Compact Extended Aeration Reactor (CEAR) – Study on Nitrogen Removal

by

Farah Adiba binti Abdul Sani

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CERTIFICATE OF APPROVAL

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Civil Engineering Programme
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Approved by,

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(Assoc. Prof. Dr. Shamsul Rahman Mohamed Kutty)

UNIVERSITI TEKNOLOGI PETRONAS

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September 2012

CERTIFICATION OF ORIGINALITY

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

FARAH ADIBA BINTI ABDUL SANI

ABSTRACT

Nutrient compounds are becoming increasingly significant in wastewater management, since their concentrations are observed to be escalating in the past few years. This condition is mostly due to the human activities, from the production and use of nitrogen fertilizers to the burning of fossil fuels in automobiles, power generation plants, and industries. Concern over this matter, the Department of Environment (DOE) Malaysia had significantly reduced the discharge limit for nitrogenous compound such as ammonia-nitrogen and nitrate through amendment of Environmental Quality (Sewage) Regulation 2009. Thus, the purpose of this study is to produce a new integrated wastewater treatment system that can help in meticulously remove nitrogen and produce high quality effluent. To achieve this, an integrated reactor consists of two - (2) aeration tanks, one - (1) anoxic tank and one - (1) clarifier was designed. This reactor, which is known as Compact Extended Aeration Reactor (CEAR) was operated under SRT of 40 days and was filled with approximately 330 litres of wastewater. During operation of the reactor, synthetic wastewater made from dilution of finely grinded dogs' food was used to imitate medium strength domestic wastewater, thus creating more consistent organic loading. Sludge from UTP sewage treatment plant was also added inside the reactor as the source of biomass and total of 48 litres/day recycle rate was imposed on the reactor. After acclimatization period over, it is found out that the effluent discharge of ammonia-nitrogen and nitrate become consistent at 0.5 mg/L and 0.3 mg/L, respectively. This result is true for both incoming flowrate of 8 mg/L and 10 mg/L.

ACKNOWLEDGEMENT

All praises to Allah, the Most Gracious and the Most Merciful for His will upon the completion of my Final Year Project (FYP) and for giving me the strength to successfully perform throughout this journey. I can proudly say that I have taken efforts in this subject; however I still believe it would not have been possible without the continuous and kind support of many individuals. With this given opportunity, I would like to extend my sincere and humble gratitude to all of them.

First and foremost, I would like to express much appreciation towards my supervisor. I am highly indebted to Assoc. Prof. Shamsul Rahman Mohamed Kutty for his genuine guidance and constant supervision as well as his broad knowledge regarding my project. Not only that, I am also beholden to his counsel and encouragement during the two – (2) semester period of my FYP.

Deepest thanks and appreciation to my internal examiner, Dr. Mohamed Hasnain Isa and external examiner, Puan Mardhiyah Mohd Bakir for their kind cooperation, constructive suggestion and full support during my proposal defense and final presentation. They definitely are the backbone to the completion of this project because of the advices and solutions that they had provided along the way.

Last but not least, I would like to take this chance to show gratitude to my parents, family, and friends for their unconditional support and for having faith in me. Thank you for the continuous guidance that they had provided throughout the hardship in completing this project.

May Allah bless all of you.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Project Background

Numerous wastewater treatment systems have been developed over the last 30 years to ensure safe effluent discharge to the water bodies. Most of these systems are the modifications of the existing activated-sludge processes that had evolved progressively over time. The activated sludge process is by far is the most common treatment system used to remove organic pollutant from wastewater since it is very cost-effective, flexible (can be adapted to any kind of wastewater), reliable, and poses high capability in producing high quality effluent (Mulas M., 2006).

Since its development in the early 20th century, the activated-sludge process had undergone and continues to experience many changes in its operational features and design to improve both its efficiency and flexibility (Seviour, 2010). Despite its reputable features mentioned earlier, most activated-sludge processes still suffer from few operational problems since its inception. Problem associated with the activated-sludge process can usually be related to four – (4) conditions (Schuyler, 1995); which are foam, high effluent suspended solids, high concentration of soluble materials, and low effluent pH. However, these problems will not necessarily develop inside every activated-sludge process, in fact, with proper operation and careful consideration such problems can definitely be obviate.

According to Indah Water Konsortium (IWK) website, there are currently over 5,834 operating wastewater treatment plant throughout Malaysia where different conventional activated-sludge processes are implemented. Regardless of the various existing process of activated-sludge system, it still seems that they were not able to produce low effluent discharge. These treatment systems are only efficient in removal of biological oxygen demand (BOD) and total suspended solids (TSS), but provide less than optimal removal of nitrogen (10-30%)(WSDOH, 2005). This condition is due to nitrification being inhibited due to insufficient solids retention time and sludge age of biomass (S.R.M Kutty, M.H. Isa, L.C Leong, 2011).

Nitrogen is present in wastewater in several forms, the important ones being organic nitrogen (both soluble and particulate), ammonia, and nitrate (A.V.Hanndel, 2007). The removal of nitrogen from wastewater using an onsite wastewater treatment system involves natural biological processes namely, ammonification, nitrification, and denitrification. These processes will change the many forms of the nitrogenous matter into nitrogen gas (N_2), which is the most stable and safe form of nitrogen. A variety of proprietary technologies have been developed for the purpose of enhancing these natural processes. However, none of them had been demonstrated to provide a simple, effective, and consistently reproducible effluent (WSDOH, 2005). As a result, an increasing effort had been put in managing nitrogen removal from wastewater by many environmental bodies.

1.2 Problem Statement

In the promotion of environmentally sound and sustainable development, the Department of Environment (DOE) Malaysia has revised the discharge standard of all wastewater effluent parameters among other re-establishment of environmental consideration. As a result, the Environmental Quality Regulations 2009 is implemented and the discharge limits for most parameters are significantly reduced. Among parameters that are affected are ammonia-nitrogen (NH_4-N) and nitrate (NO_3) which has been reduced to 10 mg/L and 20 mg/L, respectively. The exact same values had been imposed to all wastewater treatment plant all over Malaysia until this day. The significant reduction for both parameters called the need for better wastewater treatment system that is efficient in performing nitrification and denitrification processes.

The needs to produce better treatment process also arise as the population increase rapidly; placing pressure on the environment and threatening water supplies. It was then recognized that the problem of human waste needed to be tackled. The developments of wastewater treatment plant has evolved fleetly in urban centers and cities, whereas simpler systems is still been used to serve small communities. However, the ever-increasing environment standard and population growth will eventually cause these areas to install better treatment systems as well in the future.

Although many wastewater treatment systems today are capable in handling municipal wastewater, but the reasons stated above have prove that there are always constant needs for better system. Even the most ideal system will collapse after certain duration if proper maintenance is absence and equipments starts to wear off. That is the reason why it is so important to continue improvising the existing activated-sludge process and take responsibility on the waste we produce, instead of putting heavy burden on the lakes and rivers

Thus, this research will focus on demonstrating an understanding of activated sludge process which will be reflected on a modified reactor. Various experiments will be conducted to measure its overall performance in treating wastewater. It is hope that the modified reactor will performed well and can eventually benefit the environmental and wastewater treatment industry.

1.3 Objectives of Study

The primary objective of this study is to produce a reliable integrated wastewater treatment system by incorporating two – (2) aeration tank, an anoxic tank, and a clarifier; that can comply with the latest DOE discharge limit on both organic matter and nitrogen compound.

1.4 Scope of Study

This research is an extended study over two semesters in fulfilling the requirement of Final Year Project I and II courses prior graduating. The project's aims for FYP I course are to produce a literature review on the subject, to design a well-functioning tank, to fabricate the designated tank using clear fiber glass material, produce synthetic wastewater made from dog's food, and to perform preliminary experiments to test the functionality of the tank by measuring the rate of degradation of ammonia nitrogen (NH_4-N) and nitrate (NO_3).

Post-FYP I demands data analysis to be conducted within FYP II. More detailed experiments were carried out throughout FYP II period. Among the experiments for FYP II are optimum Return Activated Sludge (RAS), optimum Solid Retention Time (SRT), optimum incoming flow rate, and optimum oxygen diffusion rate. All of these parameters were identified by monitoring the reactors' success in removing organic matter and nitrogen.

In order to design the best integrated wastewater treatment system, this research concentrates on studies of organic oxidation process, aerobic digestion process, nitrification and denitrification processes, sedimentation and decanting processes. This is to ensure that this system was design in such way that BOD and nitrogen compound could be removed according to DOE current effluent guidelines.

Research on synthetic wastewater was also conducted to imitate the typical medium strength wastewater composition. Various concentration of dogs' food were diluted into one liters of tap water and the concentration that were able to produce the most similar composition is adapted in the experiment.

The scope of this research also include the best sampling and testing method for ammonia nitrogen (NH_4-N) and nitrate (NO_3). The fifth edition of the Water Analysis Handbook by Hach was used as the comprehensive sources to determine the exact procedure that handling method that must be carried out.

1.5 Relevancy of the Project

This research pays attention to the human health factor and deterioration of waterways due to discharge of bad quality effluent from wastewater treatment plant. According to Florida Rural Water Association (FRWA), nitrogen, in its various forms, can deplete dissolved oxygen in receiving wasters, stimulating aquatic plant growth, exhibit toxicity towards aquatic life, present a public health hazard, and affect the suitability of wastewater for reuse purposes. Wastewater effluents containing nutrients such as nitrogen can also cause eutrophication, the excessive growth of plant and algae bloom in lakes and rivers.

Nitrogen in the forms of ammonia can cause acute toxicity to several species of fish (WSDOH, 2005). Many mechanical sewage treatment plants in Malaysia had been required by the government to nitrify their effluent in order to avoid ammonia toxicity in the receiving waters. As for nitrogen in the forms of nitrate; the primary contaminant in drinking water, can cause a human health condition known as baby blue syndrome. This is due to the conversion of nitrite by nitrate reducing bacteria in the gastrointestinal tract. Ammonia toxicity, in particular, is not a significant issue because of the relatively low volumes and concentrations that would be released from sewage treatment plant.

