MONITORING OF AMMONIA, TOTAL PHOSPHORUS AND NITRATE IN UNIVERSITI TEKNOLOGI PETRONAS SEWAGE TREATMENT PLANT

by:

ENGKU NUR NAZUHA BT CHE ENGKU ABDUL AZIZ

Dissertation submitted
in partial fulfillment of the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

JANUARY 2007

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Monitoring of Ammonia, Nitrate and Total Phosphorus in Universiti Teknologi PETRONAS Sewage Treatment Plant

by

Engku Nur Nazuha bt Che Engku Abdul Aziz

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

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

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2007

CERTIFICATION OF ORIGINALITY

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

ENGKU NUR NAZUHA BINTI CHE ENGKU ABDUL AZIZ

ABSTRACT

Malaysia does not regulate any standard limit for Total Phosphorus, Ammoniacal Nitrogen and Nitrate yet. The objective of this project is to characterize the concentration of Total Phosphorus, Ammoniacal Nitrogen and Nitrate in the wastewater samples taken at different points in the sewage treatment plant before and after the rectification of the sewage treatment plant. Whenever the sewage treatment plant was closed for system upgrading, the samples were taken at the inlet and outlet of the oxidation pond. Methodologically, the wastewater samples were collected by using grab sample method and auto-sampler device. Continuous experiments and tests were carried out to the wastewater samples to record the concentration of the abovementioned substances. The project was divided into two phases, which are before and after rectification of the sewage treatment plant. Overall, there were no significant improvements observed after the facility had been rectified. This indicated that the rectification works did not help in removing in the abovementioned contaminants. As a conclusion, the concentration of Ammoniacal Nitrogen and Nitrate in the final effluent met the standard limit set by the Environment Protection Agency (EPA). However, the concentration of Total Phosphorus in the final effluent was significantly and constantly high. The existing sewage treatment plant must be upgraded so that it could function to remove or reduce the concentration of Total Phosphorus to the accepted limit. The most cost effective method to remove or reduce ammonia and nitrate in the sewage treatment plant is by establishing nitrification and denitrification process within the system. Thus, design and operating strategies for nitrification and denitrification had been briefly discussed in Chapter 6. The design can be used by the future students to be applied to the current treatment system. Nitrification was achieved twice during the second phase of this project. During nitrification, the removal percentages of Ammoniacal Nitrogen to Nitrate were 87% and 92% respectively. By combining the nitrification results with the other team mates, it was concluded that, nitrification took place when the effluent is equivalent to TSS = 50 mg/L, TCOD = 32 mg/L, SCOD = 18 mg/L, TOC = 18 mg/L and MLSS = 1235 mg/L at 21/03/2007.

ACKNOWLEDGEMENTS

First and foremost, this progress report could not have been written without the blessing of Allah S.W.T, the Almighty. Thank you for guiding me towards completing this progress report successfully. No work can be done single handedly. It takes sincere efforts from many people together to finish this final year project successfully. My case is no such exception. I would first like to thank my supervisor, Dr. Shamsul Rahman bin Mohamed Kutty for introducing and giving me a chance to involve myself in the final year project under his supervision. I used to nearly swear that I won't take the wastewater topics for the final year project, but he has made my perception changed. If everyone feels disgusting in dealing with the wastewater like I used to be, then this environment will never be preserved as it should. Besides, this page is specifically designed to note my appreciation to those people who stand out most notably in my mind as contributing to the gist of this final year project, which are my team mates. They include Siti Hasna Malinda bt Halimansyah, Haryati bt Timan and Suraya bt Sabri Afifi. Last but not least, thank you to all people and parties involved, directly and indirectly. Thank you for being with me, for helping me and most of all is for supporting me in making my final year project successful.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1. BACKGROUND OF STUDY

Sewage treatment plant of Universiti Teknologi PETRONAS (UTP) is an extended aeration activated sludge system that consists of an inlet/primary screen, equalization tank, pumping station, secondary screens, grit chamber, grease chamber, two aeration tanks in parallel, two secondary clarifier in parallel, chlorine contact tank, Parshall flume, sludge thickener, sludge holding tank, sludge sand drying beds, dewatering facility and an air blower/control room.

At the beginning of its operation, the influent coming into the sewage treatment plant was only from the new academic complex. However, the facility is now receiving full organic load and hydraulic load with the decommissioning of the north and south oxidation ponds in August 2004 and October 2004, respectively. It served all the student villages, cafeterias, old University Sains Malaysia (USM) buildings and the new academic complex.

Sewage discharged from toilets, baths, showers, laundry and kitchen was disposed via sewers line into the sewage treatment plant. It is often contaminated with toxic organic and inorganic compound that may affect the ecological system. The contaminants include Total Phosphorus, Ammoniacal Nitrogen and Nitrate. Thus, it is crucial to treat the sewage first before it is being discharged out of the sewage treatment plant. Before implementing any treatment systems, the contaminants of the wastewater flowing into the treatment plant must be characterized first.

The characterization of the wastewater from the sewage treatment plant of UTP in terms of the concentration of Total Phosphorus, Ammoniacal Nitrogen, and Nitrate was the major concern to this final year project. The characterization process was carried out in two phases, which are before and after the sewage treatment plant was being rectified.

