreases for the consecutive days. As for the effluent result, the graph shows that the effluent TSS is quite constant throughout the 30 days of experiments although the influent flowrate varied from time to time. The average reduction percentage of the TSS is 75% with average TSS reading of the effluent is 37 mg/L which comply with the Standard A of sewage discharge limit. Besides that, **Figure 18** as shown above is the result of TSS removal kinetics and the graph shows that the removal kinetic was observed to be 0.0002 respectively. This value is considerably low as compared to typical value of TSS removal kinetics.

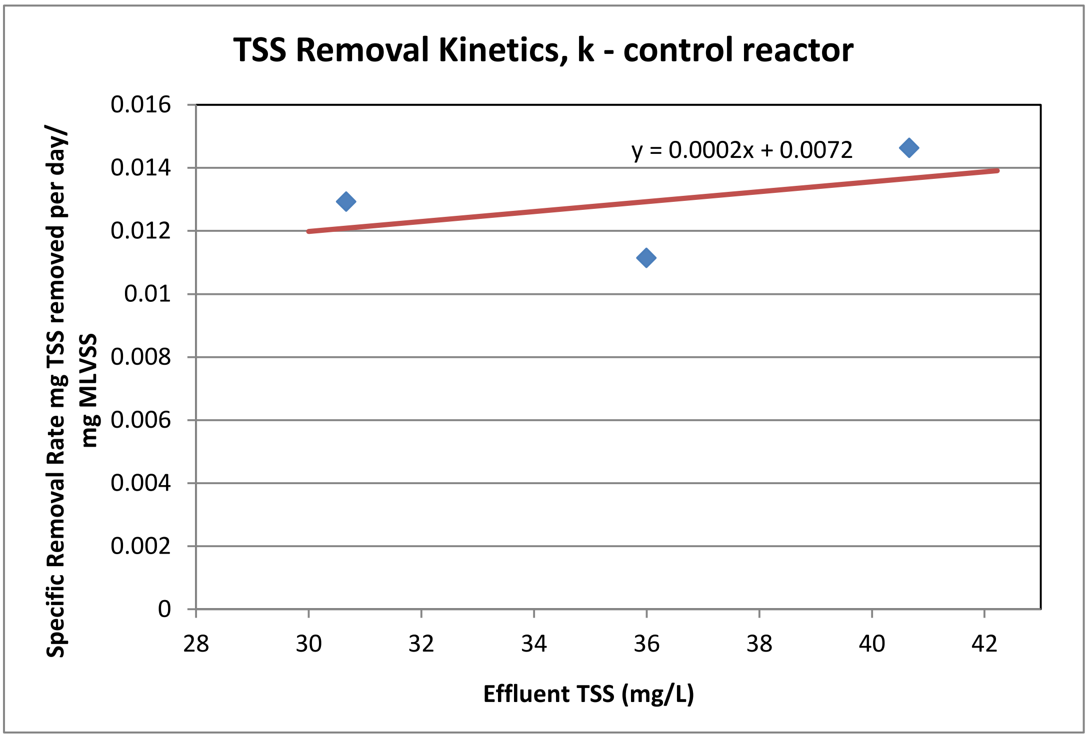


Figure 18: Graph of TSS Removal Kinetics, k.

BOD Results

Based on the graph of **Figure 19**, the influent BOD reading of the first day of sampling is 135 mg/L and then it increased gradually until day 10 before reducing again on day 14 before became constant up until day 30. The graph however shows that the reduction in BOD level from each point of sampling does occur constantly. This shows that the reactor is working properly. Lastly, the BOD reading of final effluent is a bit high on the first 10 days in which may be due to acclimatization period of the bacteria. Starting from day 10 however, the effluent BOD shows better result with average reading of 39 mg/L which comply with the Standard B of sewage discharge limit.

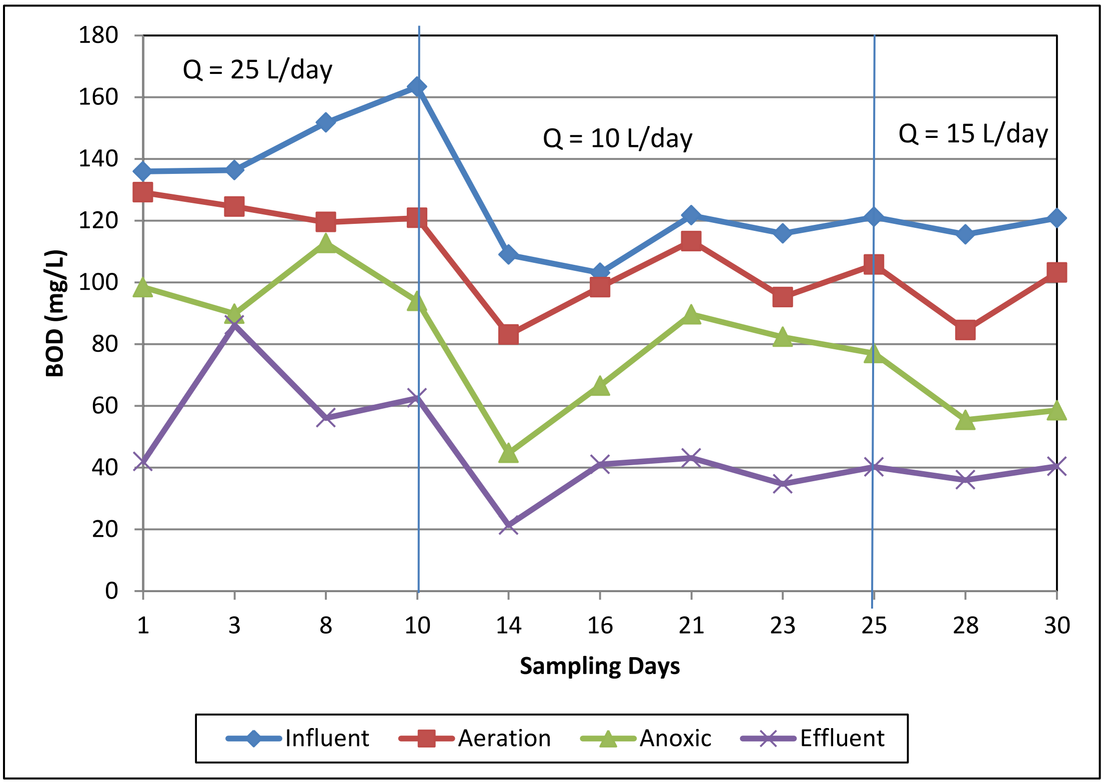


Figure 19: Graph of BOD (mg/L) vs Sampling Days

Besides that, **Figure 20** shows the graph of BOD removal kinetics based on the laboratory experiments. From the graph, the removal kinetics of the reactor is observed to be 0.0003 and this value is considered as low.

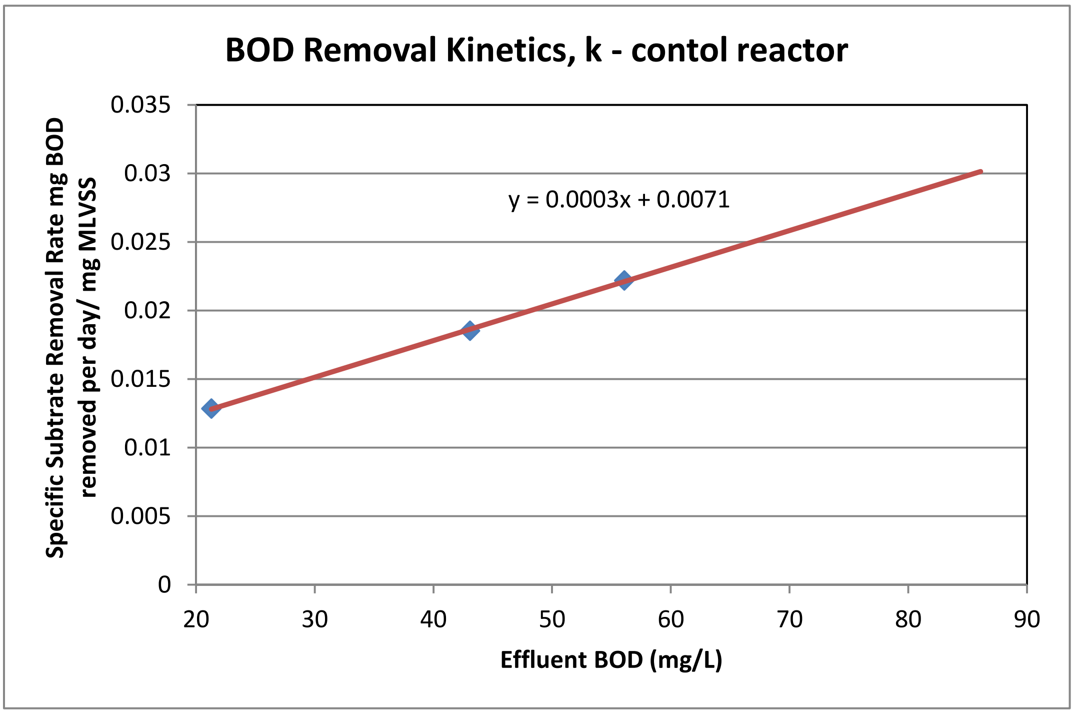


Figure 20: Graph of BOD Removal Kinetics, k.

COD Results

From the **Figure 21,** initially the observed influent COD is low as compared to the typical domestic medium strength wastewater. During the first 10 days, the average COD reading of the influent is 290 mg/L. However, after the add up of dog food in the synthetic wastewater, the COD reading of influent shows increment day by day before become constant on day 25 onwards. As for the effluent COD, although the influent loading has been changed gradually, the effluent COD however shows not much changes in the result with average reduction percentage of 64%. The effluent COD of sample day 1 is 125 mg/L before gradually decrease until day 10. After day 10, the reading started to increase before it became constant on day 25 and onwards. Although there has been increment of effluent COD started from day 10 up until day 35, the final effluent reading however still comply with the sewage discharge limit of Standard B.