To counter all of these issues, the roots cause need to be identified and action to should be taken. In this case, the root cause begins at the feckless wastewater treatment system which produces effluent with high BOD and nutrients contents. The problem can be rectify by taking one foreseeable measures, which is to design a new and validated wastewater treatment system that is highly reliable.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Description of Activated Sludge Process

The evolution of wastewater treatment system was at its peak when a process known as activated sludge was observed and quickly became the accepted system for treating both municipal and industrial wastewater. The activated sludge process was discovered in 1913 in the United Kingdom (UK) by two engineers, Edward Ardern and W.T. Lockett (Beychok, 1967), who were conducting research for the Manchester Corporation Rivers Department at Davyhulme Sewage Work.

Even so, only after decades later, a number of general studies were carried out to determine if activated sludge was basically a biological process or a physical-chemical process with the assistance of microorganism. These intense studies are the result from the loss of thousands lives in European cities during the 19^{th} century; where it was later discovered that the bacteria from river Elbe are the caused for the illness, and all the victims had been supplied with drinking water coming directly from it without any filtration. Only in 1960s that they realize that wastewater must be treated biologically before being discharged into surface water (Wiesmann, 2007). Soon after the discovery, various studies on activated sludge were conducted and different types of treatment systems are invented to protect human race from possibility of deadly diseases.

Today, the activated sludge process is the most commonly used system for the treatment of municipal wastewater, and is probably the most versatile and effective of all wastewater treatment processes (Gerardi, 2002). The National Small Flows Clearinghouse, a West Virginia University (WVU) Research Corporation defines activated sludge as the sludge particles that produced in wastewater by the growth of organism in the aeration tanks. The term 'activated' comes from the fact that the particles teem with bacteria, fungi, and protozoa; that can feed on the incoming wastewater. The activated sludge process is widely used by large cities and communities where large volumes of wastewater must be highly treated economically, because this process is capable of producing a high quality effluent for a reasonable amount of cost. Other widely known advantages of this process are the low cost construction and the relatively small land requirement.

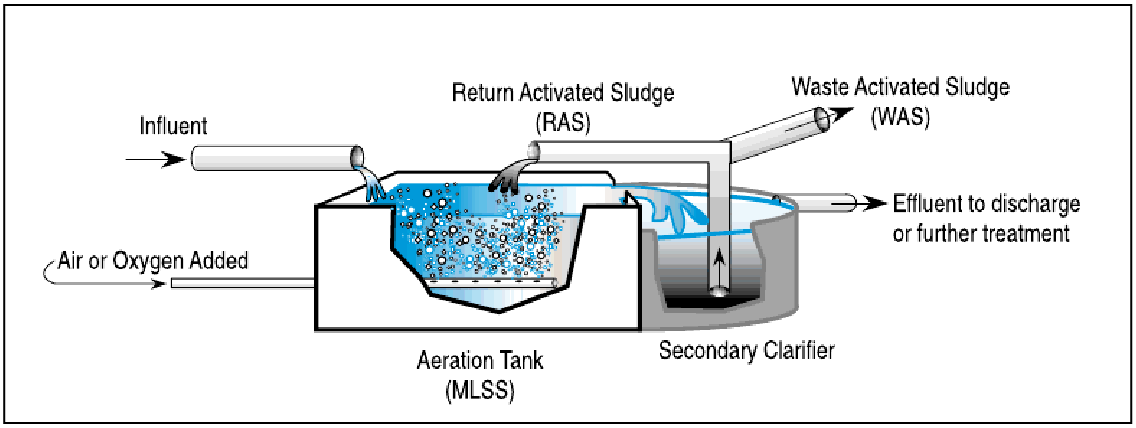

Figure 1: Illustration of a Typical Activated Sludge Process
Adapted from National Small Flows Clearinghouse, WVU Research Corporation

Figure 1 above shows the basic activated sludge process which consists of several interrelated components, namely; aeration tank – where the biological reaction occurs, aeration source – to provide oxygen and mixing, clarifier tank – where the solids settle and are separated from treated wastewater, and the means of collecting the solids, either Return Activated Sludge (RAS) – to return solids to the aeration tank, or Waste Activated Sludge (WAS) – to remove excessive solid from the process.

During the activated sludge process, the aerobic bacteria thrive as they travel through the aeration tank. They will multiply rapidly with enough food and oxygen; and by the time the waste reaches the end of the tank, the bacteria have used most of the organic matter to produce new cells. The organisms will then settle to the bottom of the clarifier tank, separating from the clearer water, while the sludge is pumped back to the aeration tank where it is mixed with the incoming wastewater or removed from the system as excess, a process called wasting. The relatively clear liquid above the sludge is sent on for further treatment as required (National Small Flows Clearinghouse, 2003).

2.2 Types of Activated Sludge Process

Many of the early plants including the original design were fill and draw, and semi-continuous system (Ardern and Lockett, 1941; Seviour, 2010), which is now becoming popular again as sequencing batch reactor (SBR) systems. These two are the basic main type of activated sludge processes and they can be differentiated on the basis of their mixing regimes, being referred to as either plug flow or completely mixed system.

The following discussion will be on the existing type of activated sludge system which will be used in the design and focused mainly on the advantages and disadvantages of each system; so that clear understanding can be attain on the area of improvement in the future design.

2.2.1 Completely Mixed System

A completely mixed reactor has uniform characteristics throughout the content of entire reactor (Vesilind, 2003). Based on the configuration in Figure 3, the incoming flow will be distributed throughout the tank and mixed rapidly with the biomass. This means that the operating characteristics of Mixed Liquor Suspended Solid (MLSS), respiration rate, and soluble Biological Oxygen Demand (BOD) are uniform throughout; unlike plug flow system. This characteristic is cited as the primary reason why the completely mixed process can handle surges in organic loading and toxic shocks to a limited extend without producing a change in effluent quality (Vesilind, 2003), although slightly increasing chances of short circuiting of bulk liquid (Seviour, 2010). To add up, it can also produce good nitrification since Chemical Oxygen Demand (COD) is uniformly low.

Comparing to plug slow system, this system had been rejected by certain engineers because it can stimulate the growth of filamentous bacteria which will eventually result in poor settling characteristics; which are caused by low food concentration and low or variable DO levels. However, such problem can be obviated with proper design consideration and excellent maintenance. Apart from that, completely mixed system has another downside; where organic overloading and under-aeration will restrict nitrification (Gray, 1990). Based on Seviour, 2010, this problem can be alleviated by incorporating several tanks in series, to produce what is really a 'pseudo plug flow' generating a better settling sludge, and avoiding any possibility of eventual denitrification and N_2 gas evolution in the clarifiers. Figure 2 below shows the typical completely mix process.

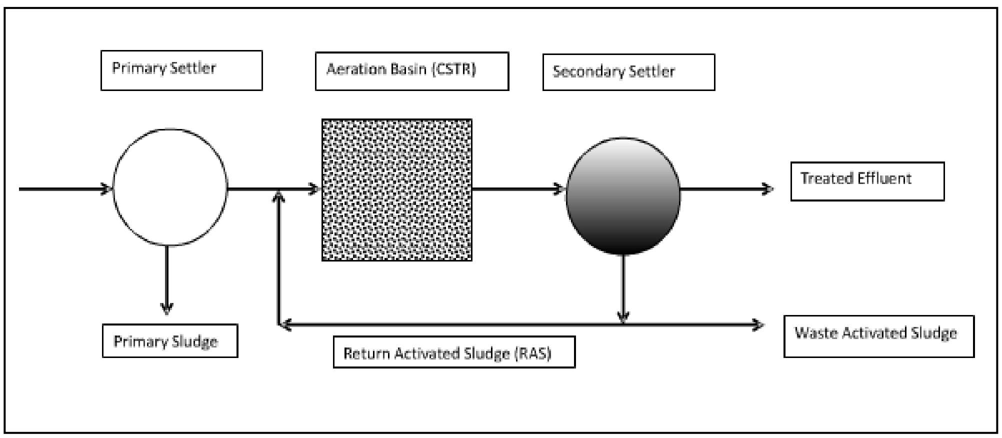

Figure 2: Typical Completely Mix Process

2.2.2 Plug Flow

a) Conventional Plug Flow

The activated sludge process in typical plug flow system can be seen in Figure 3.1. Settled wastewater and Return Activated Sludge (RAS) enter the front end of the aeration tank and are mixed by diffused air or mechanical aeration. Based on Wanner (1994) in his book "Activated Sludge Bulking and Foaming Control", the implementation of plug flow is based on the thought to encourage less filamentous bacterial growth, and hence produce better settling sludge than completely mixed system.

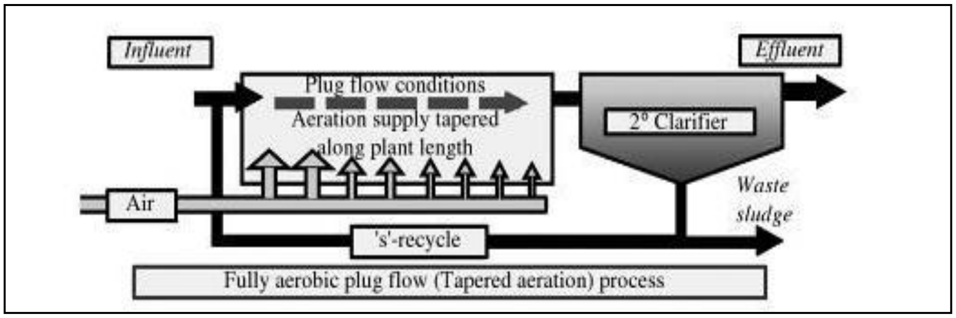

Figure 3.1: General Features of a Plug Flow Process.
Adapted from Seviour, Microbial Ecology of Activated Sludge (2010)

b) Tapered Aeration

Regardless the magnificent advantage it poses, plug flow has its own downside where such plants often operate inefficiently from uneven load distribution along the reactors (Seviour, 2010). This condition cause high O_2 demand at the inlet, thus reducing the dissolved oxygen (DO) level near to zero. However, modification had been made to the plug flow system to overcome the imbalances of O_2 demand by introducing tapered aeration system, that will attempts to supply air to match the oxygen demand along the length of the tank. Figure 3.2 illustrates the arrangement of the tapered aeration system, which attempted to distribute the O_2 according to biomass requirement.