Effluent coming out from the end of the sewage treatment plant will directly channeled into the nearby river. Excessive amount of the abovementioned contaminants may enter the receiving stream and can lead to adverse ecological and human health effects. A major problem in the field of water pollution is eutrophication, which is defined as excessive plant growth or algae blooms. Eutrophication can result in deterioration in the appearance of previously clear waters, odor problems from decomposing plant growth, and a lower dissolved oxygen level, which can adversely affect the respiration of fish and other aquatic life (Stensel, 1991).

Besides, Nitrate and nitrite nitrogen constitute a public health concern, related primarily to *methemoglobinemia* and carcinogenesis. *Methemoglobinemia* is a disease primarily affecting infants and is often described as "Baby Blue Syndrome". The acute toxicity of nitrate occurs as a result of its reduction to nitrite, a process that can occur under specific conditions in the stomach and saliva. The nitrite ion formed oxidizes iron in the hemoglobin molecules from the ferrous to the ferric state. The resulting methemoglobin is incapable of exchanging oxygen. Suffocation is often accompanied by a bluish tinge to the skin. Death may occur if the condition is left untreated (Stensel, 1991).

In order to eliminate or at least to minimize the effects, the wastewater must first be treated within the sewage treatment plant, so that only acceptable amount of the abovementioned contaminants will be received by the river. The cheapest way to remove Ammoniacal Nitrogen and Nitrate is through the nitrification—denitrification process. So, the facility must be designed so that nitrification and denitrification will take place in the system. The designs of these two biological processes are included in this report for the future improvements for this project.

1.2. PROBLEM STATEMENT

After the decommissioning of the oxidation ponds, most of the raw sewage was "flushed through" the system with minimal treatment. With the increased loading, the sewage treatment plant should be sustainable enough to function not only as the receptor of the wastewater, but also to produce clean and treated effluent.

However, the existing sewage treatment plant had many deficiencies that need to be rectified. The defect was identified starting from the beginning of the facility, which is the primary screen that could not be closed completely. Grit chamber and chlorination tank have never been operated since a contractor took over the operation of the facility. Besides, the oil and grease trap, anoxic chamber, aeration tank and clarifier didn't function in such way they suppose to be.

All these defects will absolutely affect the operation and performances of the sewage treatment plant, where contaminants like Total Phosphorus, Ammoniacal Nitrogen, and Nitrate cannot be removed efficiently. This situation may lead to some environmental problems such as eutrophication that can kill the aquatic life, health problem among the human beings due to direct contact with the contaminated receiving stream, as well as bad quality to the drinking water.

Miscommunication with the contractor had become a major constraint during the analysis of the wastewater sample. In certain aspects, the operators needed to follow the instructions issued by the contractor company. For an instance, the operators wasted the sludge once a week, while the project required the sludge to be kept to maintain the amount of MLVSS in the system.

The other constraint in the characterization process is that, Malaysia does not regulate any discharge limits for Total Phosphorus, Ammoniacal Nitrogen, and Nitrate yet. So, every analysis made to the wastewater samples, comparisons and conclusion could not be made whether the abovementioned contaminants were meeting the limit or not.

1.3. OBJECTIVES AND SCOPE OF STUDY

UTP Policy is to strive for excellence in all its activities including health, safety and environment, where it shall take proactive steps towards the conservation and preservation of the environment. The prime objective of this project is to characterize the wastewater samples from UTP sewage treatment plant before and after rectification was made to the current system of the facility. The characterization is in term of the amount of Total Phosphorus, Ammoniacal Nitrogen and Nitrate available in the samples. The results of the characterization can be used for the future works to remove of the abovementioned contaminants from the sewage system.

For the first phase of this project, the characterization process was carried out using samples taken from the sewage treatment plant that has not been rectified yet. The characterization process will be continued until the second part of the project, but this time, the characterization process was carried out using samples taken from the sewage treatment plant that has been rectified.

Besides, the UTP sewage treatment plant has to be designed so that nitrification and denitrification will occur in the system. Nitrification plays an important role in the removal of nitrogen from municipal wastewater. If a facility is required to nitrify, denitrification should be considered as well as well. This process will make a plant run more efficiently, thus saving money, energy, and lowering sludge production by 5%.

Finally, the objective of this project is to identify the most optimum method to remove the high amount of Total Phosphorus available in the wastewater. The selection of the method is based on three main criteria, which are: (i) adapt easily with the current system of UTP sewage treatment plant, (ii) low cost, and (iii) easy maintenance.

CHAPTER 2
LITERATURE REVIEW

2.1. TOTAL PHOSPHORUS

Phosphorus is the eleventh most abundant element on earth.. It is an essential element in the metabolism of organic organisms, especially to the growth of plants. Therefore it is known as nutrient.

Phosphorus originates in wastewater from the following sources: (i) the carriage water (usually minor), (ii) fecal and waste materials, (iii) industrial and commercial uses and (iv) synthetic detergents and household cleaning products. (Sedlak, 1991, p.91).

Good phosphorus is called Phosphites and it is widely used for fertilization and the soil regeneration. In the other way around, bad phosphorus is called Phosphates. Only a minimal concentration is necessary to achieve the optimum operation of biological treatment systems (Sedlak, 1991). Excessive amount of Phosphates can cause the alga growth, eutrophication and the dissolved oxygen depletion.

2.1.1. Forms of Phosphorus

Phosphorus in natural waters is divided into three component parts: (i) soluble reactive phosphorus (SRP), (ii) soluble unreactive or soluble organic phosphorus (SUP), and (iii) particulate phosphorus (PP). The sum of SRP and SUP is called soluble phosphorus (SP), and the sum of all phosphorus components is termed total phosphorus (TP). Soluble and particulate phosphorus are differentiated by whether or not they pass through a 0.45 micron membrane filter (Rigler, 1973).