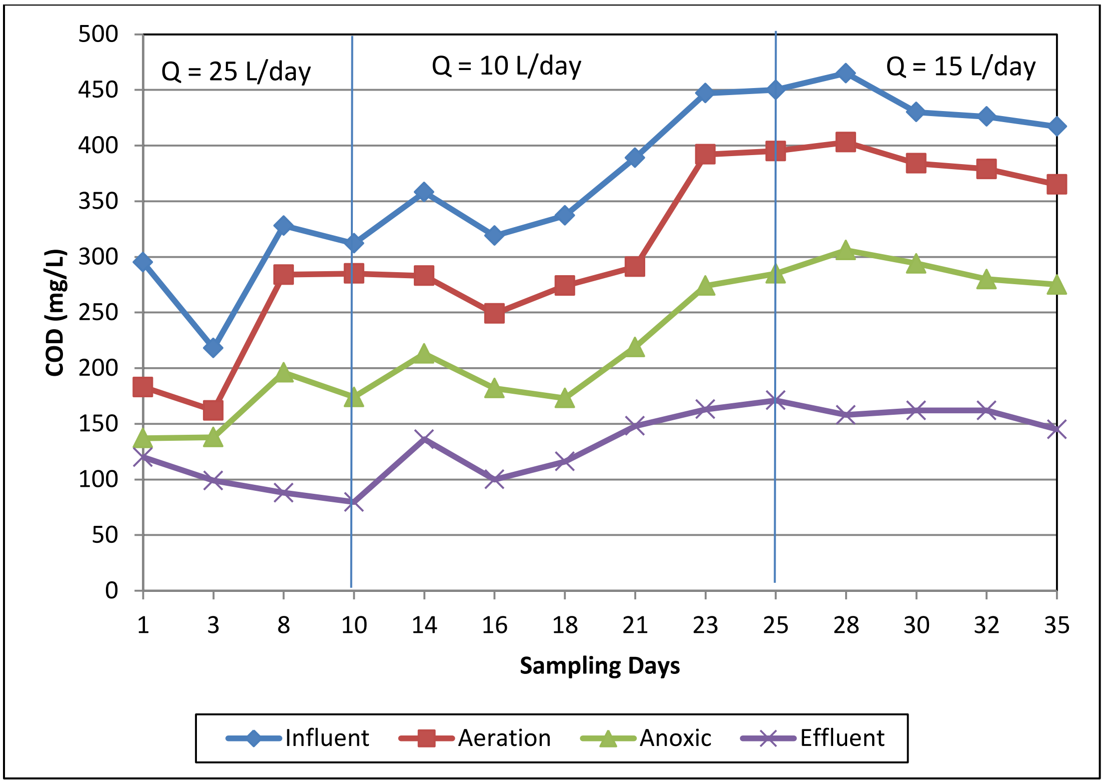


Figure 21: Graph of COD (mg/L) vs Sampling Days

In addition to that, **Figure 22** shows the graph of COD removal kinetics. From the graph, it shows that the removal kinetics is 0.0001 and this shows that the performance of the reactor can be enhanced to get better result.

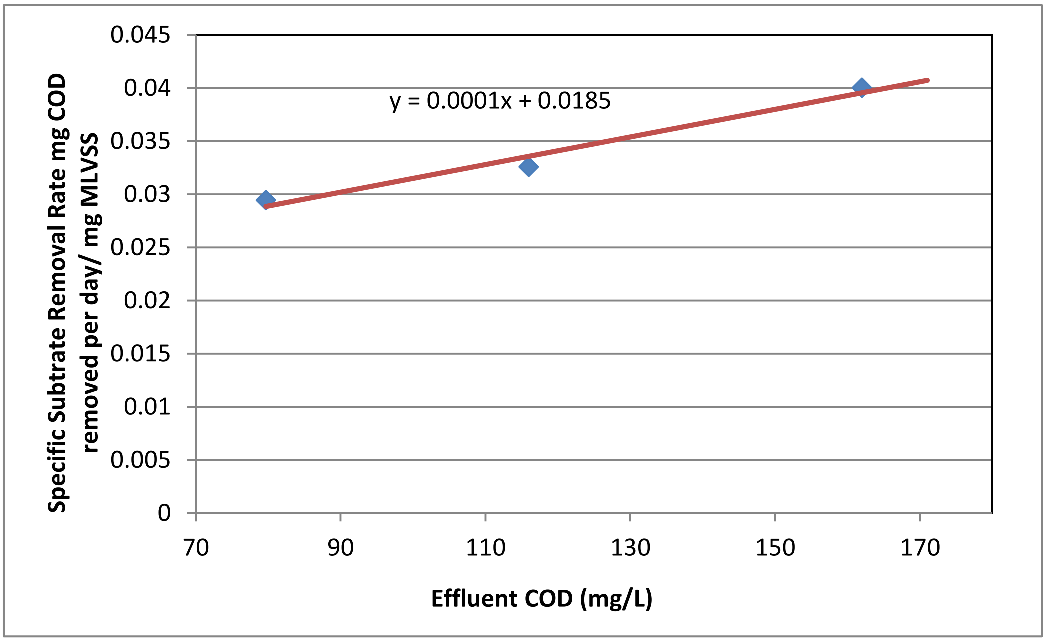


Figure 22: Graph of COD Removal Kinetics, k.

MLSS Results

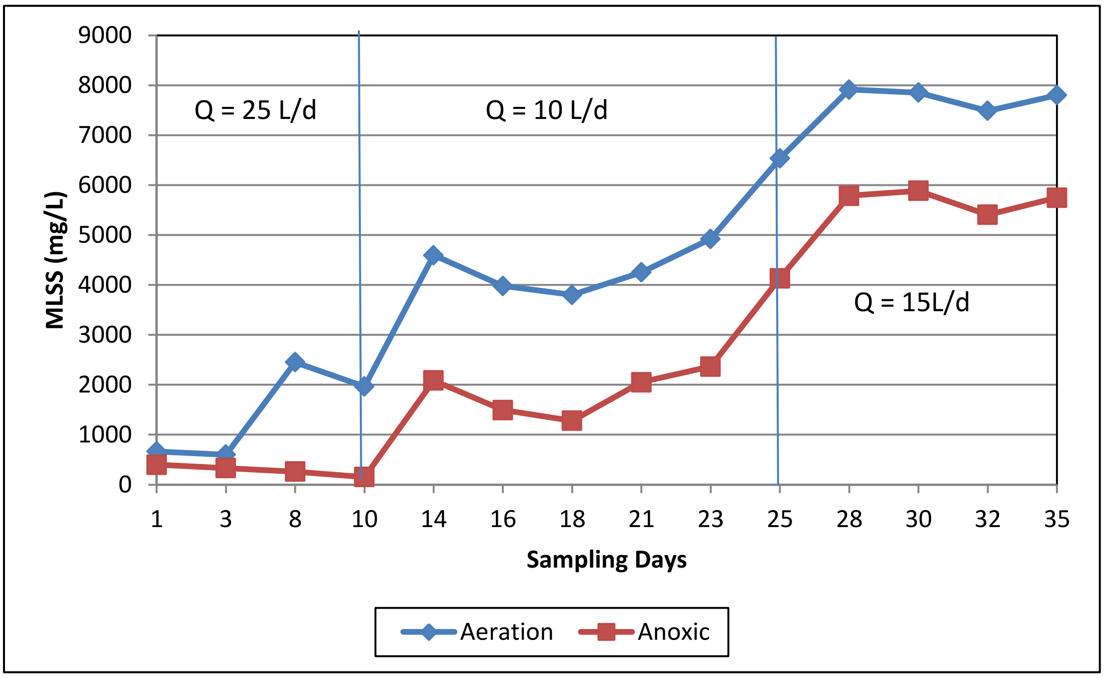


Figure 23: Graph of MLSS vs Sampling Days

MLVSS Results

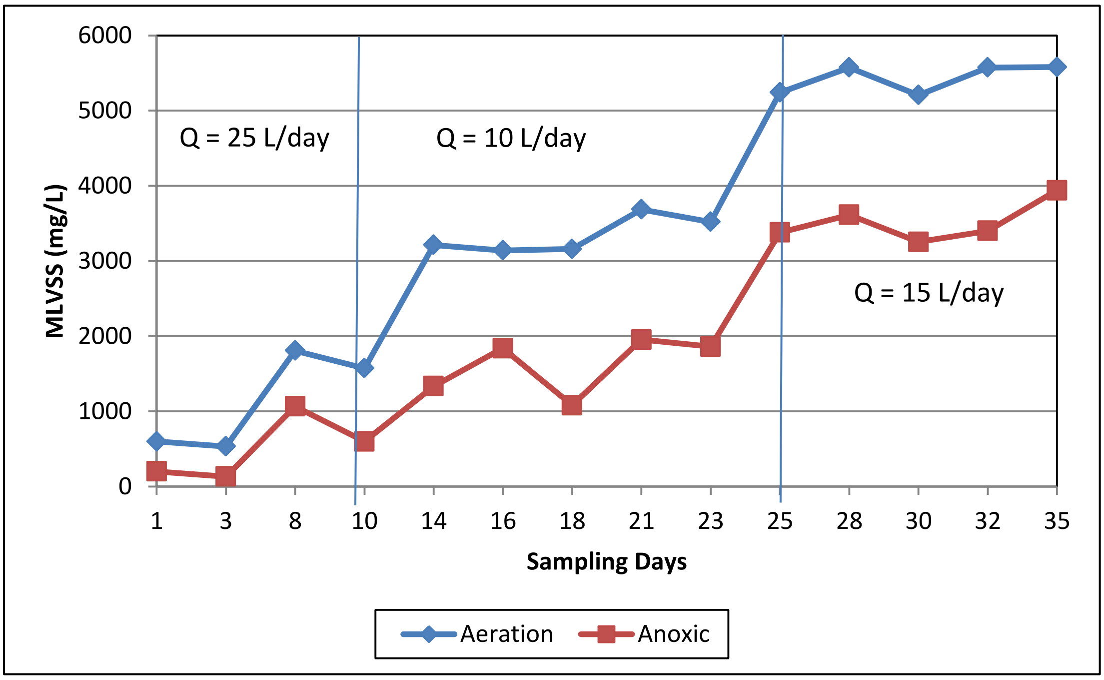


Figure 24: Graph of MLVSS vs Sampling Days

Based on the graph, it shows that the MLSS level on day 1 until day 10 is very low. This may be due to insufficient biomass obtained from the UTP sewage treatment plant and also poor recycle rate. The increase in MLSS reading on day 8 and day 10 may be due to high influent flowrate. On day 10, more sludge were taken from the UTP STP and added up with the existing sludge in the reactor. This explains why the MLSS reading increases from day 10 onwards. The reactor also has been monitored regularly to ensure that the sludge is recycled properly. With the increase influent flowrate on day 25, it has causes increment on the MLSS reading before it became constant up until day 35 with average reading of 7500 mg/L in aeration tank and 5400 mg/L in anoxic tank. The MLSS reading shows that the biomass is sufficient enough in the aeration tank and anoxic tank for degradation process to take place. The MLVSS value also shows increment from day 1 until day 35 accordingly with the increment of MLSS value with average value of 4476 mg/L in overall.

4.3.2 After Installation of Aero-Packer and Bio-Balls (After Enhancement)

TSS Results

From the **Figure 25**, it is observed that the value of TSS influent and TSS effluent is constant throughout the 24 days of experiment. This may be because of the constant loading of 15 L/day is used. As for the TSS influent, the lowest value recorded is 132 mg/L and highest value is 160 mg/L while the average of TSS influent is 146 mg/L. The effluent TSS in the other way around has minimum value of 13 mg/L, maximum value of 29 mg/L and average value of 22 mg/L. The total reduction percentage observed after the enhancement is 85% which is 15% higher than the TSS reduction before enhancement.