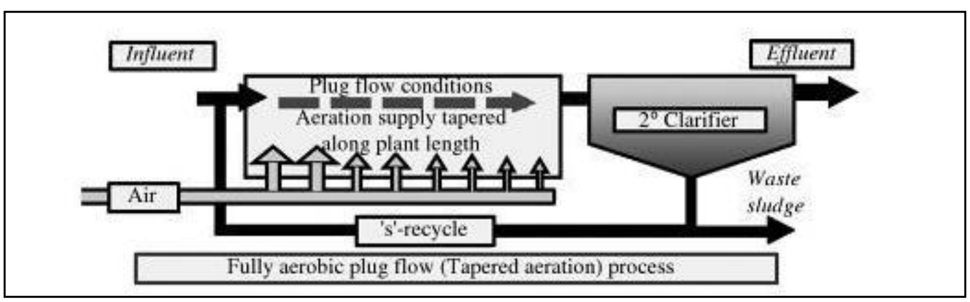

Figure 3.2: Plug Flow Activated Sludge System with Tapered Aeration.
Adapted from Seviour, Microbial Ecology of Activated Sludge (2010)

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c) Step Aeration

Following the advancement of tapered aeration in plug flow system, it has been found out that possibility of biomass to settle in plug flow process will increased in the area with low velocity input. Step aeration was thus introduces at several points along the tank length which is capable in producing more uniform oxygen demand throughout. It is achieved by dividing air supply into two portions and supplying the larger to the inlet half of the plant (Seviour, 2010). This condition allow the system to produce a lesser effluent quality, in terms of BOD and TSS concentration. Refer to Figure 3.3 below for the illustration of plug flow activated sludge system with step aeration.

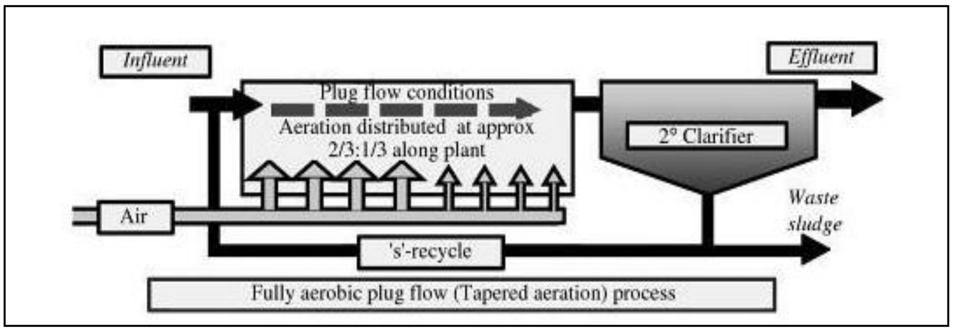


Figure 3.3: Plug Flow Activated Sludge System with Step Aeration.
Adapted from Seviour, Microbial Ecology of Activated Sludge (2010)

d) Step Feed Aeration

Step feed is a modification of the conventional plug-flow process in which the settled wastewater is introduced at 3 to 4 feed points in the aeration tank to equalize the F/M ratio, thus lowering peak oxygen demand (Metcalf & Eddy, 2004). The main objective of step feed is to has the same effect of tapered aeration by introducing raw feed at several points along the length of the plug flow system. The graphic can be seen in Figure 3.4. Based on C. Y. Shi, this design may also provide increased operational flexibility. Note that in plug flow system, complete nitrification and high reactivation of the sludge is guaranteed in long hydraulic retention time.

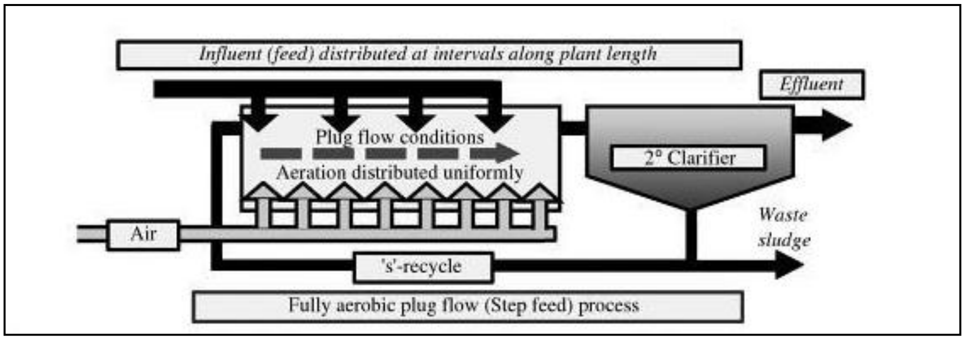


Figure 3.4: Plug Flow Activated Sludge System with Step Feed
Adapted from Seviour, Microbial Ecology of Activated Sludge (2010)

e) Contact Stabilization

Contact stabilization has been heralded as a method of reducing aeration-tank volume requirements with little or no loss in treatment efficiency (Dague et al., 1972). Based on Gujer and Jenkins (1975), the real aim is to achieve a more rapid adsorption of solids onto the flocs, by allowing contact between the incoming waste and RAS in a small aerobic tank (known as contact tank) for up to one hour. In order to complete the biological oxidation process (removal of BOD), the recycled activated sludge (RAS) is aerated for 3 to 8 hours in a 'stabilization tank'.

As a result, improved removal of particulate and readily biodegradable organic substrates is claimed, but not removal of the slowly degraded particulate matter (Gray, 1990), which include ammonia removal. Another clear advantage coming from contact stabilization process is reduced aeration requirement with short contact tank residence time. Refer to Figure 4 for overall arrangement configuration. Although the configuration is slightly less efficient than the conventional activated sludge process, it is more stable when subjected to large variations in flow or BOD loading.

The contact stabilization process is the best candidate for treating wastewater with very low soluble organic concentration and high insoluble organic materials (Schroeder, 1977). Part of the system is physical or absorption and therefore is less temperature sensitive and requires less aeration volume then the biooxidation process (Niku and Schroeder, 1981).

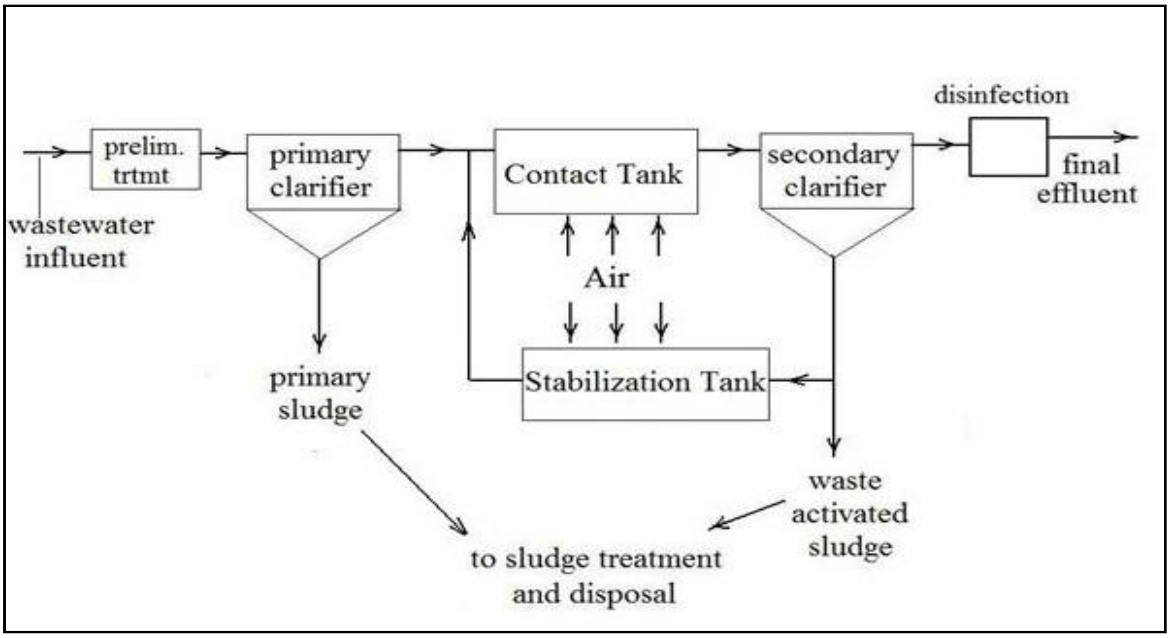


Figure 4: Configuration of Contact Stabilization Process

f) Multistage/Two-Sludge Treatment System

The multistage/two-sludge process is a two stage system using high-rate activated sludge fro BOD removal for BOD removal followed by second stage for nitrification, which is operated at a longer SRT (Metcalf & Eddy, 2004). A portion of wastewater influent may be bypassed around the first stage to provide BOD and suspended solids for the nitrification process and also to promote flocculation and solids removal in secondary clarification.

The need for multistage treatment process depends on the ability of the biomass to adapt to toxic or inhibitory influent material, which may affect nitrification (Seviour, 2010). If a well nitrified effluent is needed, elimination of harmful or toxic elements maybe achieved by an adapted sludge in the first level of treatment, which will treats the influent partially. The treatment will only be completed when it undergo the second level of treatment, where the product of first stage treatment is nitrifies. Refer to Figure 5 for the configuration of multistage/two-sludge treatment system.

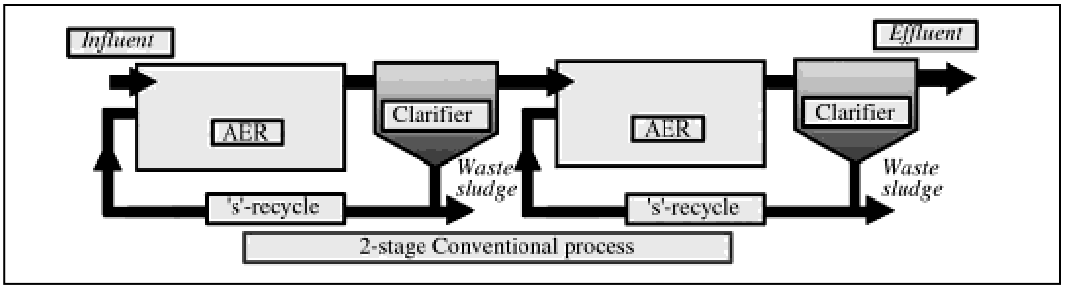


Figure 5: Configuration of Multistage/Two-Sludge Treatment System
Adapted from Seviour, Microbial Ecology of Activated Sludge (2010)

This system produce very high quality effluent but the expense of installing and maintaining the treatment system must also be taken into consideration; since it involved two major processes. Note that this process can either be the combination of different or similar completely mix processes or plug flow processes.