2.1.2. Phosphorus Removal Methods

Phosphorus concentration in the final effluent of sewage treatment plant is governed by the concentration of the suspended solids, which averages 3.5% of total phosphorus. Typically, the legal limit for effluent in USA is 10 mg/L SS (EPA, 1995). However, a new regulation of a certain regions in USA requires the limit to be 1 mg/L. Since it is not possible to achieve the 1 mg-/L effluent limit with conventional biological wastewater treatment processes, additional or alternative treatment methods must be employed. This can be achieved through three treatment methods, which are: (i) physical treatment, (ii) chemical treatment, and (iii) biological treatment.

2.1.2(a) Physical Treatment

Two types of physical treatment technologies that can be applied in removing Total Phosphorus from the wastewater are: (i) filtration for particulate phosphorus and (ii) membrane technologies.

Typically, particulate forms of phosphorus will contain bacteria, algae, detritus, and inorganic particulates such as clays, smaller zooplankton, and occasionally, larger zooplankton, sediments, or large plant material (Carlson, 1996). All these fractions will be captured on the filter, preventing them from passing into the treated water stream. However, filtration method cannot be used to capture tiny sediments.

Membrane technologies have been one of the growing interests for wastewater treatment in general, and particularly for the phosphorus removal to replace the conventional clarification stage. After pre-treatment (e.g. screening), raw water flows into the aeration tank. Membrane filtration then separates the purified water from the activated sludge. The treated water is drawn off using a low-pressure pump. The sludge retained by the membrane creates a sludge cake outside the membrane surface. The excess sludge is directly removed from the biological tank for dewatering.

2.1.2(b) Chemical Treatment

Chemical precipitation has long been used for the phosphorus removal. Chemicals that are most often employed in this method are compounds of calcium, aluminum, and iron (Tchobanoglous et al., 2003). Chemical addition points include prior to primary settling, during secondary treatment, or as part of a tertiary treatment process (Neethling and Gu, 2006).

Problems associated with chemical precipitation include high operating costs, increased sludge production, sludge with poor settling and dewatering characteristics, and depressed pH. A major concern with chemical precipitation for phosphorus removal continues to be the additional sludge that is produced. This can be dramatic, especially if the method selected is lime application during primary treatment (Tchobanoglous et al., 2003). Use of alum after secondary treatment can be predicted to produce much less sludge, but the increase could still be problematic (Strom, 2006a).

2.1.2(c) Biological Treatment

Two types of biological treatment technologies that can be applied in removing Total Phosphorus from the wastewater are: (i) assimilation and (ii) enhanced biological phosphorus removal (EBPR).

Biological assimilation incorporates phosphorus as an essential element in biomass, particularly through the growth of photosynthetic organisms, such as plants, algae, and some bacteria, such as cyanobacteria. Traditionally, this was achieved through treatment ponds containing planktonic or attached algae, rooted plants, or even floating plants (e.g., water hyacinths, duckweed). It is necessary to remove the net biomass growth in order to prevent eventual decay of the biomass and re-release of the phosphorus (Strom, 2006a).

The greatest interest and most recent progress have been made in EBPR. This is because of its potential to achieve a very low (<0.1 mg/L) levels phosphorus in the effluent at modest cost and with minimal additional sludge production. Removal of traditional carbonaceous contaminants (BOD), nitrogen, and phosphorus can all be achieved in a single system.

Phosphorus appears in wastewater as orthophosphate, polyphosphate and organically bound phosphorus, the last two components accounting usually for up to 70 % of the influent phosphorus. Microbes utilize phosphorus during cell synthesis and energy transport. As a result, 10 to 30 % of the influent phosphorus is removed during traditional mechanical/biological treatment (Metcalf and Eddy, 1991).

When enhanced phosphorus removal is desired, the process is modified, so that the sludge is exposed to both anaerobic and aerobic conditions. Then certain microorganisms, capable of storing phosphorus in the form of polyphosphates, metabolize it for energy production and cell synthesis, resulting in the removal of phosphorus from the system through the waste activated sludge.

2.2. NITROGEN

Nitrogen is an essential ingredient in the formation of proteins for cell growth. It is also categorized as a nutrient as every living organism needs some form of nitrogen to survive. However, excess nitrogen discharged into the waterways can contribute to the following consequences: (i) nitrogen in the form of ammonia is toxic to fish, (ii) accelerate the eutrophication in waters, stimulate the growth of algae and aquatic plants, resulting in the death of fish, and deplete dissolved oxygen in waters, exhibiting toxicity toward aquatic life, (iii) aesthetically unsightly as presence of algae and aquatic plants may interfere with beneficial uses of water bodies such as recreation, water supplies and fish propagation (Stensel, 1991).

2.2.1. Forms of Nitrogen

In wastewater, nitrogen appears in four types: (i) organic nitrogen, (ii) ammonia, either as NH_3 gas or NH_4^+ ions, (iii) nitrite and nitrate ions, and (iv) Total Kjeldahl Nitrogen. Ammonia, nitrite and nitrate are all classified as inorganic nitrogen. These different forms constitute the total nitrogen content.

2.2.1(a) Organic Nitrogen

Nitrogen is incorporated into organic compounds and inorganic compounds due to its ability to easily form chemical bonds with other elements such as carbon, hydrogen, and oxygen. When elements bond together, compounds are formed (Gerardi, 2002).