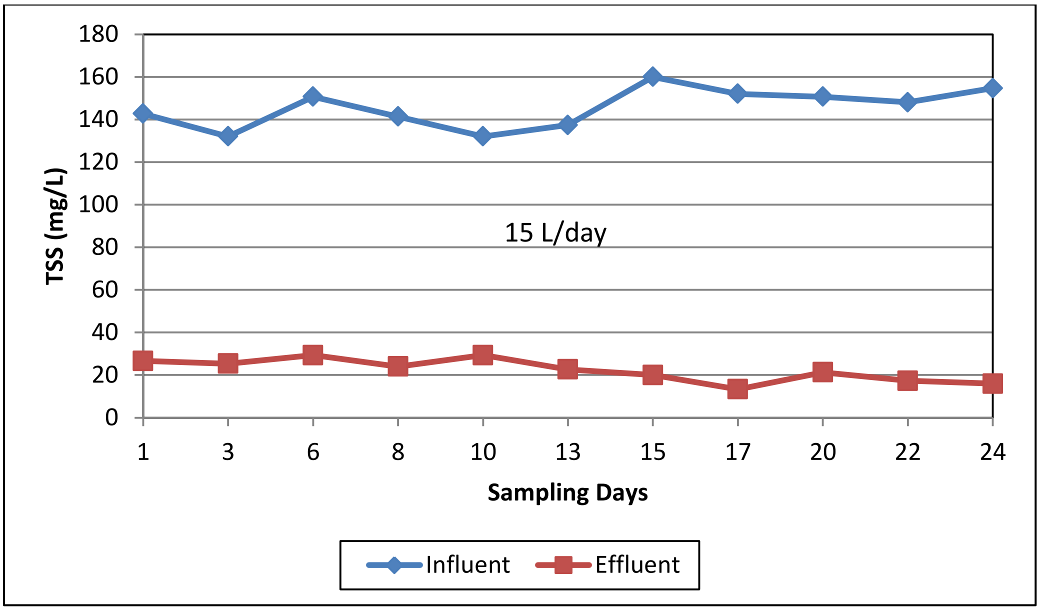


Figure 25: Graph of Total Suspended Solid (mg/L) vs Sampling Days

BOD Results

The result as shown in **Figure 26** indicates that the result for BOD reading is quite constant throughout the experiment process. Although there some increment and decrement in influent and effluent reading from day 13 until day 22, the value variations is still within acceptable range. As for the influent, the minimum value recorded is 117 mg/L while maximum value is 144 mg/L and overall average value of 130 mg/L. The effluent meanwhile has minimum value of 18 mg/L and maximum value of 40 mg/L with average value of 30 mg/L which comply with the Standard B of effluent discharge and the total reduction percentage is 77 %.

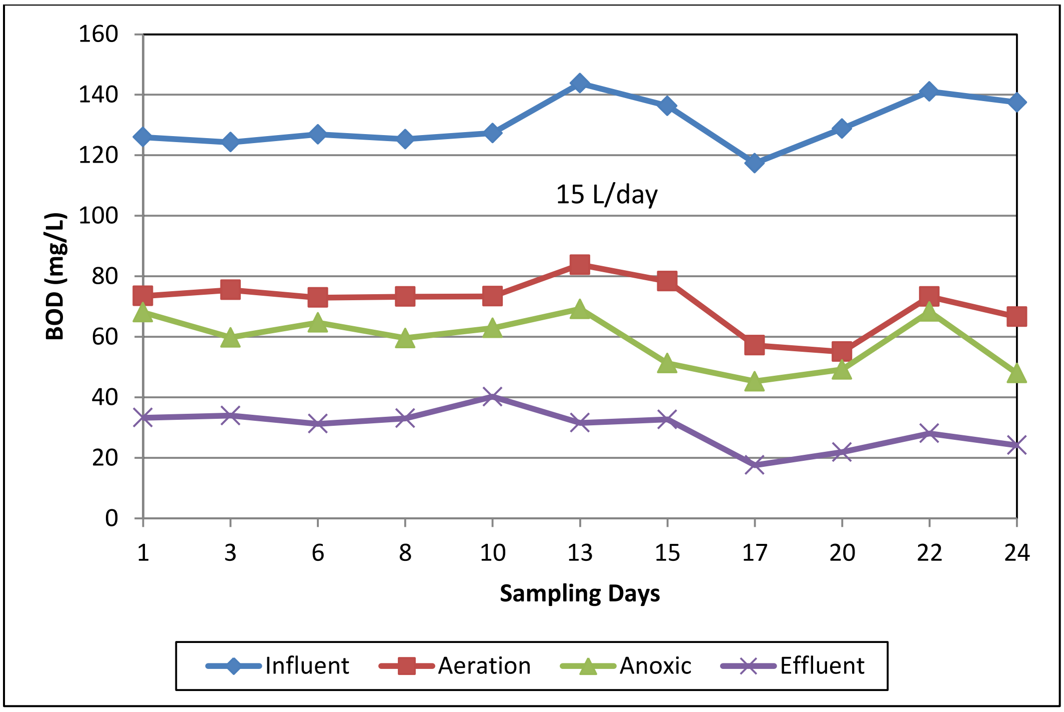


Figure 26: Graph of BOD (mg/L) vs Sampling Days

COD Results

From the graph of **Figure 27**, the result shows that there are significant reductions of COD from day 1 until day 24. The COD reading abruptly drop from influent to effluent of aeration. The COD reading however does not show much decrement from effluent of anoxic tank as the degradation process does not occur in the anoxic tank. The COD reading then continue to reduce for the final effluent. The maximum value recorded for the influent COD is 451 mg/L and minimum value of 406 mg/L. As for the effluent, the minimum observed COD reading is 75 mg/L and maximum value of 90 mg/L. The average COD reading for the influent is 424 mg/L while for the effluent is 83 mg/L which comply with the Standard A of sewage discharge limit. The total reduction percentage is 80% which is 16% higher than before installation of Aero-Packer.

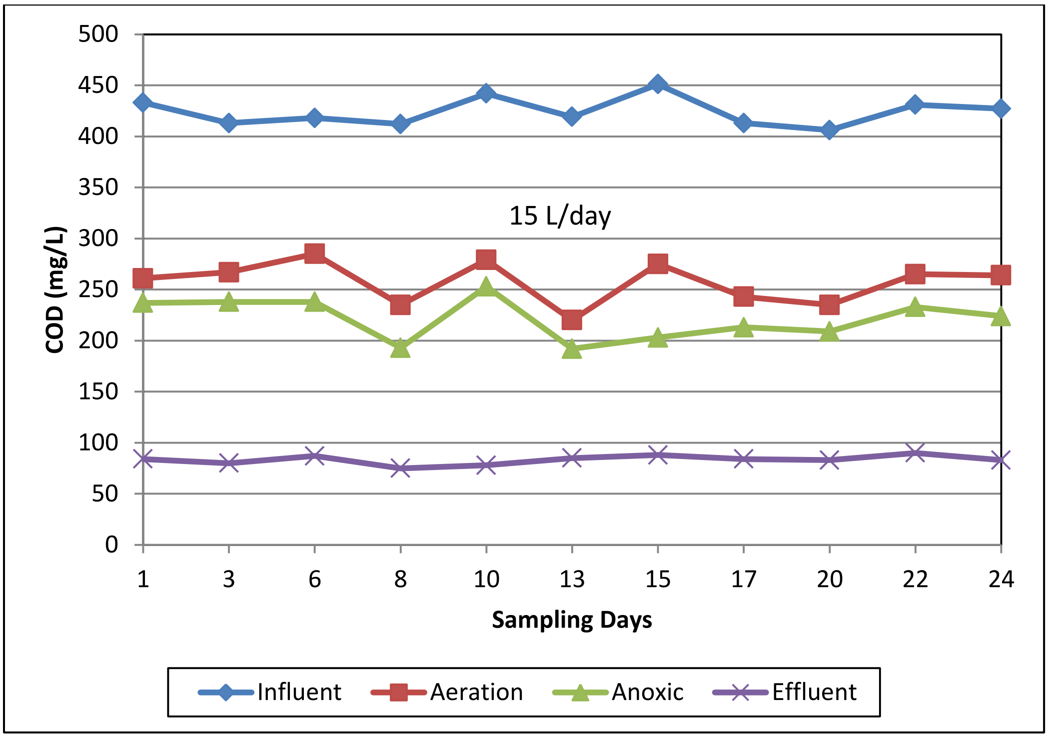


Figure 27: Graph of COD (mg/L) vs Sampling Days

MLSS Results

From the results obtained as shown in **Figure 28** and **Figure 29**, it shows that the microorganism inside the tank is in good condition. For the MLSS reading, the average reading in aeration tank is 7556 mg/L while in anoxic tank is 5137 mg/L. The MLVSS value meanwhile shows the amount of biodegradable microorganism inside the reactor is at a good state with average reading of 5534 mg/L in aeration tank and 3548 mg/L in anoxic tank. The ratio of MLSS after enhancement is 1.73 as compared to before enhancement while the MLVSS ratio is 1.67. The good condition of microorganism is as result of good sludge recycle and also due to constant loading.