2.2.3 Extended Aeration

a) Conventional Extended Aeration

Extended aeration is a process that operates with low loadings and high Suspended Solid (SS) levels, and long aeration periods and sludge ages (Wanner, 1994). These conditions allow complete oxidation and improved stabilization of sludge (Seviour, 2010). As a result, this process can consistently produce high quality effluent. That is the reason why it is the preferred choice and it is projected to have significant amount of extended aeration plant in the future.

Extended aeration process is one example of completely mix process with high solids retention time, which allow endogenous respiration process to occurs the system; hence reducing the cost of sludge handling. That is why the aeration tank for an extended aeration process must be larger than that for a conventional activated sludge process (also a completely mix process), in order to give detention time of about 24 hours instead of 6 to 8 hours used for conventional activated sludge (Bengston, 2011). This process is typically used in prefabricated “package plants” which intended to minimize design costs for sludge disposal from small communities, tourist facilities, and school. Refer to Figure 6 for the illustration of extended aeration process.

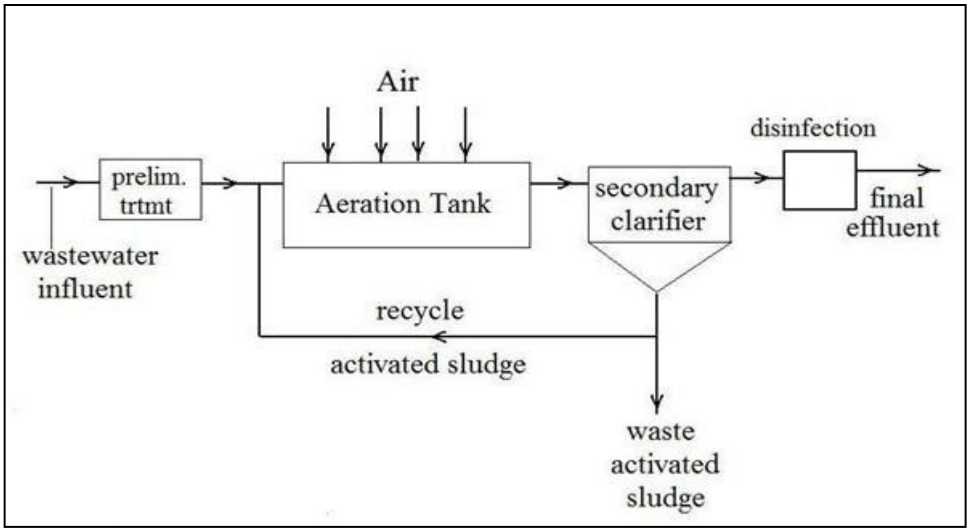


Figure 6: Flow of Extended Aeration Process
Adapted from Journal by Bengtson H. (2011)

b) Oxidation Ditch

Oxidation ditch is mechanical secondary treatment systems which are tolerant of variations in hydraulic and organic loads (Indah Water, 1994). In a classical oxidation ditch system, wastewater and mixed liquor are pumped around an oval pathway (racetrack) by brushes, rotors, or other mechanical aeration devices and pumping equipment located at one or more points along the flow circuit (Vesilind, 2003). Similar to extended aeration, oxidation ditch also have high hydraulic retention time (24 hours) and solids retention time (20 to 30 days).

Based on Vesilind (2003), oxidation ditch may be viewed as a complete-mix reactor even though they have some plug flow characteristics as flow traverse the loop. The good thing about this process is that it can easily be adjusted to meet most combinations of incoming wastewater and effluent standards. This process is able to achieve both high BOD reduction and some nutrient removal. However, oxidation ditches require more land than other processes but it is cheaper to construct and operate. Refer to Figure 7 below for the flow of oxidation ditch process.

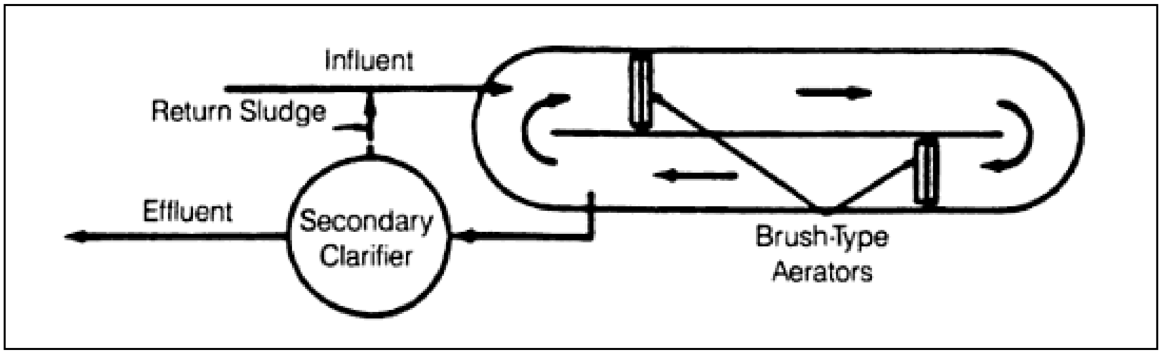


Figure 7: Flow of Oxidation Ditch Process
Adapted from Vesilind (2003), "Wastewater Treatment Plant Design"

c) Orbal®

The typical Orbal® multichannel oxidation ditch has three concentric channels. The outer channel known as the aerated anoxic reactor is where the majority of the process 'work' takes place. The DO of the second channel operates in a swing mode to vary with the daily load conditions. The last channel maintains a polishing mode removing remaining BOD and ammonia before the flow exits to final clarifiers. Based on Siemens website, the mechanical backbone is its unique aeration disc with its high oxygen transfer and unmatched mixing efficiency.

Orbal® multichannel oxidation ditch process, using completely mixed reactors in series, provides economical, flexible, and reliable treatment performance. Its arrangement in series provides more opportunity to minimize cost by using common wall construction. Because of the mixing capability of the disc aerators, there is no need for mixers in the aeration-anoxic outer channel. One version of the Orbal design (Bionutre®) limits the aeration rate in the first channel so that both nitrification and denitrification can occur. Refer to Figure 8 for illustration of the reactor's process.

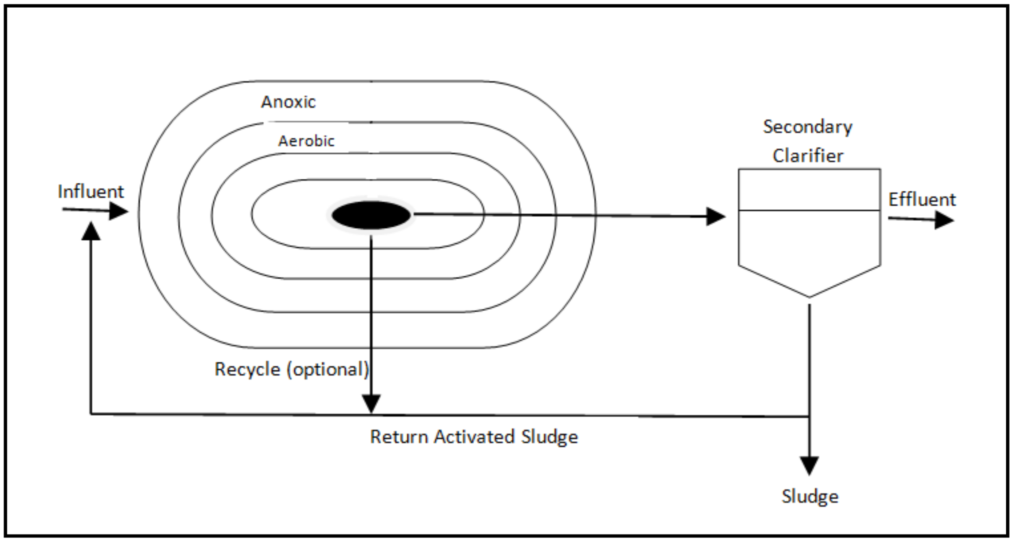


Figure 8: Flow of Orbal®
Adapted from Metcalf & Eddy (2003), "Wastewater Engineering: Treatment and Reuse"

2.2.4 Sequentially Operated System

a) Sequencing Batch Reactor (SBR)

According to Metcalf & Eddy (2004), SBR is a fill-and-draw type of reactor involving a single complete mix reactor in which all steps of the activated-sludge process occur. For municipal wastewater treatment with continuous flow, at least two – (2) basins are used so that one – (1) basin is in the fill mode while the other goes through react, solids settling, and effluent withdrawal. The major difference between the SBR reactor and conventional continuous-flow activated sludge system is that SBR carries out functions of equalization, aeration, and sedimentation in a time sequence rather than in conventional space sequence. Hence, a lot of space can be saved if SBR is implemented in a certain area since it only requires minimal footprint.

The operation of an SBR is based on the fill-and-draw principle, which consists of the following five basic steps; fill, aerate, settle, decant, and idle. The idle step occurs between decant and fill steps, in which treated effluent is removed and influent water is added. The length of the idle step varies depending on the influent flow rate and the operating strategy. Equalization is achieved during this step if variable idle times are used. During fill, influent wastewater is added while the mixed liquor remains in the reactor during all the cycles, thereby eliminating the need for separate secondary sedimentation tanks. Decanting of supernatant is accomplished by either fixed or floating decanter mechanism. Figure 9 shows the process cycle of a typical SBR.