Urea and proteins are the main sources of nitrogen in wastewater. These include the product of our eating habits and food preparation, body exudates washed off in the bath or shower and products washed from clothes. Cleaning chemicals also contribute organic compounds in varying amounts. Bacterial decomposition of proteinaceous matter and hydrolysis of urea transform this organic nitrogen to the ammonium ion (Sedlak, 1991).

2.2.1(b) Ammonia and Ammonium Ions

At the beginning of the main sewer line, nitrogen is mostly in the form of organic nitrogen. Through a process called hydrolysis, organic nitrogen begins conversion to ammonia or ammonium. The form of nitrogen depends on pH and temperature. When the pH of the wastewater is acidic or neutral, the majority of the nitrogen is ammonium (NH_4^+). When the pH increases over 8.0, the nitrogen is mostly ammonia (NH_3).

The difference between ammonia and ammonium is that, ammonia is in the form of gas, while ammonium is in the form of ions. In water a very small percentage of NH_3 is converted into the ammonium cation (NH_4^+).

Substances containing ammonia are called *ammoniacal*. Ammonium ions are the principle inorganic compound in domestic watewarer (Gerardi, 2002). However, in the activated sludge process, nitrification requirement is usually issued as an ammonia (NH_3) or Ammoniacal Nitrogen (NH_3 –N) discharge limit (Gerardi, 2002).

2.2.1(c) Nitrite and Nitrate

Nitrite ion is the product of the oxidation of the ammonium ion by the bacteria, which is also called as nitrification. When ammonium ions are oxidized, bacteria obtain energy and release nitrite ions in the aeration tank (Gerardi, 2002).

Nitrification is the biological conversion of ammonium to nitrate nitrogen, and is a two-step process. First, bacteria known as *Nitrosomonas* convert ammonia and ammonium to nitrite. Next, bacteria called *Nitrobacter* finish the conversion of nitrite to nitrate. The reactions are generally coupled and proceed rapidly to the nitrate form; therefore nitrite levels at any given time are usually low (Gerardi, 2002).

2.2.1(d) Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) is the combination of ammonia and organic nitrogen in biological wastewater treatment.. Denitrification requirement in activated sludge system is usually issued as total nitrogen or Total Kjeldahl Nitrogen (TKN) discharge limit (Gerardi, 2002)

2.2.2. Nitrogen Cycle

Nitrogen cycle is the process whereby nitrogen passes from the atmosphere into living things and back into the atmosphere (Skinner, 1999). Four processes that participate in the nitrogen cycle are: (i) nitrogen fixation, (ii) assimilation, (iii) ammonification, (iv) nitrification, (v) anaerobic ammonium oxidation, and (vi) denitrification.

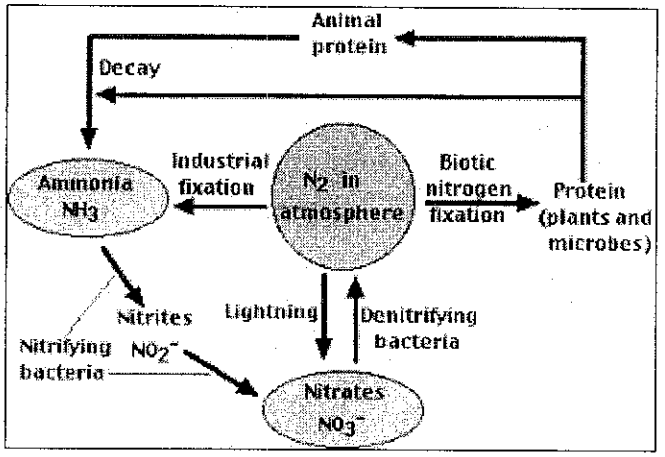


Figure 1: Nitrogen Cycle (Smill V., 2000)

2.2.2(a) Nitrogen Fixation

Nitrogen fixation is the process of converting the molecular form of nitrogen (N_2) from the atmosphere into nitrogen compounds, such as ammonia, nitrate and nitrite so that it can be used for other chemical processes.There are four ways to convert N_2 into more chemically reactive forms, which are: (i) biological fixation, (ii) industrial N-fixation, (iii) combustion of fossil fuels, and (iv) photons and lightning (Smil, 2000).

2.2.2(b) Assimilation

Assimilation is the process by which plants and animals incorporate the nitrate and ammonia formed through nitrogen fixation and nitrification. Plants take up these forms of nitrogen through their roots, and incorporate them into plant proteins and nucleic acids. Animals are then able to utilize nitrogen from the plant tissues (Smil, 2000).

2.2.2(c) Ammonification

Ammonification is the decomposition process of organic nitrogen back to ammonium, which is carried out mainly by bacterial and fungal decomposers. Because it has a positive charge, ammonium can be adsorbed and fixated onto the negatively charged soil particles or be taken up by plants (Smil, 2000).

2.2.2(d) Nitrification

Nitrification is a process of converting ammonia to nitrites, followed by the oxidation of these nitrites into nitrates. It is performed primarily by soil-living bacteria and other nitrifying bacteria. The primary stage of nitrification is the oxidation of ammonia (NH_3), performed by bacteria such as the *Nitrosomonas* species. This bacteria converts ammonia to nitrites (NO_2^-). Other bacterial species, such as the *Nitrobacter*, are responsible for the oxidation of the nitrites into nitrates (NO_3^-) (Smil, 2000).