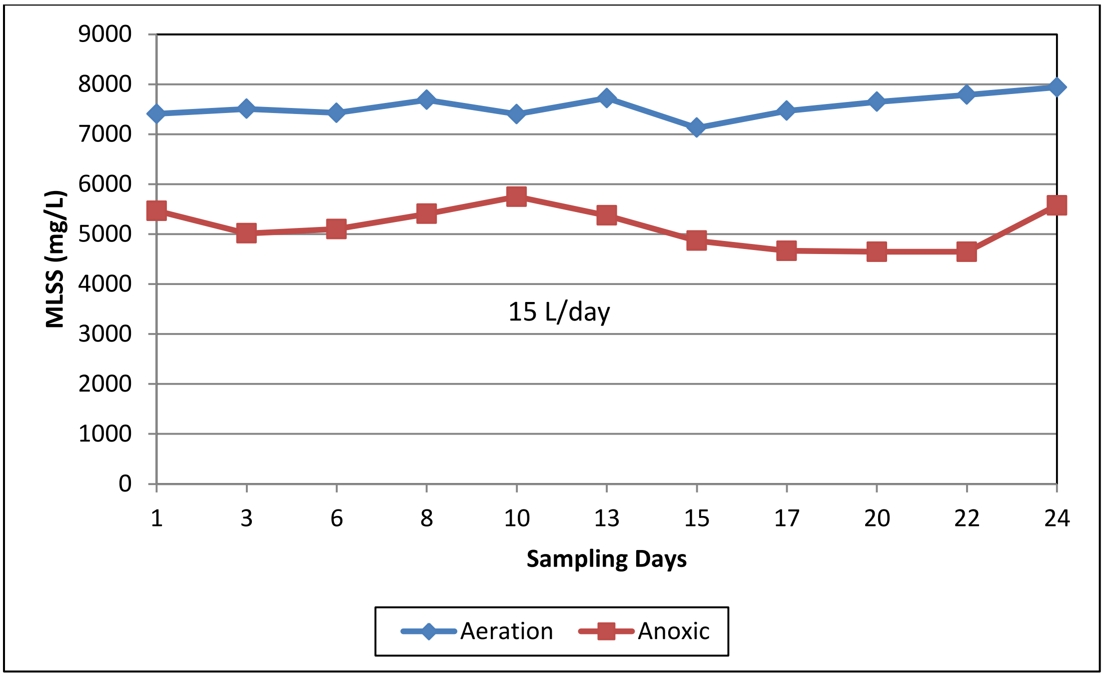


Figure 28: Graph of MLSS vs Sampling Days

MLVSS Results

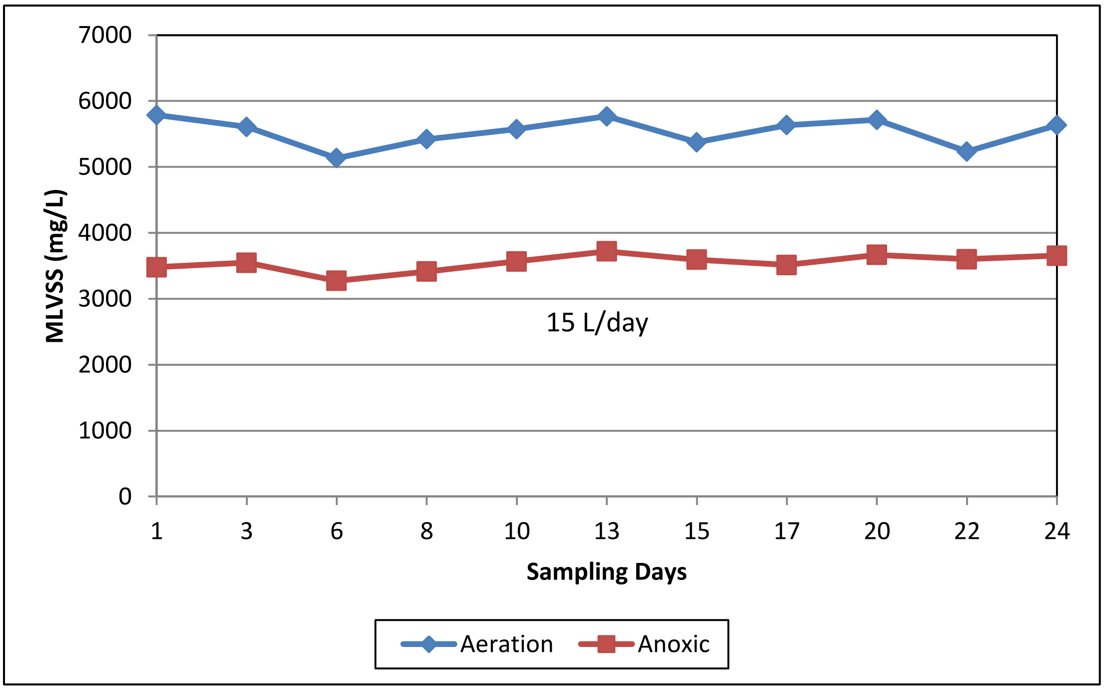


Figure 29: Graph of MLVSS vs Sampling Days

4.4 Summary of Results

The **Table 8** shows the summary of reduction percentage for all parameters before the enhancement and after the enhancement of the reactor.

Table 8: Summary of Reduction Percentage

Before Installation of Aero-Packer and Bioballs (Before Enhancement)			
Parameter	**Average Influent (mg/L)**	**Average Effluent (mg/L)**	**Reduction %**
BOD_5	119	39	67
COD	438	160	64
TSS	144	37	75
After Installation of Aero-Packer and Bioballs (After Enhancement)			
Parameter	**Average Influent (mg/L)**	**Average Effluent (mg/L)**	**Reduction %**
BOD_5	130	30	77
COD	424	83	80
TSS	146	22	85

Before the installation of Aero-Packer and Bio-balls in the reactor, the total reduction observed is 67% for BOD, 64% for COD and 75% for TSS. The reduction percentage increases after the installation of Aero-Packer and Bio-Balls with increment of 10% for BOD, 16% for COD and 10% for TSS. This shows that the Aero-Packer and Bio-Balls is significantly efficient to enhance the performance of the CEAR.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

With some preparation done during the early stage of the project, several parameters has been managed to be fixed up by the student such as the preparation of synthetic wastewater. The preparation of synthetic wastewater uses 1.5 gram of dog food and 0.15 g of Ammonium Chloride powder in 1 L of tap water. The flowrate of the influent flowrate has been fixed as 15 L/day with recycle rate of every one and a half hour with duration of 1 minute for every cycle.

As for the experiments activities, the first phase of the experiment which is without the installation of Aero-Packer and Bio-balls has been done. The result from the experiment shows that there is reduction in several parameters such as BOD with 67%, COD with 64% and finally TSS with 75%. The MLSS reading also shows excellent condition of biomass in the reactor. The reduction percentage also shows significant increment after the installation of Aero-packer and Bio-balls with reading of 77% for BOD, 80% for COD and 85% for TSS. The result shows that the performance of the CEAR in removing organic is better with the implementation of attached growth system.

For future work, several additional studies can be done to further evaluate the performance of the reactor. Among of the alternatives that can be done is by using various wastewater loading for the influent. This is to test the maximum capacity of the reactor in receiving and treating wastewater. Besides that, the sludge retention time (SRT) also could be extended to test the performance of the reactor after a long period of time of treatment.

All in all, the objective of the project has been achieved and the attached growth system has been proven effective in enhancing the overall performance of the reactor in removing organic. With further studies conducted on the reactor, the system can be a new solution to effective wastewater treatment.

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Appendix

A

Appendix

Appendix A (Excel Calculation Formula)

Biomass Production(Q. 11)

Px,bio(kg VSS/d)	Q(m3/d)	Y	So	kd	µm	S	Ks	SRT(d)	Yn	Fd	NOx	Kdn
0.000611	0.015	0.4	224	0.088	3.5	0.79	20	22	0.12	0.15	28.3	0.06
0.000784	0.015	0.4	224	0.088	3.5	0.79	20	12	0.12	0.15	28.3	0.06
0.000532	0.015	0.4	224	0.088	3.5	0.79	20	30	0.12	0.15	28.3	0.06
0.001773	0.05	0.4	224	0.088	3.5	0.79	20	30	0.12	0.15	28.3	0.06
0.124069	3.048	0.4	224	0.088	3.5	0.79	20	22	0.12	0.15	28.3	0.06
0.000000												
0.000000												
0.000000												
0.000000												
0.000000												

Nitrogen Balance(Q.12)

NOx	TKN	Ne	Px,bio	Q
29.62	35	0.5	0.0006106	0.015
28.23	35	0.5	0.0007842	0.015
30.25	35	0.5	0.0005318	0.015
30.25	35	0.5	0.0017727	0.05
29.62	35	0.5	0.1240687	3.048
#DIV/0!			0	0
#DIV/0!			0	0
#DIV/0!			0	0
#DIV/0!			0	0
#DIV/0!			0	0

Concentration and Mass of VSS and TSS(Q.13)

Concentration(kg/d)		Mass(kg)	
Px,vss	Px,tss	MLVSS	MLSS
0.000911	0.001168	0.020032	0.025703
0.001084	0.001373	0.013010	0.016471
0.000832	0.001076	0.024955	0.032270
0.002773	0.003586	0.083182	0.107567
0.185029	0.237403	4.070632	5.222871
0.000000	0.000000	0.000000	0.000000
0.000000	0.000000	0.000000	0.000000
0.000000	0.000000	0.000000	0.000000
0.000000	0.000000	0.000000	0.000000
0.000000	0.000000	0.000000	0.000000

Px,bio	Q	nbVSS	TSS	VSS	SRT
0.000611	0.015	20	70	60	22
0.000784	0.015	20	70	60	12
0.000532	0.015	20	70	60	30
0.001773	0.05	20	70	60	30
0.124069	3.048	20	70	60	22
0.000000	0				0
0.000000	0				0
0.000000	0				0
0.000000	0				0
0.000000	0				0

Aeration Tank Volume and Detention Time(Q.14)

V(m3)	Detention time(h)	Fraction VSS	MLVSS(g/m3)
0.008568	14	0.78	2338
0.005490	9	0.79	2370
0.010757	17	0.77	2320
0.035856	17	0.77	2320
1.740957	14	0.78	2338
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

MLSS	X,tss	Q	VSS	TSS
0	3000	0.015	0.020032	0.025703
0	3000	0.015	0.013010	0.016471
0	3000	0.015	0.024955	0.032270
0	3000	0.05	0.083182	0.107567
5	3000	3.048	4.070632	5.222871
0		0	0.000000	0.000000
0		0	0.000000	0.000000
0		0	0.000000	0.000000
0		0	0.000000	0.000000
0		0	0.000000	0.000000

<u>F/M and BOD Volumetric Loading(Q.15)</u>

F/M(g/g.d)	BOD(kg/m 3.d)
0.104830	0.245108
0.161411	0.382493
0.084153	0.195227
0.084153	0.195227
0.000000	0.000000
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!

Q	So	X	V
0.015000	140.000000	2338.156284	0.008568
0.015000	140.000000	2369.681818	0.005490
0.015000	140.000000	2319.911260	0.010757
0.050000	140.000000	2319.911260	0.035856
3.048000		2338.157874	1.740957
0.000000		#DIV/0!	#DIV/0!
0.000000		#DIV/0!	#DIV/0!
0.000000		#DIV/0!	#DIV/0!
0.000000		#DIV/0!	#DIV/0!
0.000000		#DIV/0!	#DIV/0!

<u>Oxygen Demand (Q.17)</u>

Oxygen Demand(kg /d)	Oxygen Demand (kg/h)	Q	So	S	Px,bio	NOx
0.004319	0.000180	0.015	224	0.79	0.000611	28.3
0.004073	0.000170	0.015	224	0.79	0.000784	28.3
0.004431	0.000185	0.015	224	0.79	0.000532	28.3
0.014770	0.000615	0.05	224	0.79	0.001773	28.3
0.877665	0.036569	3.048	224	0.79	0.124069	28.3
0.000000	0.000000	0	0	0.00	0.000000	0
0.000000	0.000000	0	0	0.00	0.000000	0
0.000000	0.000000	0	0	0.00	0.000000	0
0.000000	0.000000	0	0	0.00	0.000000	0
0.000000	0.000000	0	0	0.00	0.000000	0

Alkalinity Balance(Q.19)

Alk used for nitri.	alk to be added	alkanity needed	Na(HCO3) needed
202.06	142.06	0.002131	0.003580
202.06	142.06	0.002131	0.003580
202.06	142.06	0.002131	0.003580
202.06	202.06	0.010103	#DIV/0!
202.06	202.06	0.615885	#DIV/0!
0.00	0.00	0.000000	#DIV/0!
0.00	0.00	0.000000	#DIV/0!
0.00	0.00	0.000000	#DIV/0!
0.00	0.00	0.000000	#DIV/0!
0.00	0.00	0.000000	#DIV/0!

constant	NOx	influent alk.	residual alkalinity	Q	eq. weight of CaCO3	eq. weight of Na(HCO3)
7.14	28.3	140	80	0.015	50	84
7.14	28.3	140	80	0.015	50	84
7.14	28.3	140	80	0.015	50	84
7.14	28.3			0.05		
7.14	28.3			3.048		
7.14	0			0		
7.14	0			0		
7.14	0			0		
7.14	0			0		
7.14	0			0		

Clarifier design(Q.21)

R	Clarifier Area	Clarifier dia.	Solids loading
0.6	0.000682	0	4.4
-1	#DIV/0!	#DIV/0!	#DIV/0!
-1	#DIV/0!	#DIV/0!	#DIV/0!
-1	#DIV/0!	#DIV/0!	#DIV/0!
-1	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Xr	X	hydraulic rate	Q
8000	3000	22	0.015
	3000		0.015
	3000		0.015
	3000		0.05
	3000		3.048
	0		0
	0		0
	0		0
	0		0
	0		0

*moderate settling/thickening sludge range(Xr)=4000-12000 mg/L(assume)
*hydraulic application range=16-28 m3/m2.d(assume)

*within acceptable range of solids=4-6 kg/m2.d

Appendix

B

Appendix B (Feasibility Study Lab Result Data)