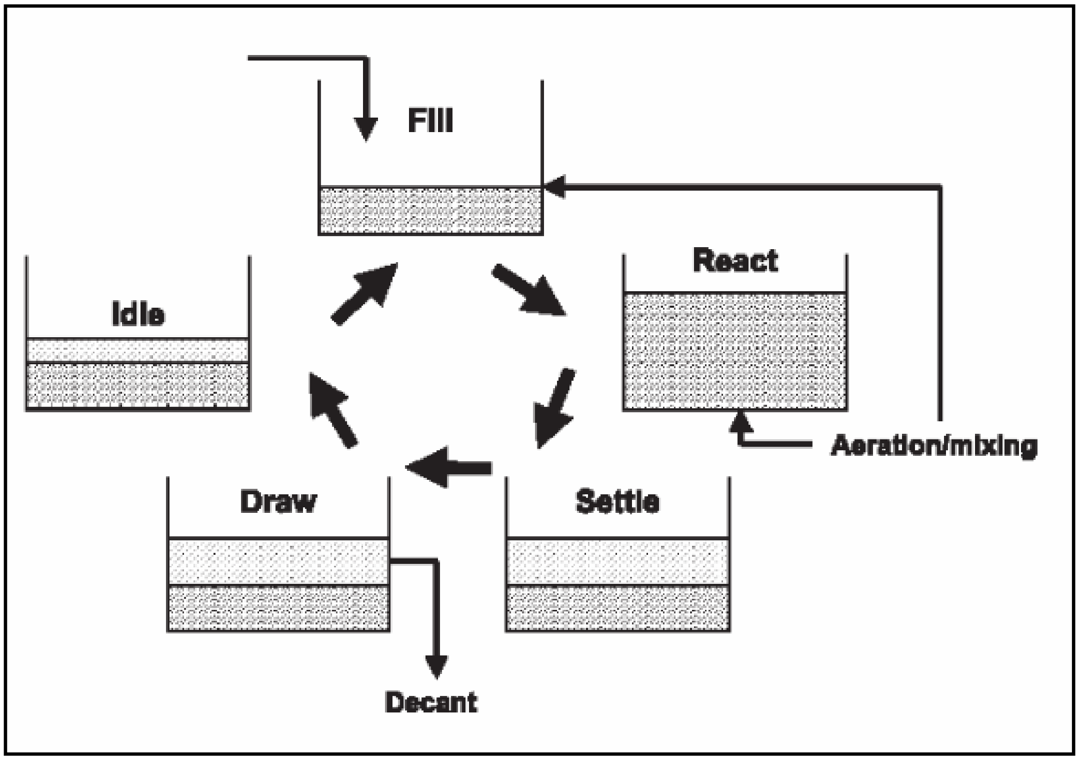


Figure 9: Process of Sequencing Batch Reactor

SBR is also said to be very cost-effective since the need for clarifiers and many other equipment can be eliminated. It also posses operating flexibility and control compared to other type of wastewater treatment system. Despite that, a higher level of sophistication on timing unit and controls are required especially for larger SBR system, which will eventually cause higher degree of maintenance. SBR also suffer from the potential of plunging of aeration devices during selected cycles, depending on the aeration system used by the manufacturer.

2.3 Nitrogen in Wastewater

Nitrogen compounds are becoming increasingly important in wastewater management, because of the many effects that nitrogenous material can have on the environment. Nitrogen, in its various forms can deplete oxygen due to nitrification, fertilize aquatic plant growth, exhibit toxicity toward aquatic life, affect chlorine disinfection efficiency and present a public health hazard (Halling-Sorensen et al., 1993). Nitrogen concentration in wastewater can be significant and are sometimes more refractory than what has been observed.

2.3.1 Nitrogen Forms

There are four stable forms of inorganic nitrogen in the aquatic system, namely, ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), and N_2. The first three forms are highly soluble, although ammonium can also lose a proton as pH increases above neutral to become ammonia (NH_3), which exist primarily as insoluble gas (WEF Press, 2010). The fourth form exists in gaseous state, which is the most abundant form of nitrogen in the earth. However, the principal nitrogen types of concern to wastewater treatment are more complicated, which are, total nitrogen (T-N), Total Kjeldahl Nitrogen (TKN), ammonia (NH_3), organic nitrogen (org-N), nitrate (NO_3), and nitrite (NO_2). With correct chemical stoichiometry and presence of correspondent bacteria, these forms are interchangeable between one and another depending upon whether aerobic or anaerobic condition prevails. Table 1 shows the definition of nitrogen species that are commonly used.

Table 1: Terms used to define various nitrogen species.

Form of nitrogen	Abbrev.	Definition
Ammonia gas	NH_3	NH_3
Ammonium ion	NH_4^+	NH_4^+
Total ammonia nitrogen	TAN[a]	$NH_3 + NH_4^+$
Nitrite	NO_2^-	NO_2^-
Nitrate	NO_3^-	NO_3^-
Total inorganic nitrogen	TIN[a]	$NH_3 + NH_4^+ + NO_2^- + NO_3^-$
Total Kjeldahl nitrogen	TKN[a]	Organic N $+ NH_3 + NH_4^+$
Organic nitrogen	Organic N[a]	TKN $- (NH_3 + NH_4^+)$
Total nitrogen	TN[a]	Organic N $+ NH_3 + NH_4^+ + NO_2^- + NO_3^-$

Adapted from Metcalf & Eddy (2004)

2.3.2 Nitrogen Chemistry

a) Ammonification

Ammonification is the biochemical degradation of organic-N into ammonia (NH_3) or ammonium (NH_4^+) by heterotrophic bacteria under aerobic or anaerobic condition (Oakley, 2004). This process is driven by a wide variety of microorganisms (Bitton, 2005). While traveling through sewer pipes, majority of the nitrogen contained in the raw sewage, such as urea and fecal material, is converted through a process called hydrolysis. The process is described by the simplified equation below:

$$\text{Organic-N} + \text{Microorganisms} \rightarrow NH_3 / NH_4^+$$

Based on the equation above both ammonia (NH_3) and ammonium (NH_4^+) are being produced during ammonification process. The ratio of ammonia (NH_3) versus ammonium (NH_4^+) is affected by pH and temperature. For typical condition in most wastewater treatment plants, far more ammonium than ammonia is produced. The typical condition refers to pH of 6 to 7, and temperatures of 10 to 20^{o}C.

b) Nitrification

Nitrification is the biological oxidation of ammonia (NH_3) and ammonium (NH_4^+) to nitrate (NO_3^-) through a two-step autotrophic process by the bacteria Nitrosomonas and Nitrobacter (Rittman and McCarty, 2001). Bacteria known as Nitrosomonas is responsible for the conversion of ammonia or ammonium into nitrite while bacteria called Nitrobacter finish the conversion of nitrite (NO_2^-) to nitrate (NO_3^-). The two-step reaction are usually very rapid and hence it is rare to find nitrite (NO_2^-) levels higher than 1.0 mg/L in water (Sawyer, et al., 1994).

These bacteria, known as "nitrifiers," are strict "aerobes;" which means that presence of free dissolved oxygen is imperative to perform their work. Nitrification can occurs only under aerobic conditions at dissolved oxygen levels of 1.0 mg/L or more. It also requires a long retention time because growth of nitrifiers bacteria are very slow. In addition, it also demand low food to microorganism ratio (F:M) and a high mean cell residence time.

Similar to ammonification process, nitrification process also required optimum temperature in order to have successful treatment. It has been investigated that the optimum temperature for nitrification are between 30 to 35^o Celsius. In case of high temperature, the nitrification rate of reaction will fall to zero immediately if it reaches 40^o Celsius or higher. On the other hand, if the temperature falls below 20^{o}C, the rate will become slower but will continue its reaction until 10^{o}C. However, if nitrification is lost in low temperature wastewater, it will not resume until the temperature increases to well over 10^{o}C.

Another important factor not to be neglected is the pH during nitrification process. The optimum pH for Nitrosomonas and Nitrobacter is between 7.5 and 8.5. However most treatment plants are able to effectively nitrify with a pH of 6.5 to 7.0 because the production of acid during nitrification process, which will lower the pH of the biological population in the aeration tank. Since low pH is considered toxic to nitrifiers, reduction in the growth rate of nitrifying bacteria will take place. Nitrification will eventually stops at a pH below 6.0.

The following equations describe the nitrification process:

$$NH_4^+ + 1.5O_2 \rightarrow 2H^+ + 2H_2O + NO_2^-$$

(Nitrosomonas)

$$NO_2^- + 0.5O_2 \rightarrow NO_3^-$$

(Nitrobactor)

$$NH_4^+ + 1.83O_2 + 1.98HCO_3^- \rightarrow 0.021C_5H_70_2N + 0.98NO_3^- + 1.041H_2O + 1.88H_2CO_3^-$$

$$NH_4^+ + 1.9O_2 + 2HCO_3^- \rightarrow 1.9CO_2 + 2.9H_2O + 0.1CH_2$$

From the above equations, it can be calculated that for every pound of ammonia oxidized to nitrate, the following occurs:

- 4.18 pounds of oxygen are consumed and
- 7.14 pounds of alkalinity are consumed measured as calcium carbonate $(CaCO_3)^-$ or -12 pounds of alkalinity measured as sodium bicarbonate ($NaHCO_3$)

c) Denitrification

Nitrate (NO_3^-) can be reduced, under anoxic conditions, to N_2 gas through heterotrophic biological denitrification (US EPA, 1993). Denitrification occurs when oxygen levels are depleted and nitrate becomes the primary oxygen source for microorganism. The process is performed under anoxic condition; that is when the dissolved oxygen concentration is less than 0.5 mg/L, or ideally less than 0.2 mg/L (WPC, n.p.). When bacteria break apart nitrate (NO_3^-) to gain the oxygen (O_2), the nitrate is reduced to nitrous oxide (N_2O), and in turn, nitrogen gas (N_2). Since nitrogen gas has low water solubility, it escapes into atmosphere as gas bubbles. The reaction is as follows:

$$6NO_3^- + 5CH_3OH \rightarrow 3N_2 + 5CO_2 + 7H_2O + 6OH^-$$

A can be seen from the equation; heterotrophic bacteria need a carbon source as food. In this case, carbon can be obtained from the presence of sufficient soluble organic matter, which may be in the form of raw wastewater or supplemental carbon. Similar to other reaction, this process is also temperature dependant. It will occurs between 5 to 30^o Celsius and the rate will increases with temperature and type of organic present, such as methanol or acetic acid. It has been found that the lowest growth rates occur when relying on endogenous carbon sources at low temperature.

Another important aspect of the reaction is the pH in the system. Dissimilar from nitrification process, denitrification produces alkalinity during the reaction. Approximately 3.0 to 3.6 pounds of alkalinity (as $CaCO_3$) is produced per pound of nitrate, thus partially mitigating the lowering pH caused by nitrification in the mixed liquor. The optimum pH values for denitrification are between 7.0 and 8.5.

CHAPTER 3

3.0 Methodology

3.1 Design of Compact Extended Aeration Reactor

The main concept of the reactor is to combine various processes inside one integrated tank. The reactor does not concern with any preliminary treatment processes such as screening or grit and grease chamber that are usually presence in typical wastewater treatment plant. Instead, the influent wastewater will directly flow into biological treatment tank. After careful consideration, it is decided to set-up two – (2) aeration tank, an anoxic tank, and a sedimentation tank inside one integrated reactor. Figure 10 shows the cross-section of integrated wastewater treatment reactor.