2.2.2(e) Anaerobic Ammonium Oxidation

This process is commonly known as *Anammox*, the latest addition to the knowledge on the nitrogen cycle. In this type of biological process, nitrite and ammonium are converted directly into dinitrogen gas. This process makes up a major proportion of dinitrogen conversion in the oceans. The chemical equation for this process can be expressed as ($NH_4^+ + NO_2- \rightarrow N_2 + 2H_2O$).

2.2.2(f) Denitrification

Denitrification is the reduction of nitrates back into nitrogen gas (N_2), completing the nitrogen cycle. This process is performed by bacterial species such as the *Pseudomonas* and *Clostridium* (Smil, 2000). This process only occurs where there is little to no oxygen. Some bacteria can obtain the oxygen they need for metabolism from nitrate rather than from oxygen under anaerobic conditions (Campbell & Reece, 2002).

2.2.3. Effects of Nitrogen-Containing Compounds

Nitrogen-containing compounds act as nutrients in streams and rivers. The toxicity of ammonia solutions does not usually cause problems for humans and other mammals, as a specific mechanism exists to prevent its build-up in the bloodstream. Ammonia is converted to *carbamoyl phosphate* by the enzyme *carbamoyl phosphate synthase*, and then enters the urea cycle to be either incorporated into amino acids or excreted in the urine (Swotinsky, 1990). However fish and amphibians lack this mechanism, as they can usually eliminate ammonia from their bodies by direct excretion. Ammonia even at dilute concentrations is highly toxic to aquatic animals, and for this reason it is classified as dangerous for the environment.

Nitrate reactions in fresh water can cause oxygen depletion. Thus, aquatic organisms depending on the supply of oxygen in the stream will die. Nitrite can produce a serious condition in fish called "brown blood disease." It also reacts directly with hemoglobin in human blood and other warm-blooded animals to produce methemoglobin that destroys the ability of red blood cells to transport oxygen. This condition is especially serious in babies under three months of age. It causes a condition known as *methemoglobinemia* or "blue baby" disease. Water with nitrite levels exceeding 1.0 mg/l should not be used for feeding babies. Nitrite levels below 90 mg/l and nitrate levels below 0.5 mg/l seem to have no effect on warm water fish (Stensel, 1991).

Due to the abovementioned potential effects, the Environment Protection Agency (EPA) has regulated a Drinking Water Standard to be 10 mg/L for nitrate and 1 mg/L for nitrite.

2.2.4. Removal Methods

The cheapest way to prevent ammonia, nitrate and nitrite from entering the receiving stream is by establishing the nitrification and denitrification process in the sewage treatment plant. Through nitrification, ammonia is fully converted into nitrate, leaving little or no remaining ammonia or intermediate nitrite in the effluent. Then, the nitrate can be converted to a harmless nitrogen gas through the denitrification process. So, all these three contaminants are removed within the treatment system. The operating strategy for nitrification and denitrification are discussed in details under Chapter 6.

2.3. BIOLOGICAL NUTRIENT REMOVAL

Consequences of discharge of treated effluent containing significant concentration of nitrogen and phosphorus include: (i) Nitrogen in the form of ammonia is toxic to fish. (ii) Discharge of nitrogen and phosphorus will accelerate the eutrophication that exhibites toxicity toward aquatic life. (iii) Aesthetically unsightly as presence of algae and aquatic plants may interfere with beneficial uses of water bodies such as recreation and water supplies. Principle of the Biological Nutrient Removal (BNR) is to use the microorganisms to remove nitrogen and phosphorus.

2.3.1. Nitrogen removal

There are three major approaches to the biological nitrogen removal, which are: (i) separate stage carbon oxidation, nitrification, and denitrification, (ii) combined carbon oxidation and nitrification but separate stage denitrification, and (iii) combined carbon oxidation, nitrification, and denitrification. All of the options are illustrated in Figure 2