TSS Test

TEST 1

Material Weight:
3.5g/L
3.6g/L
3.7g/L
sample: 0.01 L

Initial pan + filter paper weight (before dry)(g)		Pan + filter paper (after dry)(g)		TSS	Average TSS
3.5g/L	1.281	3.5g/L	1.289	800	433
	1.338		1.341	300	
	1.283		1.285	200	
3.6g/L	1.344	3.6g/L	1.347	300	333
	1.329		1.331	200	
	1.264		1.269	500	
3.7g/L	1.338	3.7g/L	1.342	400	467
	1.075		1.08	500	
	1.293		1.298	500	

COD Test

TEST 1

Material Weight:

3.5g/L

3.6g/L

3.7g/L

sample: 10 ml

dilution: 1:100

Sample Weight (g)	COD(mg/L)	Note
3.5g/L	500	
3.6g/L	570	shaked
3.6g/L	570	not shaked
3.7g/L	650	

TEST 2(3/4/2013)

Material Weight:

0.5g/L

2.0g/L

sample: 10 ml

dilution: 1:100

Sample Weight (g)	COD(mg/L)	Note
0.5g/L	100	
2.0g/L	400	

BOD Test

TEST 1

influent 3.5 g/l
3.6 g/l
3.7g/l

no dilution

Sample	sample added(ml)	DO Reading(mg/l)		Diff.(mg/l)	Average (mg/l)
		Initial	Final		
Blank	only aerated water	8.73	8.34	0.39	0.31
		8.82	8.44	0.38	
		8.79	8.64	0.15	
3.5g/l	10	8.78	0.14	8.64	8.70
		8.85	0.12	8.73	
		8.85	0.11	8.74	
3.6g/l		8.83	0.13	8.70	8.67
		8.72	0.11	8.61	
		8.82	0.11	8.71	
3.7g/l		8.85	0.10	8.75	8.74
		8.84	0.11	8.73	
		8.83	0.10	8.73	

TEST 2

influent 0.5g/l
2.0g/l

Sample	Dilution	Sample Added(ml)	DO Reading(mg/l)		Diff.(mg/l)	Average (mg/l)
			Initial	Final		
Blank(0.5g/l)	none	only aerated water	8.96	13.16	-4.20	-4.26
			9.03	13.25	-4.22	
			9.03	13.40	-4.37	
0.5g/l	1:10	2	9.04	12.62	-3.58	-3.66
			9.06	12.92	-3.86	
			9.10	12.65	-3.55	
		5	9.08	11.91	-2.83	-3.42
			9.07	12.60	-3.53	
			9.07	12.96	-3.89	
		10	9.07	11.57	-2.50	-3.18
			9.03	12.31	-3.28	
			9.00	12.77	-3.77	
	1:100	2	9.06	13.68	-4.62	-4.52
			9.03	13.55	-4.52	
			9.08	13.51	-4.43	
		5	9.08	13.17	-4.09	-4.13
			9.08	13.27	-4.19	
			9.09	13.21	-4.12	

		10	9.02	12.80	-3.78	-4.16
			9.00	13.43	-4.43	
			9.01	13.27	-4.26	
Blank(2.0g/l)	none	only aerated water	8.79	9.35	-0.56	-0.41
			8.88	9.33	-0.45	
			8.89	9.11	-0.22	
2.0g/l	1:10	2	8.84	9.51	-0.67	-0.21
			8.91	8.76	0.15	
			8.83	8.93	-0.10	
		5	8.82	4.33	4.49	2.42
			8.92	7.46	1.46	
			8.93	7.63	1.30	
		10	8.91	8.34	0.57	1.21
			8.80	8.12	0.68	
			8.90	6.52	2.38	
	1:100	2	8.84	9.01	-0.17	0.15
			8.85	8.45	0.40	
			8.82	8.60	0.22	
		5	8.84	9.78	-0.94	-0.91
			8.81	9.67	-0.86	
			8.81	9.74	-0.93	
		10	8.78	9.56	-0.78	-0.72
			8.81	9.52	-0.71	
			8.77	9.44	-0.67	

Appendix C

Appendix C (Lab Result Data) [Before Enhancement]

TSS Test

Test Date	Sample Day/Date	Point	Sample Added (L)	Initial pan + filter paper weight (before dry)(g)	Pan + filter paper (after dry)(g)	TSS	Average TSS(mg/L)
23/5/2013	1 (21/5/2013)	Influent	0.01	1331.0	1332.7	170	127
				1324.0	1324.4	40	
				1074.0	1075.7	170	
		Effluent	0.01	1090.5	1090.6	10	37
				1091.5	1091.8	30	
				1075.5	1076.2	70	
23/5/2013	3 (23/5/2013)	Influent	0.01	1316.0	1317.5	150	110
				1336.0	1336.4	40	
				1321.0	1322.4	140	
		Effluent	0.01	1093.5	1093.7	20	40
				1094.5	1094.9	40	
				1073.5	1074.1	60	
30/5/2013	8 (28/5/2013)	Influent	0.01	1094.7	1095.2	50	97
				1344.6	1345.2	60	
				1303.6	1305.4	180	
		Effluent	0.01	1082.0	1082.2	20	30
				1310.0	1310.5	50	
				1334.8	1335.0	20	

30/5/2013	10 (30/5/2013)	Influent	0.01	1327.4	1328.9	150	103
				1091.0	1091.7	70	
				1318.6	1319.5	90	
		Effluent	0.01	1321.9	1322.3	40	37
				1082.8	1083.2	40	
				1334.6	1334.9	30	
6/6/2013	14 (3/6/2013) Monday	Influent	0.015	1318.4	1320.1	113	133
				1088.3	1089.7	93	
				1076.2	1079.1	193	
		Effluent	0.015	1081.0	1081.7	47	42
				1267.1	1267.9	53	
				1344.4	1344.8	27	
6/6/2013	16 (5/6/2013) Wednesday	Influent	0.01	1312.8	1313.9	110	127
				1086.2	1087.2	100	
				1306.1	1307.8	170	
		Effluent	0.01	1305.2	1305.3	10	33
				1086.1	1086.7	60	
				1321.5	1321.8	30	
7/6/2013	18 (7/6/2013) Friday	Influent	0.01	1310.7	1312.1	140	150
				1082.4	1083.9	150	
				1306.1	1307.7	160	
		Effluent	0.01	1078.2	1078.4	20	30
				1086.7	1087.1	40	
				1279.0	1279.3	30	
10/6/2013	21 (10/6/2013)	Influent	0.025	1330.4	1333.6	128	140
				1073.2	1077.4	168	

	Monday			1330.1	1333.2	124	
		Effluent	0.025	1340.4	1341.4	40	31
				1270.1	1270.8	28	
				1097.0	1097.6	24	
13/6/2013	23 (12/6/2013) Wednesday	Influent	0.025	1090.5	1093.9	136	159
				1091.5	1095.5	160	
				1083.3	1087.8	180	
		Effluent	0.05	1280.7	1282.9	44	41
				1091.3	1093.0	34	
				1325.1	1327.3	44	
14/6/2013	25 (14/6/2013) Friday	Influent	0.025	1089.9	1093.9	160	132
				1086.3	1087.8	60	
				1317.3	1321.7	176	
		Effluent	0.05	1300.1	1301.9	36	36
				1273.2	1274.5	26	
				1329.0	1331.3	46	
18/6/2013	28 (17/6/2013) Monday	Influent	0.025	1093.5	1096.1	104	139
				1330.7	1334.7	160	
				1274.7	1278.5	152	
		Effluent	0.05	1331.0	1333.6	52	35
				1284.6	1285.8	24	
				1277.1	1278.5	28	
20/6/2013	30 (19/6/2013) Wednesday	Influent	0.025	1317.9	1321.0	124	152
				1331.0	1334.2	128	
				1071.0	1076.1	204	
		Effluent	0.025	1315.6	1315.9	12.0	41

				1074.6	1076.0	56.0	
				1342.5	1343.9	56.0	

COD Test

Test Date	Day	Dilution	Point	COD (mg/L)
23/5/2013	1 (21/5/2013)	1:100	Influent	295
		1:100	Aeration	183
		1:100	Anoxic	137
		1:100	Effluent	120
23/5/2013	3 (23/5/2013)	1:100	Influent	218
		1:100	Aeration	162
		1:100	Anoxic	138
		1:100	Effluent	99
30/5/2013	8 (28/5/2013)	-	Influent	328
		-	Aeration	284
		-	Anoxic	196
		-	Effluent	88
5/6/2013	10 (30/5/2013)	-	Influent	312
		-	Aeration	285
		-	Anoxic	174
		-	Effluent	80
6/6/2013	14 (3/6/2013) Monday	-	Influent	358
		-	Aeration	283
		-	Anoxic	213
		-	Effluent	136
6/6/2013	16	-	Influent	319

	(5/6/2013) Wednesday	-	Aeration	249
		-	Anoxic	182
		-	Effluent	100
7/6/2013	18 (7/6/2013) Friday	-	Influent	337
		-	Aeration	274
		-	Anoxic	173
		-	Effluent	116
10/6/2013	21 (10/6/2013) Monday	-	Influent	389
		-	Aeration	291
		-	Anoxic	219
		-	Effluent	148
13/6/2013	23 (12/6/2013) Wednesday	-	Influent	447
		-	Aeration	392
		-	Anoxic	274
		-	Effluent	163
14/6/2013	25 (12/6/2013) Wednesday	-	Influent	450
		-	Aeration	395
		-	Anoxic	285
		-	Effluent	171
18/6/2013	28 (17/6/2013) Monday	-	Influent	465
		-	Aeration	403
		-	Anoxic	306
		-	Effluent	158
20/6/2013	30 (19/6/2013) Wednesday	-	Influent	430
		-	Aeration	384
		-	Anoxic	294

		-	Effluent	162
21/6/2013	32 (21/62013) Friday	-	Influent	426
		-	Aeration	379
		-	Anoxic	280
		-	Effluent	162
24/6/2013	35 (24/6/2013) Monday	-	Influent	417
		-	Aeration	365
		-	Anoxic	275
		-	Effluent	145

BOD Test

Test Date	Sampling Day/Date	Point	sample added(L)	seed (L)	DO Reading(mg/l)		Diff.(mg/l)	Average (mg/l)	BOD (mg/L)
					Initial	Final			
23/5/2013	1 (21/5/2013)	Blank	only aerated water	none	8.32	5.14	3.18	3.30	
					8.34	4.94	3.40		
					8.37	5.06	3.31		
		Influent	0.01	none	8.29	3.92	4.37	4.53	136
					8.28	3.58	4.70		
					8.31	3.79	4.52		
		Aeration		none	8.34	3.86	4.48	4.30	129
					8.32	4.07	4.25		
					8.33	4.15	4.18		
		Anoxic		none	8.36	4.83	3.53	3.28	98
					8.33	5.02	3.31		
					8.34	5.34	3.00		
		Effluent		none	8.38	6.97	1.41	1.40	42
					8.37	7.03	1.34		
					8.37	6.93	1.44		
23/5/2013	3 (23/5/2013)	Blank	only aerated water	none	8.32	5.14	3.18	3.30	
					8.34	4.94	3.40		
					8.37	5.06	3.31		
		Influent	0.01	none	8.20	3.81	4.39	4.54	136
					8.19	3.67	4.52		