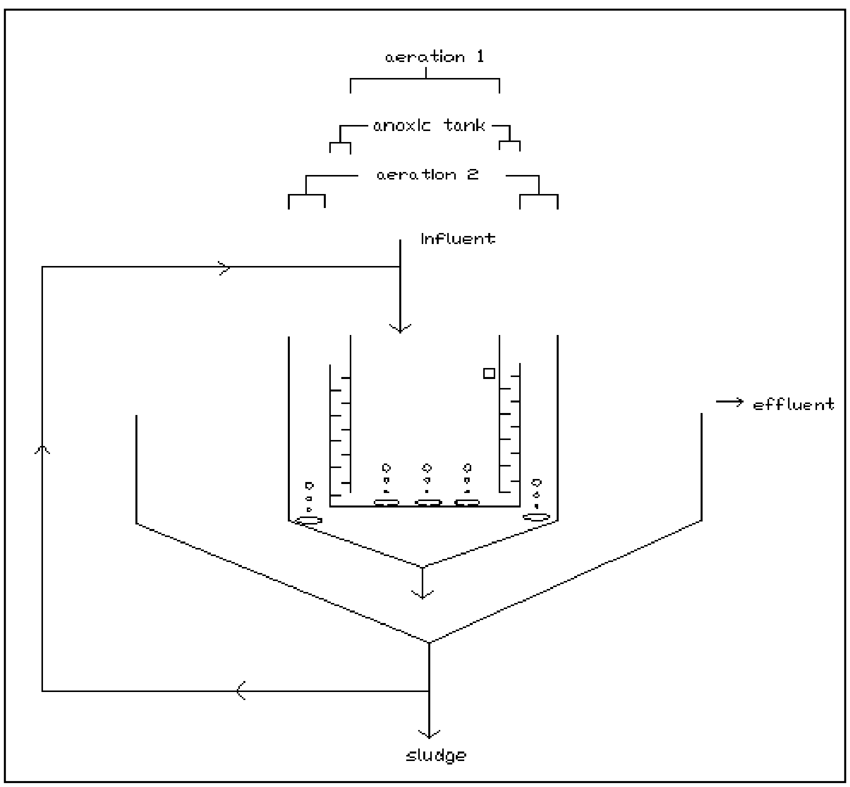


Figure 10: Process Flow of Designated CEAR

The reactor is purposely built with two – (2) aeration tanks under circumstance where longer retention time can be achieved, thus allowing nitrification process to take place. The first tank can take up to 17 liters (HRT = 2 days) whereas the second tank can take up almost 40 liters (HRT = 3 days). In the anoxic tank, a series of continuous narrow baffle path of 6 cm width are built to ensure proper mixing of wastewater and keeping the biomass in complete suspension. As for the clarifier, it is designed to have volume of 273 liters (HRT = 23 days) so that supernatant can be contained before being released as effluent. The influent is set to directly enter the first aeration tank, and then goes to the baffled anoxic tank, and followed by second aeration tank and clarifier, respectively. Refer to Figure 11 for illustration of the overall process in CEAR.

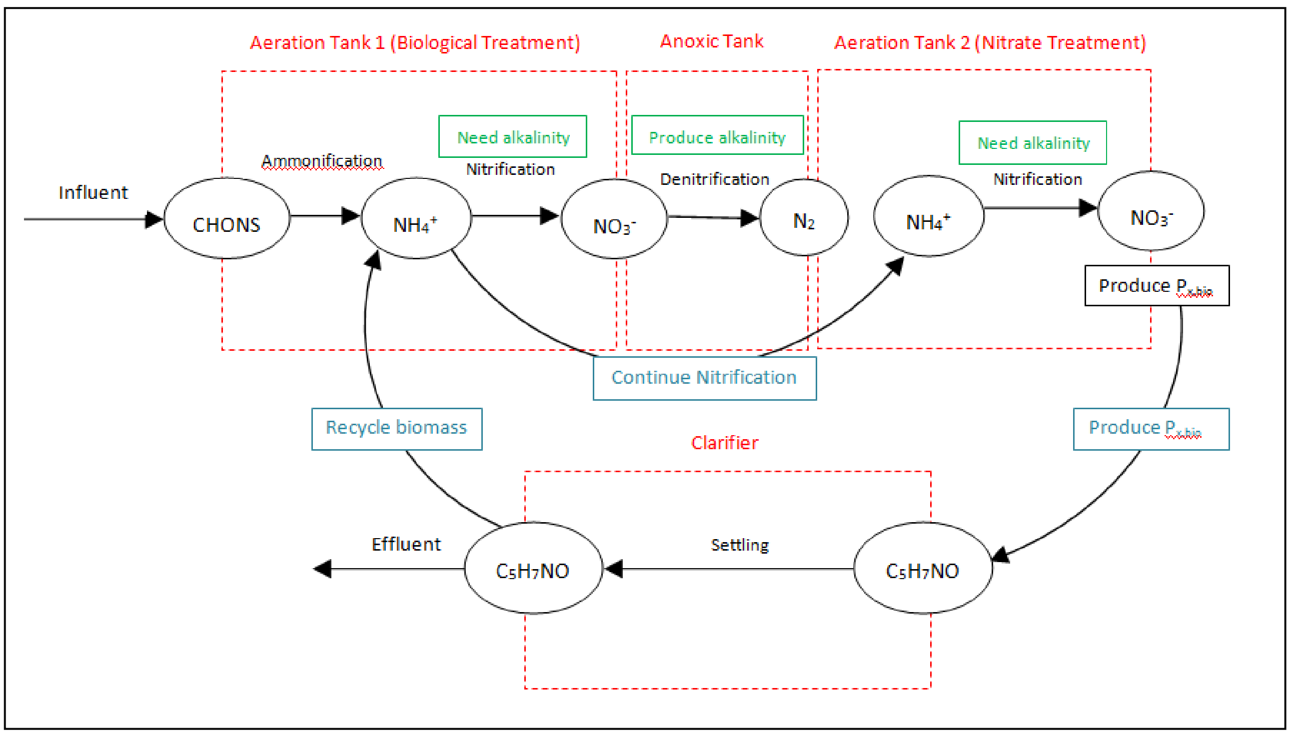


Figure 11: Flow of Treating Wastewater inside CEAR

The biomass from clarifier will be recycled directly into the first aeration tank for every two – (2) hours to ensure sufficient biomass is present in order for biological reaction to occurs. As for the moment, the incoming flow is set to be as low as possible; which is 8 mL/min. This is to allow the reactor to attain and accomplish its acclimatization period. As a result, the current SRT for the reactor is 28 days. The stated rate will be used until acclimatization period ended, and constant effluent quality is obtained. Only then, the incoming synthetic wastewater flow rate will be modified according to sustainability of the tank.

3.2 Feasibility Study of Synthetic Wastewater

The study was conducted using synthetic wastewater and biomass from UTP's wastewater treatment plant. The objective of using synthetic wastewater is to ensure a consistent organic loading throughout the experimental period. In order to simulate the synthetic wastewater, dogs' food of brand Purino Alpo High Protein Puppy Dog Meal is grinded for 5 minutes. The grinded dog's food was then sieve for finer result. This is to ensure that the dogs' food will be easily diluted when it is mixed with tap water. An experiment was then conducted in the laboratory to study the effect various concentration of dog's food in 1 mL of tap water to the value of COD. Table 2 shows the result of the experiment:

Table 2: COD Values for Different Concentration of Dogs' Food

Weight of Grinded Dogs' Food (mg/L)	COD
600	493
800	573
1 000	809
1 200	702
1 500	1478
2 000	1425
2 500	1673

It has been found out that the most suitable synthetic wastewater ratio is 600 mg in 1 liters of tap water. After that, several other tests were conducted to further verify the characteristic of the synthetic wastewater. The characteristic of synthetic wastewater with comparison to the typical medium strength wastewater are tabulated in Table 3.

Table 3: Composition of Synthetic Wastewater against Medium Strength Wastewater

Parameter	Average Reading (mg/L)	Typical Medium Strength Wastewater Composition (mg/L) [1]
COD	500	430
BOD_5	150	190
TSS	150	210
NH_3-N	5	25
NO_3	4	0

As can be seen in the table above, the ammonia content in the synthetic wastewater is much lower than the typical medium strength wastewater value. However, since ammonia will be produced during the degradation of organic matters in biological treatment stage, the ammonia is predicted to increase in aeration tank.

3.3 Experimental Methodology

3.3.1 Setting-up of Reactor

Compact Extended Aeration Reactor was set up on ground floor of Block 13, UTP Academic Complex while further experimental works were conducted in 14-02-10, UTP Environmental Laboratory. Figure 12 below shows the reactor during (a) setting up process and (b) completely assembled reactor.

(a) (b)

Figure 12: Experimental Methodology

The reactors' body was fabricated with fiber glass, and two windows are placed at its side. All pipes and connections used are made from 60 mm PVC pipes and connectors. Diffusers are also installed to ensure minimum DO of 2 mg/L. Note that the biological reactor was examined with hydraulic test prior operation to ensure all piping connections are properly attached; while other mechanical equipments were tested beforehand. When ready, influent is pumped into the reactor continuously at the rate of 8 m^3/min and 10 m^3/min using Masterflex Pump. Samples from the reactor is taken once every two – (2) day to be tested on NH_4-N and NO_3.

3.3.2 Measurement of the Parameters

a) Ammonia-Nitrogen (NH_3-N)

To test for ammonia-nitrogen, USAPA Nessler Method (Method 8038) was used.

For the first step, sample and blank were prepared by filling 25 mL of sample and deionized water into separate mixing cylinder. Three drops of Mineral Stabilizer was then added to both mixing cylinders before they were inverted for mixing. The Mineral Stabilizer will complexe hardness in the sample. After that, three drops of Polyvinyl Alcohol Dispersing Agent (to aids in color formation in the reaction) were added to each cylinder, followed by 1.0 mL of Nessler Reagent. Following these processes, the cylinders were inverted several times for better mixing.

The mixture was then left for one-minute reaction period and once the timer goes off, 10 mL of the mixture of each solution were poured into sample cell. The content of ammonia-nitrogen was then measured afther the instrument is zero using the blank.