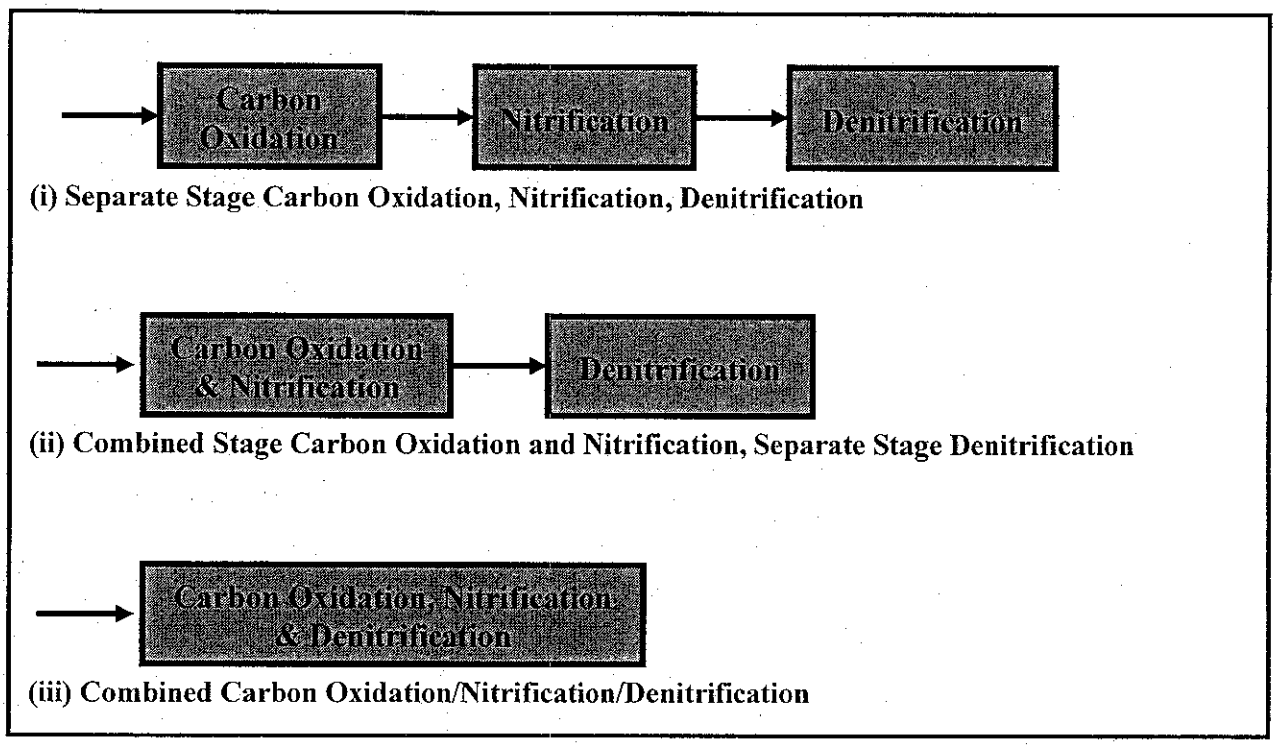


Figure 2: Three Major Approaches to Biological Nitrogen Removal (Sedlak, 1991)

Separate stage nitrification involves the use of two biological processes in series. The first one removes carbonaceous biochemical oxygen demand (BOD), and the second one is used to nitrify the removal of low BOD effluent from the first process. In a combined carbon oxidation and nitrification system, the removal of BOD and nitrification are accomplished in a single biological process. Both nitrification approaches have been used successfully to nitrify municipal wastewaters. The choice between them depends primarily on cost factors (Sedlak, 1991). Two options are available to accomplish denitrification, which are: (i) separate stage denitrification and (ii) single sludge denitrification.

Separate stage denitrification involves the use of a separate biological process to remove nitrate-nitrogen from the effluent of an upstream biological nitrification process (Sedlak, 1991). Either a separate stage nitrification system (Figure 8i) or a combined carbon oxidation and nitrification system (Figure 8ii) may be used in this system. However for separate stage denitrification, both stages require the removal of carbonaceous BOD removal. Thus, it is necessary to add an external carbon source to the wastewater. Methanol is normally used for this purpose.

Two different process options are typically used for separate stage denitrification, which are: (i) suspended growth and (ii) attach growth.

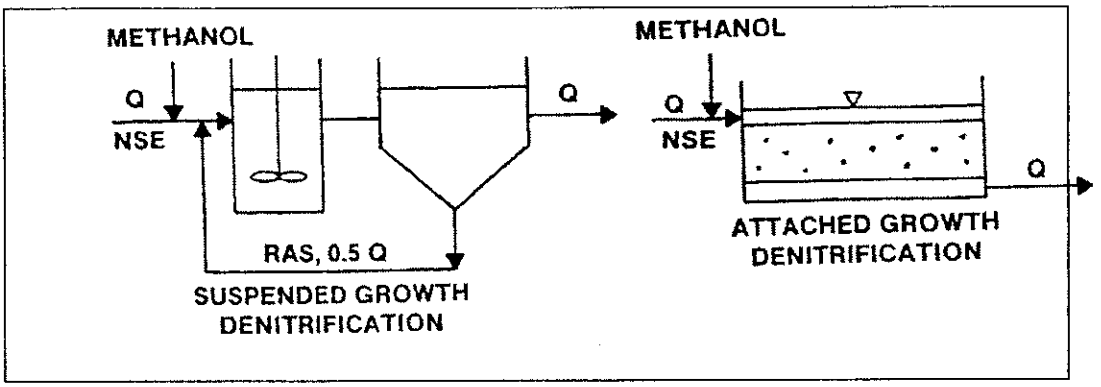


Figure 3: Separate Stage Nitrogen Removal System (Sedlak, 1991)

In order to avoid the operating cost associated with the continual addition of methanol required by the separate stage denitrification process, single sludge denitrification process has been developed, in which the carbon source present naturally in the wastewater to sustain the denitrification process. The carbon source can be either: (i) endogenous decay of the activated sludge microorganisms or/and (ii) wastewater influent to the secondary treatment system. The biological reactor consists of aerobic zones for nitrification and anoxic zone for denitrification. This system is easily incorporated into an existing activated sludge plant. However, it has the disadvantages of a very low denitrification rate due to the relatively low availability of carbon from endogenous decay and in the secondary effluent. Besides, it has the potential to release some Ammoniacal Nitrogen due to the decay of biological solids (Sedlak, 1991).