					8.19	3.47	4.72		
		Aeration		none	8.33	4.15	4.18	4.15	125
					8.31	4.09	4.22		
					8.32	4.27	4.05		
		Anoxic		none	8.34	5.18	3.16	2.99	90
					8.34	5.30	3.04		
					8.34	5.56	2.78		
		Effluent		none	8.37	5.42	2.95	2.87	86
					8.33	5.59	2.74		
					8.26	5.34	2.92		
30/5/2013	8 (28/5/2013)	Blank	only aerated water	none	8.86	5.08	3.78	3.72	
					8.93	5.33	3.60		
					8.97	5.18	3.79		
		Influent	0.01	none	8.80	3.92	4.88	5.06	152
					8.89	3.66	5.23		
					8.87	3.81	5.06		
		Aeration		none	8.41	4.67	3.74	3.98	120
					8.36	4.18	4.18		
					8.40	4.37	4.03		
		Anoxic		none	8.94	5.07	3.87	3.76	113
					8.97	5.14	3.83		
					8.96	5.39	3.57		
		Effluent		none	8.93	6.97	1.96	1.87	56
					8.99	7.00	1.99		
					8.80	7.14	1.66		
30/5/2013	10	Blank	only	none	8.86	5.08	3.78	3.72	

	(30/5/2013)		aerated water		8.93	5.33	3.60		
					8.97	5.18	3.79		
		Influent	0.01	none	8.68	3.15	5.53	5.44	163
					8.71	3.27	5.44		
					8.68	3.32	5.36		
		Aeration		none	8.48	4.75	3.73	4.03	121
					8.49	4.29	4.20		
					8.52	4.37	4.15		
		Anoxic		none	8.90	6.01	2.89	3.13	94
					8.93	5.53	3.40		
					8.89	5.79	3.10		
		Effluent		none	8.94	7.03	1.91	2.08	63
					8.86	6.99	1.87		
					8.98	6.51	2.47		
6/6/2013	14 (3/6/2013) Monday	Blank	only aerated water	none	7.99	7.40	0.59	0.58	
					8.00	7.44	0.56		
					8.02	0.39	7.63		
		Influent	0.01	none	7.90	4.15	3.75	3.63	109
					7.95	4.82	3.13		
					7.96	3.95	4.01		
		Aeration		none	7.91	5.21	2.70	2.77	83
					7.91	5.19	2.72		
					7.93	5.05	2.88		
		Anoxic		none	7.96	7.10	0.86	1.49	45
					7.97	6.59	1.38		
					7.96	5.73	2.23		

		Effluent		none	8.00	7.30	0.70	0.71	21
					7.98	7.18	0.80		
					7.98	7.35	0.63		
6/6/2013	16 (5/6/2013) Wednesday	Blank	only aerated water	none	9.02	7.34	1.68	1.54	
					9.07	7.67	1.40		
					9.14	7.59	1.55		
		Influent (0.005 L seed)	0.01	none	9.05	3.91	5.14	6.87	103
					9.08	1.88	7.20		
					9.11	0.84	8.27		
		Aeration		none	9.13	5.98	3.15	3.28	98
					9.12	5.72	3.40		
					9.12	5.83	3.29		
		Anoxic		none	8.92	6.26	2.66	2.22	67
					8.89	6.73	2.16		
					8.77	6.94	1.83		
		Effluent		none	9.18	7.98	1.20	1.37	41
					9.18	7.57	1.61		
					9.21	7.92	1.29		
13/6/2013	21 (10/6/2013) Monday	Blank	only aerated water	none	8.38	7.68	0.70	0.56	
					8.34	7.89	0.45		
					8.48	7.96	0.52		
		Influent (0.005 L seed)	0.01	none	8.28	0.25	8.03	8.11	122
					8.31	0.15	8.16		
					8.34	0.20	8.14		
		Aeration		none	8.33	4.61	3.72	3.78	113
					8.34	4.59	3.75		

					8.33	4.47	3.86		
		Anoxic		none	8.26	5.19	3.07	2.99	90
					8.23	5.25	2.98		
					8.22	5.31	2.91		
		Effluent		none	8.38	6.94	1.44	1.44	43
					8.37	6.97	1.40		
					8.40	6.93	1.47		
13/6/2013	23 (12/6/2013) Wednesday	Blank	only aerated water	none	8.38	7.68	0.70	0.56	
					8.34	7.89	0.45		
					8.48	7.96	0.52		
		Influent (0.005 L seed)	0.01	none	7.92	0.18	7.74	7.72	116
					7.90	0.17	7.73		
					7.84	0.15	7.69		
		Aeration		none	8.04	4.82	3.22	3.17	95
					8.02	4.93	3.09		
					8.08	4.87	3.21		
		Anoxic		none	7.94	5.23	2.71	2.74	82
					8.01	5.17	2.84		
					7.93	5.25	2.68		
		Effluent		none	8.56	7.30	1.26	1.16	35
					8.39	7.18	1.21		
					8.39	7.39	1.00		
14/6/2013	25 (14/6/2013) Friday	Blank	only aerated water	none	8.46	7.59	0.87	0.85	
					8.58	7.79	0.79		
					8.61	7.73	0.88		
		Influent	0.01	none	8.27	0.23	8.04	8.08	121

		(0.005 L seed)			8.33	0.19	8.14		
					8.30	0.25	8.05		
		Aeration		none	8.53	5.01	3.52	3.52	106
					8.61	5.05	3.56		
					8.59	5.10	3.49		
		Anoxic		none	8.58	5.96	2.62	2.57	77
					8.64	6.00	2.64		
					8.52	6.08	2.44		
		Effluent		none	8.55	7.14	1.41	1.34	40
					8.57	7.01	1.56		
					8.56	7.51	1.05		
20/6/2013	28 (17/6/2013) Monday	Blank	only aerated water	none	8.18	8.01	0.17	0.14	
					8.18	8.06	0.12		
					8.22	8.10	0.12		
		Influent	0.01	0.005L	7.85	0.19	7.66	7.70	116
					7.82	0.16	7.66		
					7.97	0.19	7.78		
		Seed (0.005 L)		none	8.12	0.37	7.75	7.58	227
					8.21	0.45	7.76		
					8.19	0.97	7.22		
		Aeration		none	8.20	5.05	3.15	2.82	85
					8.19	5.52	2.67		
					8.19	5.56	2.63		
		Anoxic		none	8.19	5.71	2.48	1.85	55
					8.22	6.37	1.85		
					8.19	6.98	1.21		

		Effluent		none	8.27	6.89	1.38	1.20	36
					8.22	7.12	1.10		
					8.21	7.09	1.12		
20/6/2013	30 (19/6/2013) Wednesday	Blank	only aerated water	none	8.18	8.01	0.17	0.14	
					8.18	8.06	0.12		
					8.22	8.10	0.12		
		Influent	0.01	0.005L	8.26	0.20	8.06	8.05	121
					8.23	0.18	8.05		
					8.20	0.16	8.04		
		Seed (0.005 L)		none	7.48	0.15	7.33	7.35	221
					7.56	0.15	7.41		
					7.47	0.16	7.31		
		Aeration		none	8.10	6.93	1.17	3.44	103
					8.06	5.65	2.41		
					8.03	1.30	6.73		
		Anoxic		none	8.17	6.33	1.84	1.95	59
					8.18	6.51	1.67		
					8.19	5.85	2.34		
		Effluent		none	8.21	6.55	1.66	1.35	40
					8.19	7.03	1.16		
					8.22	7.00	1.22		

MLSS Test

Test Date	Sample Day/Date	Point	Sample Added (L)	Initial pan + filter paper weight (before dry)(g)	Pan + filter paper (after dry)(g)	MLSS	Average MLSS(mg/L)	Pan + filter paper (after dry, 550C)(g)	MLVSS	Average MLVSS(mg/L)
23/5/2013	1 (21/5/2013)	Aeration	0.005	1.232	1.235	600.0	667	1.233	400.0	600
				1.298	1.303	1000.0		1.298	1000.0	
				1.279	1.281	400.0		1.279	400.0	
		Anoxic	0.005	1.054	1.056	400.0	400	1.054	400.0	200
				1.277	1.278	200.0		1.277	200.0	
				1.290	1.293	600.0		1.293	0.0	
23/5/2013	3 (23/5/2013)	Aeration	0.005	1.278	1.281	600.0	600	1.279	400.0	533
				1.289	1.292	600.0		1.289	600.0	

				1.046	1.049	600.0		1.046	600.0	
		Anoxic	0.005	1.276	1.277	200.0	333	1.275	400.0	467
				1.242	1.244	400.0		1.241	600.0	
				1.046	1.048	400.0		1.046	400.0	
30/5/2013	8 (28/5/2013)	Aeration	0.005	1046.4	1059.8	2680.0	2453	1049.6	2040.0	1807
				1234.2	1243.7	1900.0		1236.8	1380.0	
				1057.5	1071.4	2780.0		1061.4	2000.0	
		Anoxic	0.005	1288.6	1289.7	220.0	260	1288.3	280.0	1800
				1283.3	1284.9	320.0		1260.8	4820.0	
				1047.0	1048.2	240.0		1046.7	300.0	
30/5/2013	10 (30/5/2013)	Aeration	0.005	1252.7	1263.4	2140.0	1967	1255.3	1620.0	1573
				1234.2	1244.3	2020.0		1236.3	1600.0	
				1039.2	1047.9	1740.0		1040.4	1500.0	
		Anoxic	0.005	1271.7	1271.9	40.0	153	1270.0	380.0	333
				1048.3	1048.9	120.0		1047.7	240.0	

				1043.5	1045.0	300.0		1043.1	380.0	
6/6/2013	14 (3/6/2013) Monday	Aeration	0.005	1300.2	1321.2	4200.0	4593	n/a	n/a	n/a
				1289.6	1312.2	4520.0		n/a	n/a	
				1040.5	1065.8	5060.0		n/a	n/a	
		Anoxic	0.005	1238.4	1249.8	2280.0	2087	n/a	n/a	n/a
				1054.2	1066.0	2360.0		n/a	n/a	
				1234.5	1242.6	1620.0		n/a	n/a	
6/6/2013	16 (5/6/2013) Wednesday	Aeration	0.005	1045.4	1064.4	3800.0	3980	n/a	n/a	n/a
				1051.2	1072.8	4320.0		n/a	n/a	
				1306.6	1325.7	3820.0		n/a	n/a	
		Anoxic	0.005	1046.6	1052.4	1160.0	1493	n/a	n/a	n/a
				1274.3	1282.9	1720.0		n/a	n/a	
				1260.0	1268.0	1600.0		n/a	n/a	
7/6/2013	18 (7/6/2013) Friday	Aeration	0.005	1280.5	1315.3	6960.0	3800	n/a	n/a	n/a
				1293.1	1303.3	2040.0		n/a	n/a	