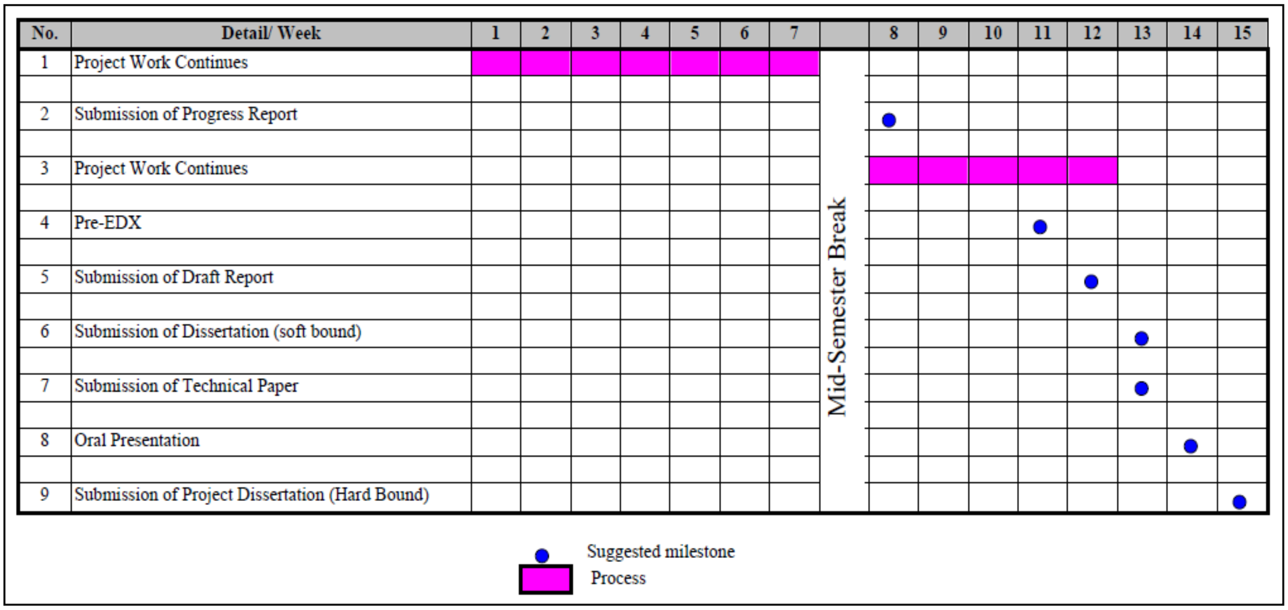
b) Nitrate (NO_3)

To test for nitrate, Cadmium Reduction Method (Method 8039) was used. Preparation of sample was done by filling the sample cell with 10mL of sample. After that content of one NitraVer 5 Nitrate Reagent was added, shake for one-minute, and left for five-minute reaction period. An amber color will develop if nitrate was present. Content of nitrate can then be measure after the instrument was zero using the blank. Blank was prepared by filling the sample cell with 10mL of similar sample.

3.4 Method of Sampling

Test on ammonia-nitrogen and nitrate are conducted on four-(4) sample, which is taken from four-(4) different point in the reactor, namely; effluent aeration tank 1, effluent anoxic tank, effluent aeration tank 2, and final effluent. The testing on ammonia-nitrogen and nitrate were also carried out three-(3) times on each samples and average of the reliable results is taken to ensure consistent value is obtained. These samples are taken once every two days.

3.5 Gantt Chart and Key Milestone



3.6 Tools and Equipments

Tools and equipments used during experimental period are summarized in Table 4 below:

Table 4: Tools and Equipment

No.	Tools / Equipment	Quantity
1.	Integrated Wastewater Treatment Reactor	1 unit
2.	Masterflex digital peristaltic pumps	1 unit
3.	Masterflex tube size 16	-
4.	Influent/Effluent container	2 unit
5.	Recycle Pump	1 unit
6.	Recycle Pipe	-
7.	Air Pump	1 unit
8.	Diffuser	10 unit
9.	Valve	1 unit
10.	Tube Diffuser	-
11.	Timer	2 unit

CHAPTER 4

4.0 Results and Discussions

The main parameter of concern in this study is ammonia-nitrogen (NH_3-N), nitrate (NO_3). In order to encourage nitrification, the reactor is operated under extended aeration condition where higher retention time is provided to allow nitrifiers to grow. The nitrification process is expected to occur partially in aeration tank 1 and continue in aeration tank 2.

Test on the mentioned parameters are conducted on four-(4) sample, which is taken from four-(4) different point in the reactor, namely; effluent aeration tank 1, effluent anoxic tank, effluent aeration tank 2, and final effluent. The testing was carried out three-(3) times and average of the reliable results is taken to ensure consistent value is obtained.

So far, the reactor has been tested on two – (2) different incoming wastewater loading; 8 m^3/min and 10 m^3/min. During the operation on first loading (8 m^3/min), the influent wastewater was not tested as frequently as the other four effluent points mentioned earlier. It is assumed that the synthetic wastewater would always possess constant characteristics. However, it is later found out that the synthetic wastewater constituent will degrades and eventually causes the reading to fluctuate. Despite that, the reactor continues to operate under the same loading until the effluent reading stabilizes.

In order to obtained better and more accurate data, the reactor is operated under different loading (10 m^3/min). This time around, the influent parameters are also tested together with the other effluent samples. Under both loading, the reactor will initially undergo acclimatization period before it start to stabilize. Data will only be reliable once the reactor stabilizes.

4.1 Removal of Ammonia-Nitrogen

Test on ammonia-nitrogen are carried out based on UESPA Nessler Method (Method 8038). The result of ammonia-nitrogen removal for 8 m^3/min influent loading is presented in Figure 13.

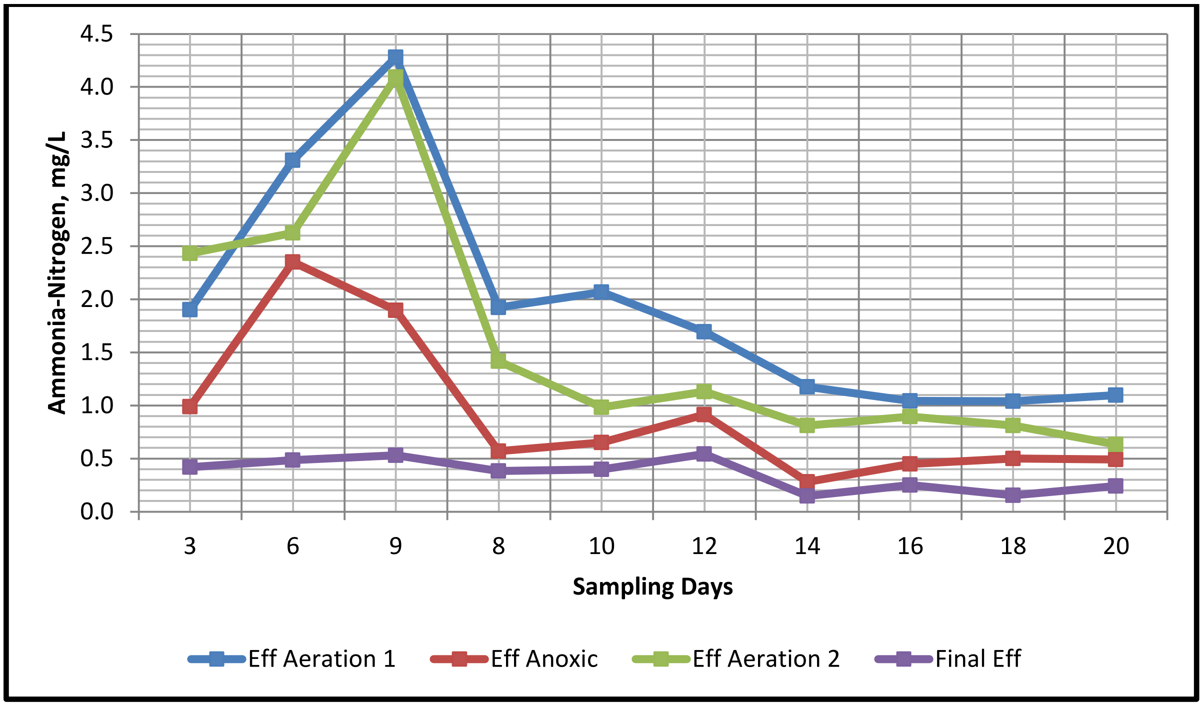


Figure 13: Effluent Ammonia Nitrogen for 8 m^3/min Incoming Load

It can be observed in the above graph that effluent from aeration 1 and aeration 2 have the highest NH_3-N content, especially in day 9 which is 4.28 mg/L and 4.50 mg/L respectively. Although value of NH_3-N are small in the influent, but it increases rapidly as it enters both aeration tank because that is where ammonification process occurs. Based on the value obtained, it can be say that both aeration tanks are working very well; since it can convert the organic matter contained in the incoming synthetic wastewater into ammonia.

As for effluent anoxic tank; which is the effluent of anoxic tank, value of NH_3-N are generally lower than values in aeration tank but slightly higher than the final effluent. It can be seen in the graph that the values did not exceed 2.5 mg/L. The values lowered because some of NH_3-N is no longer present in the anoxic tank as it has been converted into NO_2, NO_3, or N_2 by nitrification or denitrification induced bacteria. However, not all NH_3-N are converted but it is acceptable because there is another aeration tank located after anoxic tank that can further treat NH_3-N before it is discharge.

In the final effluent, values of NH_3-N were drastically decreased. Their values merely reach 0.5 mg/L at the discharge point. The values can be considered successful since they have fulfilled the Malaysia's DOE Standard A requirement on NH_3-N, which is 10 mg/L. From the graph, it can be seen that the reactor start to stabilize from day 21 onwards.

Starting from 3rd December 2012, the incoming load imposed on the reactor had been increased to 10 m^3/min. The result of ammonia-nitrogen removal for 10 m^3/min influent loading is presented in Figure 14.