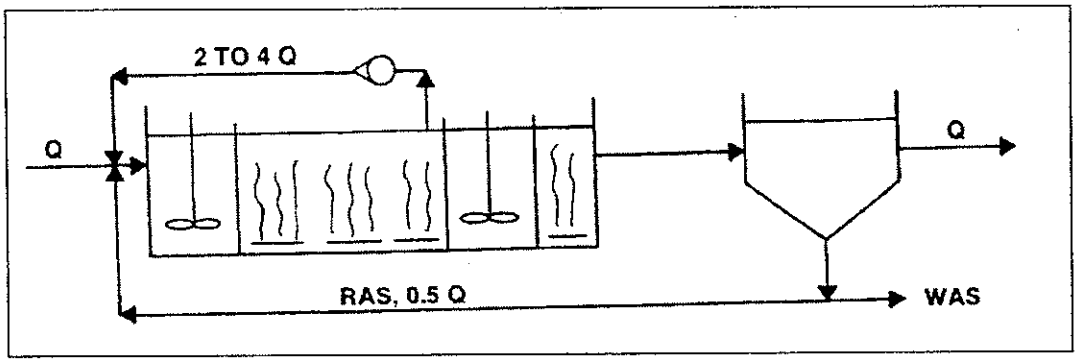


Figure 4: Single Sludge Nitrogen Removal System (Sedlak, 1991)

The selection of a treatment process for nitrogen removal takes into accounts three major factors, which are: (i) performance, (iii) operation and maintenance, and (iv) operational cost.

2.3.1(a) Performance

Both processes can achieve high removals of nitrogen, which is between 85 to 95 percent. Similar quality of effluent can also be achieved by both processes. However, the single sludge process does not enhance total suspended solid (TSS) in the effluent from the process. On the other hand, separate stage process may either impede or enhance the control of TSS in the effluent.

2.3.1(b) Operation and Maintenance

For the single sludge system, the denitrification process is controlled by the rate of nitrate recycle in the mixed liquor to the first anoxic zone. The primary operation that controls the performance of the separate stage system is the rate of methanol addition. Single sludge system does not require the use of external chemical, while the separate system stage involves the storage and handling of methanol. Methanol is flammable, explosive, and hazardous to breath, thus special procedures are required for its safe storage and handling (EPA, 1995).

2.3.1(c) Operational Cost

Two major operational cost items for nitrogen removal systems are electrical power and chemicals. Single sludge system consumes more power due to the various recycling processes. However, since UTP owns its own power generator (Gas District Cooling), where it utilizes gas obtained from PETRONAS to generate the power system throughout UTP, the cost for the electrical power is significantly reduced, theoretically.

As for the separate stage denitrification system, the primary operating cost is for the methanol. Operating labor may also be greater since more unit processes must be operated in this system. Due primarily to the cost of the methanol, separate stage denitrification systems generally have higher operating cost than the single sludge system. Table 6.1 provides the simplified qualitative comparison of two denitrification approaches. The plus (+) sign indicates a favorable characteristic of the particular option, and the minus (-) sign indicates an unfavorable characteristic.

Table 2.1: Denitrification Process Comparison

Factor	**Characteristics**	**Separate Stage**	**Single Sludge**
Performance	Nitrogen removal	+	+
	TSS control	+ / - / 0	0
Operation and Maintenance	Control	+	+
	Operations	0	+
	Chemical storage and handling	–	+
	Maintenance	0	0
Cost	Operating	Higher	Lower

The discussions above suggest that single sludge biological nitrogen removal system will be applied for the UTP sewage treatment plant. The system is generally the most cost-effective and the most desirable from an operational standpoint. It has an added advantage of using technology familiar to operators of typical activated sludge system. A separate stage system might be suitable if the facility is required to meet stringent effluent suspended solids criteria.

2.3.2. Phosphorus Removal

Phosphorus removal has three steps. First, the microorganism will release phosphorus in the anaerobic zone, with the assimilation of volatile fatty acids (VFA). Secondly, in the aerobic zone, the microorganisms will utilize the VFA and at the same time uptake a significant amount of phosphorus that is more than what they release in anaerobic zone. This is also called "luxury uptake". Thirdly, a certain amount of activated sludge (the microorganisms) will be removed, preferably everyday out of the biological treatment system.

The wasted activated sludge (WAS) will go to digesters for anaerobic digestion and then be trucked out. In short, the phosphorus in influent is absorbed by microorganisms and removed from the process and the treatment plant. Microorganisms also use some phosphorus for their reproduction.

The VFA exists in the raw influent. If it is not enough, fermentation of primary sludge is used to generate some VFA. Without sufficient VFA, the release of phosphorus in anaerobic zone will not take place well, and eventually the microorganisms will not uptake a lot of phosphorus in aerobic zones, and a lot of phosphorus will go out in the effluent, resulting in high total phosphorus in effluent.

Aerobic microorganisms in the presence of dissolved oxygen (DO) and nitrate impact the phosphorus in anaerobic zone as they compete with phosphorus-removing microorganisms for the use of VFA. 2.3 g VFA will be consumed for each g of DO; about 5 g VFA will be consumed for the denitrification of each g nitrate (Stensel, 1991; Metcalf and Eddy, 2003). Thus, it is important to minimize the DO in the raw influent and in the return activated sludge (RAS). It is also important to minimize the nitrate in the final effluent and in the RAS.

Conventional activated sludge treatment was initially developed to remove carbonaceous and nitrogenous biochemical oxygen demand (BOD) from sewage. Activated sludge systems have been modified to enhance biological phosphorus removal by providing aerated and non-aerated reactors in series, along with various internal recycle systems (Sedlak, 1991). This cause the system configurations had increased in complexity and the number of design parameters involved in the processes has also increased. Therefore, additional wastewater characteristics are necessary to evaluate the feasibility of biological phosphorus removal and to design a biological treatment process for phosphorus removal.