				1290.0	1302.0	2400.0		n/a	n/a	
		Anoxic	0.005	1288.1	1294.6	1300.0	1280	n/a	n/a	n/a
				1048.9	1055.0	1220.0		n/a	n/a	
				1058.6	1065.2	1320.0		n/a	n/a	
11/6/2013	21 (10/6/2013) Monday	Aeration	0.005	1050.4	1071.9	4300.0	4253	1053.0	3780.0	3687
				1046.1	1066.1	4000.0		1048.9	3440.0	
				1045.6	1067.9	4460.0		1048.7	3840.0	
		Anoxic	0.005	1261.5	1270.6	1820.0	2053	1262.3	1660.0	1953
				1252.2	1263.7	2300.0		1253.1	2120.0	
				1244.7	1254.9	2040.0		1244.5	2080.0	
13/6/2013	23 (12/6/2013) Wednesday	Aeration	0.005	1042.2	1066.4	4840.0	4920	1049.7	3340.0	3520
				1253.1	1278.0	4980.0		1260.0	3600.0	
				1279.1	1303.8	4940.0		1285.7	3620.0	
		Anoxic	0.005	1278.5	1289.7	2240.0	2367	1281.2	1700.0	1860
				1046.4	1056.2	1960.0		1047.7	1700.0	

				1233.0	1247.5	2900.0		1236.6	2180.0	
14/6/2013	25 (14/6/2013) Friday	Aeration	0.005	1040.0	1061.7	4340.0	6533	1056.5	1040.0	3573
				1294.9	1334.1	7840.0		1309.2	4980.0	
				1291.7	1328.8	7420.0		1305.3	4700.0	
		Anoxic	0.005	1054.8	1067.6	2560.0	4133	1062.6	1000.0	3047
				1286.4	1308.5	4420.0		1291.2	3460.0	
				1278.7	1305.8	5420.0		1282.4	4680.0	
18/6/2013	28 (17/6/2013) Monday	Aeration	0.005	1236.0	1275.1	7820.0	7913	1282.3	-1440.0	-1627
				1266.4	1305.1	7740.0		1346.4	-8260.0	
				1036.0	1076.9	8180.0		1052.8	4820.0	
		Anoxic	0.005	1280.5	1295.6	3020.0	5787	1294.2	280.0	2147
				1314.4	1363.9	9900.0		1348.3	3120.0	
				1295.7	1317.9	4440.0		1302.7	3040.0	
20/6/2013	30 (17/6/20	Aeration	0.005	1277.2	1321.4	8840.0	7853	1303.5	3580.0	4007

	13) Monday			1045.6	1079.9	6860.0		1058.6	4260.0	
				1046.9	1086.2	7860.0		1065.3	4180.0	
		Anoxic	0.005	1048.0	1078.3	6060.0	5887	1064.7	2720.0	2587
				1046.5	1071.5	5000.0		1061.6	1980.0	
				1039.9	1072.9	6600.0		1057.6	3060.0	
20/6/2013	31 (20/6/2013) Thursday	Aeration	0.005	1294.6	1328.6	6800.0	7487	1329.6	-200.0	1240
				1278.9	1319.6	8140.0		1311.1	1700.0	
				1287.5	1325.1	7520.0		1314.0	2220.0	
		Anoxic	0.005	1289.1	1314.5	5080.0	5407	1301.1	2680.0	2867
				1040.3	1063.3	4600.0		1053.0	2060.0	
				1049.2	1081.9	6540.0		1062.6	3860.0	
21/6/2013	32 (21/6/2013) Friday	Aeration	0.005	1281.7	1318.1	7280.0	7800	1298.6	3900.0	4913
				1234.6	1273.6	7800.0		1250.6	4600.0	
				1054.7	1096.3	8320.0		1065.1	6240.0	
		Anoxic	0.005	1313.9	1339.9	5200.0	5747	1311.3	5720.0	6207

				1232.4	1263.1	6140.0		1230.7	6480.0	
				1295.8	1325.3	5900.0		1293.2	6420.0	

Appendix D

Appendix D (Lab Result – After Enhancement)

Total Suspended Solid (TSS)

Test Date	Sample Day/Date	Point	Sample Added (L)	Initial pan + filter paper weight (before dry)(mg)	Pan + filter paper (after dry)(mg)	TSS	Average TSS(mg/L)
	1 (3/7/2013)	Influent	0.025	1086.8	1090.3	140	143
				1094.2	1096.7	100	
				1335.2	1339.9	188	
		Effluent	0.025	1071.1	1071.7	24	27
				1322.2	1322.8	24	
				1336.0	1336.8	32	
	3 (5/7/2013)	Influent	0.025	1075.3	1078.9	144	132
				1089.1	1092.5	136	
				1324.7	1327.6	116	
		Effluent	0.025	1316.9	1317.3	16	25
				1072.8	1073.4	24	
				1048.3	1049.2	36	
	6 (8/7/2013)	Influent	0.025	1337.9	1342.5	184	151
				1327.1	1330.3	128	
				1082.5	1086.0	140	
		Effluent	0.025	1063.7	1064.3	24	29
				1041.9	1042.6	28	
				1330.5	1331.4	36	
	8 (10/7/2013)	Influent	0.025	1316.0	1319.1	124	141
				1336.0	1338.9	116	

				1321.0	1325.6	184	
		Effluent	0.025	1093.5	1094.0	20	24
				1094.5	1095.2	28	
				1073.5	1074.1	24	
	10 (12/7/2013)	Influent	0.025	1094.7	1097.8	124	132
				1344.6	1347.8	128	
				1303.6	1307.2	144	
		Effluent	0.025	1082.0	1082.6	24	29
				1310.0	1310.7	28	
				1334.8	1335.7	36	
	13 (15/7/2013)	Influent	0.025	1312.8	1315.8	120	137
				1086.2	1089.5	132	
				1306.1	1310.1	160	
		Effluent	0.025	1305.2	1305.7	20	23
				1086.1	1086.5	16	
				1321.5	1322.3	32	
	15 (17/7/2013)	Influent	0.025	1318.4	1322.0	144	160
				1088.3	1092.4	164	
				1076.2	1080.5	172	
		Effluent	0.025	1081.0	1081.6	24	20
				1267.1	1267.5	16	
				1344.4	1344.9	20	
	17 (19/7/2013)	Influent	0.025	1333.6	1337.7	164	152
				1300.4	1304.0	144	
				1328.6	1332.3	148	
		Effluent	0.025	1337.0	1337.2	8	13

				1088.1	1088.5	16	
				1338.3	1338.7	16	
	20 (22/7/ 2013)	Influent	0.025	1341.6	1344.7	124	151
				1349.6	1353.8	168	
				1075.5	1079.5	160	
		Effluent	0.025	1300.8	1301.4	24	21
				1337.7	1338.2	20	
				1335.1	1335.6	20	
	22 (24/7/2013)	Influent	0.025	1335.5	1339.5	160	148
				1345.7	1349.5	152	
				1330.9	1334.2	132	
		Effluent	0.025	1338.0	1338.4	16	17
				1333.9	1334.1	8	
				1340.7	1341.4	28	
	24 (26/7/2013)	Influent	0.025	1336.6	1341.0	176	155
				1333.1	1336.4	132	
				1334.2	1338.1	156	
		Effluent	0.025	1341.7	1342.1	16	16
				1347.1	1347.5	16	
				1334.5	1334.9	16	

MLSS & MLVSS

Test Date	Sample Day/Date	Point	Sample Added (L)	Initial pan + filter paper weight (before dry)(mg)	Pan + filter paper (after dry)(mg)	MLSS	Average MLSS(mg/L)	Pan + filter paper (after dry, 550C)(mg)	MLVSS	Average MLVSS(mg/L)
	1 (3/7/2013)	Aeration	0.005	1045.1	1081.7	7320.0	7407	1052.7	5800.0	5787
				1324.9	1360.3	7080.0		1332.0	5660.0	
				1300.6	1339.7	7820.0		1310.2	5900.0	
		Anoxic	0.005	1054.8	1077.6	4560.0	5467	1063.1	2900.0	3480
				1286.4	1318.5	6420.0		1300.3	3640.0	
				1278.7	1305.8	5420.0		1286.3	3900.0	
	3 (5/7/2013)	Aeration	0.005	1226.1	1275.1	9800.0	7507	1243.5	6320.0	5607
				1271.4	1305.1	6740.0		1278.1	5400.0	
				1047.0	1076.9	5980.0		1051.4	5100.0	
		Anoxic	0.005	1275.5	1295.6	4020.0	5013	1270.7	4980.0	3547

				1321.3	1350.9	5920.0		1337.2	2740.0	
				1292.4	1317.9	5100.0		1303.3	2920.0	
	6 (8/7/2013)	Aeration	0.005	1257.2	1311.4	10840.0	7427	1285.2	5240.0	5133
				1051.6	1079.9	5660.0		1053.9	5200.0	
				1057.3	1086.2	5780.0		1061.4	4960.0	
		Anoxic	0.005	1047.5	1068.1	4120.0	5100	1052.2	3180.0	3273
				1039.9	1067.5	5520.0		1048.6	3780.0	
				1041.8	1070.1	5660.0		1055.8	2860.0	
	8 (10/7/2013)	Aeration	0.005	1284.6	1330.6	9200.0	7687	1300.3	6060.0	5420
				1278.9	1310.6	6340.0		1284.7	5180.0	
				1287.5	1325.1	7520.0		1300.0	5020.0	
		Anoxic	0.005	1289.1	1314.5	5080.0	5407	1295.7	3760.0	3413
				1040.3	1063.3	4600.0		1047.1	3240.0	
				1049.2	1081.9	6540.0		1065.7	3240.0	
	10 (12/7/201	Aeration	0.005	1285.3	1318.1	6560.0	7400	1295.7	4480.0	5573

	3)			1236.6	1273.6	7400.0		1244.1	5900.0	
				1055.1	1096.3	8240.0		1064.6	6340.0	
		Anoxic	0.005	1313.9	1339.9	5200.0	5747	1321.0	3780.0	3567
				1232.4	1263.1	6140.0		1246.1	3400.0	
				1295.8	1325.3	5900.0		1307.7	3520.0	
	13 (15/7/2013)	Aeration	0.005	1232.8	1269.3	7300.0	7720	1243.8	5100.0	5767
				1292.0	1333.6	8320.0		1304.5	5820.0	
				1232.4	1270.1	7540.0		1238.2	6380.0	
		Anoxic	0.005	1243.5	1276.5	6600.0	5373	1259.4	3420.0	3720
				1251.5	1271.7	4040.0		1253.6	3620.0	
				1298.0	1325.4	5480.0		1304.8	4120.0	
	15 (17/7/2013)	Aeration	0.005	1300.2	1335.2	7000.0	7127	1306.9	5660.0	5373
				1289.6	1326.2	7320.0		1300.5	5140.0	
				1040.5	1075.8	7060.0		1049.2	5320.0	
		Anoxic	0.005	1238.4	1261.2	4560.0	4867	1243.8	3480.0	3593

				1054.2	1083.8	5920.0		1064.4	3880.0	
				1234.5	1255.1	4120.0		1238.0	3420.0	
	17 (19/7/2013)	Aeration	0.005	1024.5	1063.0	7700.0	7467	1034.5	5700.0	5633
				1286.0	1321.7	7140.0		1292.4	5860.0	
				1040.9	1078.7	7560.0		1052.0	5340.0	
		Anoxic	0.005	1293.0	1315.8	4560.0	4667	1298.0	3560.0	3513
				1282.7	1305.6	4580.0		1288.7	3380.0	
				1048.7	1073.0	4860.0		1055.0	3600.0	
	20 (22/7/2013)	Aeration	0.005	1041.7	1077.3	7120.0	7647	1052.4	4980.0	5713
				1271.9	1314.3	8480.0		1280.4	6780.0	
				1035.3	1072.0	7340.0		1045.1	5380.0	
		Anoxic	0.005	1231.4	1260.0	5720.0	4647	1235.9	4820.0	3667
				1045.7	1067.8	4420.0		1051.2	3320.0	
				1225.5	1244.5	3800.0		1230.2	2860.0	
	22 (24/7/201	Aeration	0.005	1050.4	1090.7	8060.0	7787	1062.5	5640.0	5233