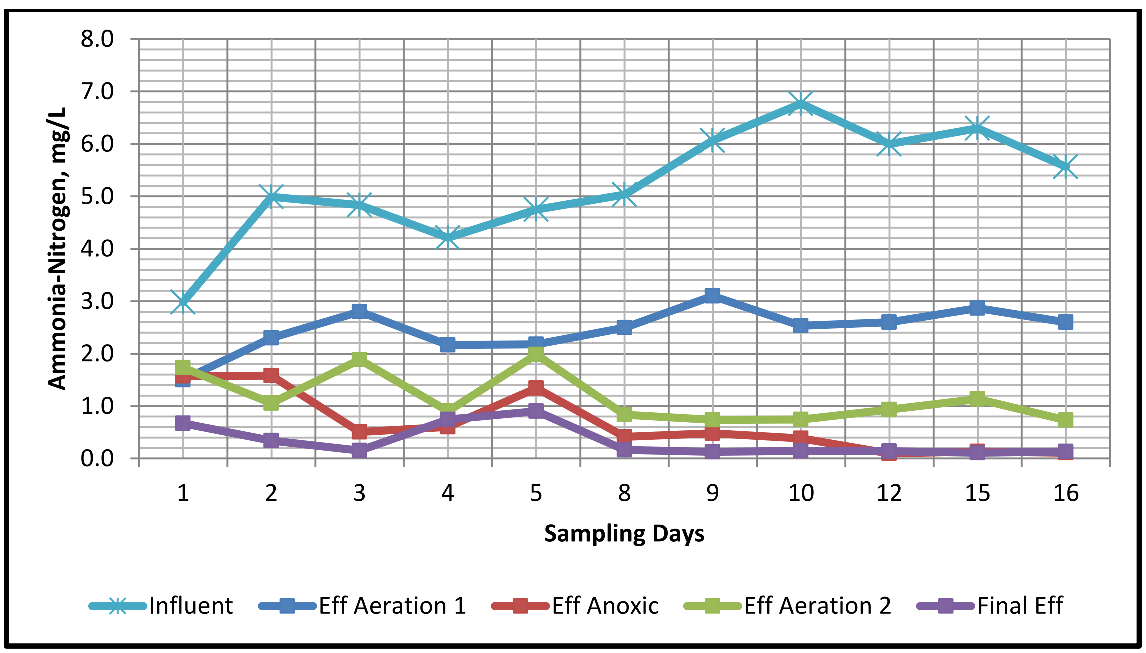


Figure 14: Effluent Ammonia Nitrogen for 10 m^3/min Incoming Load

As can be seen from the graph above, the data obtained are still fluctuating. This condition indicates that the reactor is still undergoing acclimatization period in which it is trying to adapt to the new incoming load. However, a clear pattern could still be seen from the graph. Effluent from both aeration tanks shows the highest amount of NH_3-N had presence, since ammonification process occurs rapidly in the tanks.

4.2 Removal of Nitrate

Test on ammonia-nitrogen are carried out based on Cadmium Reduction Method (Method 8039). The result of nitrate removal is presented as follows for 8 m^3/min influent loading is presented in Figure 15.

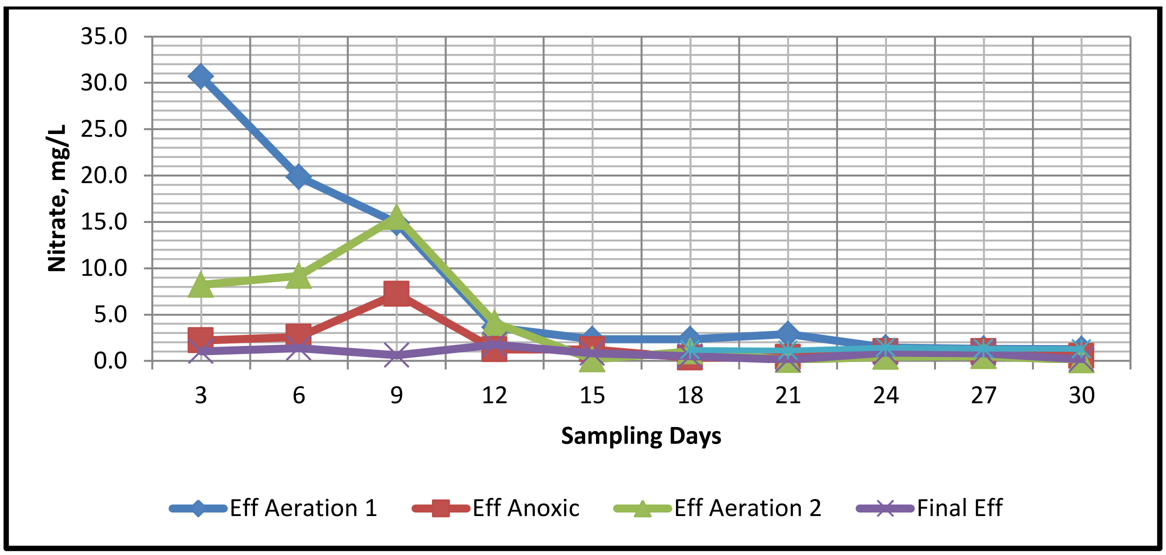


Figure 15: Effluent Nitrate for 8 m^3/min Incoming Load

Generally, effluent from first aeration tank has the highest amount of NO_3; except for when the reactor starts to stabilizes. This condition may happen due to the acclimatization period which the reactor is still undergoing or defect in preservation of NO_3 sample since the result will only be most reliable when samples are analyzed soon after collection. Theoretically, effluent 1 should have the highest amount of NO_3 as illustrated during the earlier sampling days because the completed ammonification process happened in the first aeration tank will produce high NO_3; and if nitrification haven't had the chance to occur.

On the other hand, effluent anoxic should have low NO_3 because it has been converted into N_2 in denitrification process; and it is reflected in the graph above. This means that the anoxic tank has successfully treated the NO_3 produced in the previous process. The NO_3 range in the effluent is between 1.00 mg/L to 7.5 mg/L with removal percentage efficiency as high as 95%; which occurs during second day of sampling.

As for effluent aeration 2, the NO_3 have quite similar but slightly lower ranges to effluent 1. This may be due to high-effectiveness of aeration tank 1 in treating ammonia; leaving lesser treating process to aeration tank 2. In final effluent, the NO_3 has been treated successfully in which the value did not exceed 2 mg/L. Such value is considered safe to be discharge since it is below than the DOE Standard A requirement; 20 mg/L.

Starting from 3rd December 2012, the incoming load imposed on the reactor had been increased to 10 m^3/min. The result of nitrate removal for 10 m^3/min influent loading is presented in Figure 16.

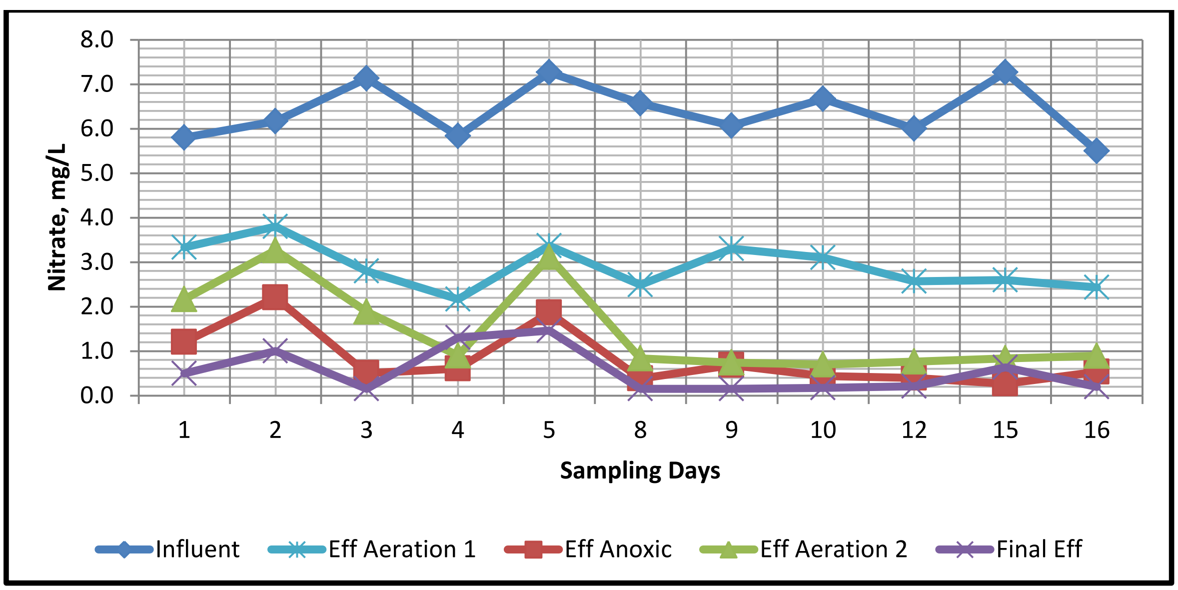


Figure 16: Effluent Nitrate for 10 m^3/min Incoming Load

As can be seen from the graph above, the data obtained are still fluctuating. This condition indicates that the reactor is still undergoing acclimatization period in which it is trying to adapt to the new incoming load. However, a clear pattern could still be seen from the graph. Effluent from both aeration tanks shows the highest amount of NH_3-N had presence, since denitrification process did not completely occurs in anoxic tank.

As a whole it can be clearly seen that both ammonia-nitrogen and nitrate has been treated to reach Standard A limit of Environmental Quality (Sewage) Regulation 2009.

CHAPTER 5

5.0 Conclusion and Recommendation

As Downing pointed out back in 1992, apart from the incorporation of more sophisticated instrumentation for in situ plant monitoring, and computerized control systems, the basic design for wastewater treatment plant had change little proceeding 80 or so years. This means that the basic concept is still there; we still apply activated sludge process in most of our system and we still use clarifier to separate supernatant from the settling sludge. As restricted as it sounds, there are still many space for development and modifications on the system. It requires creative human mind to innovate what is already there.

In this study, simple modification had been made to the arrangement of activated sludge process; where all the reaction happened in a single tank. The result obtained from the experiment conducted had shown that CEAR is capable in treating nitrogen from municipal wastewater. Although CEAR is only a laboratory-scale reactor, but it is believe with further modification, it can take up higher load and fit itself inside the industry. If so, that means the objective to design a reliable integrated wastewater treatment system is a success.

However, further modification could be done to improve CEAR such as the incoming organic load or flowrate should be varies and its capability should be recorded. This is crucial to determine the maximum capacity. Besides that, scapper should also be added at the bottom of clarifier for better sludge recycling.

CHAPTER 6

6.0 References

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APPENDIX I
EXCEL SHEET FOR NH_4-N

APPENDIX II
EXCEL SHEET FOR NO_3