	3)			1307.7	1345.6	7580.0		1320.3	5060.0	
				1231.1	1269.7	7720.0		1244.7	5000.0	
		Anoxic	0.005	1289.7	1311.0	4260.0	4647	1294.4	3320.0	3600
				1286.0	1308.1	4420.0		1290.8	3460.0	
				1242.7	1269.0	5260.0		1248.9	4020.0	
	24 (26 /7/2013)	Aeration	0.005	1288.2	1322.4	6840.0	7940	1295.6	5360.0	5633
				1026.8	1065.6	7760.0		1040.1	5100.0	
				1292.7	1338.8	9220.0		1306.6	6440.0	
		Anoxic	0.005	1301.6	1330.4	5760.0	5573	1315.1	3060.0	3653
				1286.1	1310.8	4940.0		1292.6	3640.0	
				1283.4	1313.5	6020.0		1292.2	4260.0	

Chemical Oxygen Demand (COD)

Day	Point	COD (mg/L)
1 (3/7/2013)	Influent	433
	Aeration	261
	Anoxic	237
	Effluent	84
3 (5/7/2013)	Influent	413
	Aeration	267
	Anoxic	238
	Effluent	80
6 (8/7/2013)	Influent	418
	Aeration	285
	Anoxic	238
	Effluent	87
8 (10/7/2013)	Influent	412
	Aeration	235
	Anoxic	193
	Effluent	75
10 (12/7/2013)	Influent	442
	Aeration	279
	Anoxic	253
	Effluent	78
13 (15/7/2013)	Influent	419
	Aeration	220
	Anoxic	192

	Effluent	85
15 (17/7/2013)	Influent	451
	Aeration	275
	Anoxic	203
	Effluent	88
17 (19/7/2013)	Influent	413
	Aeration	243
	Anoxic	213
	Effluent	84
20 (22/7/2013)	Influent	406
	Aeration	235
	Anoxic	209
	Effluent	83
22 (24/7/2013)	Influent	431
	Aeration	265
	Anoxic	233
	Effluent	90
24 (26 /7/2013)	Influent	427
	Aeration	264
	Anoxic	224
	Effluent	83

Biochemical Oxygen Demand (BOD)

Sampling Day/Date	Point	Point	sample added(L)	seed (L)	DO Reading(mg/l)		Diff.(mg/l)	Average (mg/l)	BOD (mg/L)
					Initial	Final			
1 (3/7/2013)	Blank	Blank	only aerated water	none	8.32	6.14	2.18	2.23	
					8.34	5.84	2.50		
					8.37	6.36	2.01		
	Influent	Influent	0.01	none	8.32	4.92	3.40	4.20	126
					8.25	3.58	4.67		
					8.32	3.79	4.53		
	Aeration	Aeration		none	8.28	5.86	2.42	2.45	74
					8.35	6.57	1.78		
					8.30	5.15	3.15		
	Anoxic	Anoxic		none	8.35	5.83	2.52	2.27	68
					8.32	6.02	2.30		
					8.33	6.34	1.99		
	Effluent	Effluent		none	8.38	7.05	1.33	1.11	33
					8.39	7.53	0.86		
					8.37	7.23	1.14		
3 (5/7/2013)	Blank	Blank	only aerated water	none	8.32	6.14	2.18	2.23	
					8.34	5.84	2.50		
					8.37	6.36	2.01		
	Influent	Influent	0.01	none	8.20	4.01	4.19	4.14	124
					8.19	4.67	3.52		
					8.19	3.47	4.72		

	Aeration	Aeration		none	8.33	6.35	1.98	2.52	76
					8.31	6.49	1.82		
					8.32	4.57	3.75		
	Anoxic	Anoxic		none	8.34	6.18	2.16	1.99	60
					8.34	6.30	2.04		
					8.34	6.56	1.78		
	Effluent	Effluent		none	8.37	7.15	1.22	1.13	34
					8.33	7.22	1.11		
					8.26	7.19	1.07		
6 (8/7/2013)	Blank	Blank	only aerated water	none	7.99	7.40	0.59	2.93	
					8.00	7.44	0.56		
					8.02	0.39	7.63		
	Influent	Influent	0.01	none	7.90	3.15	4.75	4.23	127
					7.95	3.82	4.13		
					7.96	4.15	3.81		
	Aeration	Aeration		none	7.91	6.21	1.70	2.43	73
					7.91	5.19	2.72		
					7.93	5.05	2.88		
	Anoxic	Anoxic		none	7.96	6.10	1.86	2.16	65
					7.97	5.59	2.38		
					7.96	5.73	2.23		
	Effluent	Effluent		none	8.00	6.30	1.70	1.04	31
					7.98	7.18	0.80		
					7.98	7.35	0.63		
8 (10/7/2013)	Blank	Blank	only aerated	none	8.38	7.68	0.70	0.56	
					8.34	7.89	0.45		

			water		8.48	7.96	0.52		
	Influent	Influent	0.01	none	8.28	4.25	4.03	4.18	125
					8.31	4.15	4.16		
					8.34	4.00	4.34		
	Aeration	Aeration		none	8.33	6.61	1.72	2.44	73
					8.34	6.59	1.75		
					8.33	4.47	3.86		
	Anoxic	Anoxic		none	8.26	6.19	2.07	1.99	60
					8.23	6.25	1.98		
					8.22	6.31	1.91		
	Effluent	Effluent		none	8.38	7.94	0.44	1.10	33
					8.37	6.97	1.40		
					8.40	6.93	1.47		
10 (12/7/2013)	Blank	Blank	only aerated water	none	8.46	7.59	0.87	0.83	
					8.58	7.79	0.79		
					8.61	7.73	0.88		
	Influent	Influent	0.01	none	8.27	4.03	4.24	4.24	127
					8.33	4.09	4.24		
					8.30	4.05	4.25		
	Aeration	Aeration		none	8.53	6.21	2.32	2.45	73
					8.61	6.25	2.36		
					8.59	5.93	2.66		
	Anoxic	Anoxic		none	8.58	6.25	2.33	2.10	63
					8.64	6.32	2.32		
					8.52	6.88	1.64		
	Effluent	Effluent		none	8.55	7.14	1.41	1.34	40

					8.57	7.01	1.56		
					8.56	7.51	1.05		
13 (15/7/2013)	Blank	Blank	only aerated water	none	8.54	7.66	0.88	0.66	
					8.52	8.04	0.48		
					8.55	7.92	0.63		
	Influent (0.005 L seed)	Influent	0.01	none	8.33	3.31	5.02	4.79	144
					8.38	4.05	4.33		
					8.28	3.25	5.03		
	Aeration	Aeration		none	8.53	5.89	2.64	2.79	84
					8.59	5.66	2.93		
					8.57	5.76	2.81		
	Anoxic	Anoxic		none	8.59	6.11	2.48	2.31	69
					8.57	6.10	2.47		
					8.59	6.62	1.97		
	Effluent	Effluent		none	8.53	6.62	1.91	1.05	32
					8.54	7.71	0.83		
					8.57	8.15	0.42		
15 (17/7/2013)	Blank	Blank	only aerated water	none	8.54	7.66	0.88	0.66	
					8.52	8.04	0.48		
					8.55	7.92	0.63		
	Influent (0.005 L seed)	Influent	0.01	none	8.54	4.33	4.21	4.54	136
					8.56	3.72	4.84		
					8.54	3.96	4.58		
	Aeration	Aeration		none	8.51	6.05	2.46	2.61	78
					8.51	5.95	2.56		
					8.54	5.72	2.82		

	Anoxic	Anoxic		none	8.51	6.94	1.57	1.71	51
					8.48	6.47	2.01		
					8.50	6.95	1.55		
	Effluent	Effluent		none	8.49	6.70	1.79	1.09	33
					8.56	7.78	0.78		
					8.51	7.81	0.70		
17 (19/7/2013)	Blank	Blank	only aerated water	none	8.23	8.06	0.17	0.35	
					8.31	7.99	0.32		
					8.35	7.79	0.56		
	Influent (0.005 L seed)	Influent	0.01	none	8.29	0.56	7.73	7.82	117
					8.30	0.30	8.00		
					8.28	0.54	7.74		
	Aeration	Aeration		none	8.34	6.81	1.53	1.91	57
					8.30	5.88	2.42		
					8.32	6.55	1.77		
	Anoxic	Anoxic		none	8.36	6.91	1.45	1.51	45
					8.39	6.74	1.65		
					8.39	6.96	1.43		
	Effluent	Effluent		none	8.38	7.87	0.51	0.59	18
					8.42	7.82	0.60		
					8.41	7.76	0.65		
20 (22/7/2013)	Blank	Blank	only aerated water	none	8.72	8.54	0.18	0.32	
					8.62	8.05	0.57		
					8.01	7.81	0.20		
	Influent (0.005 L seed)	Influent	0.01	none	7.74	3.36	4.38	4.29	129
					7.37	3.51	3.86		

					7.54	2.90	4.64		
	Aeration	Aeration		none	7.40	5.79	1.61	1.84	55
					7.35	5.79	1.56		
					7.35	5.01	2.34		
	Anoxic	Anoxic		none	7.30	5.62	1.68	1.64	49
					7.27	5.71	1.56		
					7.27	5.59	1.68		
	Effluent	Effluent		none	7.32	6.65	0.67	0.73	22
					7.30	6.60	0.70		
					7.40	6.58	0.82		
22 (24/7/2013)	Blank	Blank	only aerated water	none	8.72	8.54	0.18	0.32	
					8.62	8.05	0.57		
					8.01	7.81	0.20		
	Influent	Influent	0.01	none	7.73	2.98	4.75	4.70	141
					7.71	3.01	4.70		
					7.73	3.07	4.66		
	Aeration	Aeration		none	7.83	5.38	2.45	2.44	73
					7.90	5.41	2.49		
					7.89	5.50	2.39		
	Anoxic	Anoxic		none	7.97	5.70	2.27	2.28	68
					7.97	5.74	2.23		
					7.96	5.63	2.33		
	Effluent	Effluent		none	7.98	7.01	0.97	0.94	28
					8.01	7.08	0.93		
					7.96	7.05	0.91		
24	Blank	Blank	only	none	8.72	8.54	0.18	0.32	

(26 /7/2013)			aerated water		8.62	8.05	0.57		
					8.01	7.81	0.20		
	Influent	Influent	0.01	none	7.77	3.21	4.56	4.58	138
					7.80	3.35	4.45		
					7.77	3.03	4.74		
	Aeration	Aeration		none	7.83	5.84	1.99	2.22	67
					8.03	5.49	2.54		
					7.81	5.68	2.13		
	Anoxic	Anoxic		none	7.86	6.12	1.74	1.60	48
					7.84	6.05	1.79		
					7.81	6.54	1.27		
	Effluent	Effluent		none	7.91	7.06	0.85	0.81	24
					7.89	7.09	0.80		
					8.11	7.34	0.77		