The wastewater characteristics are emphasized on: (i) determination of COD fractions of wastewater, (ii) determination of kinetic parameters, and (iii) determination of nitrification and denitrification rates. These parameters can be used in biological nutrient removal process design computer programs such as ENBIR, which is based on the model developed by Ekama et al. (1984), or BIOSIMTM, a menu-driven personal computer-based simulation program that solves the equations of the International Association on Water Pollution Research and Control (IAWPRC) (now the International Association on Water Quality, IAWQ) task group model for activated sludge systems extended for enhanced BPR (EnviroSim Associates 1993).

These models can be used to determine the process volume and to evaluate the effects of COD loading, biomass concentration, and sludge age on the phosphorus and nitrogen removal efficiencies. These methods will allow smaller wastewater treatment plants or industries to evaluate the feasibility of BPR of their wastewater with minimum cost.

2.3.2(a) COD Fractions of Wastewater

Before biological phosphorus removal process design models can be used, it is necessary to determine the various fractions of the influent COD. These fractions are needed to accurately describe the behavior of the biological phosphorus removal process. Figure 5 shows the subdivisions as presented by Ekama et al. (1984).

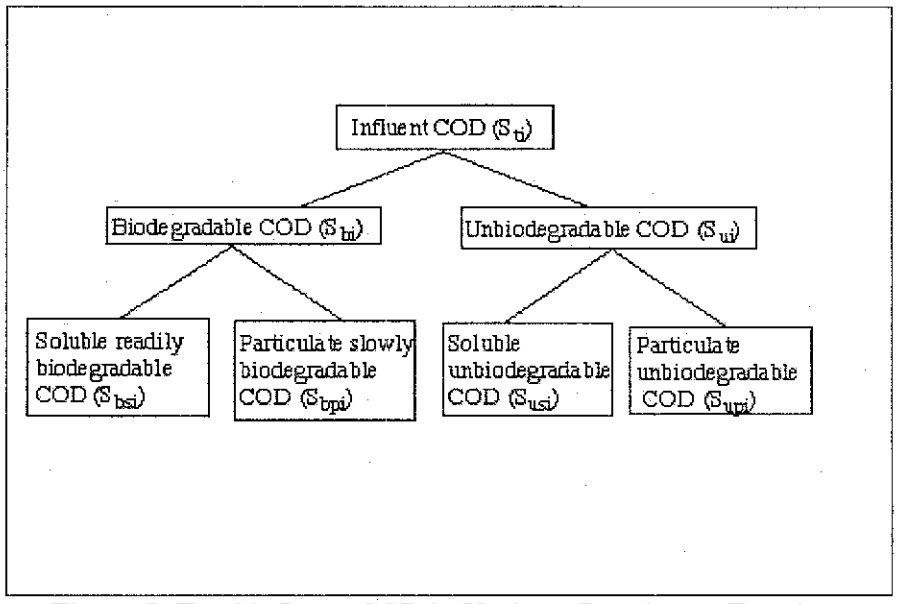


Figure 5: Total influent COD in Various Constituent Fractions

The first major subdivision of the total influent COD (S_{ti}) is into biodegradable (S_{bi}) and unbiodegradable (S_{ui}) fractions.

The unbiodegradable COD (S_{ui}) consists of two fractions: unbiodegradable soluble COD (S_{usi}) and unbiodegradable particulate COD (S_{upi}). S_{usi} will pass through the treatment process and be discharged with the effluent. S_{upi} is enmeshed in the activated sludge. The mass of S_{upi} entering the system will equal the mass leaving the system via activated sludge wasting. Thus, S_{upi} has the principal effect of increasing the mixed liquor suspended solid (MLSS) concentration.

The biodegradable COD fraction (S_{bi}) is divided into readily biodegradable soluble COD (S_{bsi}) and slowly biodegradable particulate COD (S_{bpi}). S_{bsi} is taken up by activated sludge in a matter of minutes and metabolized, giving rise to a high unit rate of oxygen demand for synthesis. S_{bpi} must first be sorbed onto the microorganisms, and broken down to simple chemical units by extracellular enzymes before finally being metabolized by the microorganisms.

The soluble readily biodegradable fraction, S_{bsi}, plays an important role in biological phosphorus removal because phosphorus-removing microorganisms sequester volatile fatty acids (VFAs) in the S_{bsi} fraction, using the energy obtained from cleavage of a phosphate bond of the polyphosphates stored within the biomass.

In the anaerobic zone of a BPR process, only the readily biodegradable soluble COD (S_{bsi}) component is susceptible to fermentation to form VFAs within the short detention time (1 - 2 hours). In seeking an explanation for the behavior of different phosphorus release patterns, Ekama et al. (1984) found that phosphorus release increased as the readily biodegradable soluble COD (S_{bsi}) increased. Ekama et al. (1984) concluded that a prerequisite for phosphorus release in the anaerobic zone is that the concentration of readily biodegradable soluble COD (S_{bsi}) surrounding the microorganisms in the anaerobic zone must exceed approximately 25 mg/L. Therefore, S_{bsi} is thought to be a very important wastewater characteristic in the process of biological phosphorus removal.

The experimental procedures for determining the COD fractions defined above are attached in the Appendices.

2.3.2(b) Kinetic Parameters

The important kinetic parameters required for biological phosphorus removal process design are listed in Table 2.2. The experimental procedures for determining the biological kinetic parameters defined above are attached in the Appendices.

Table 2.2: Important Kinetic Parameters in Biological Phosphorus Removal

Parameter	Descriptions
Y	The cell yield coefficient defined as the mass of activated sludge or biomass produced per unit of substrate removed (mg VSS/mg COD).
k_d	The endogenous decay rate or mass of cells lost during endogenous respiration per unit of time (^{1}/day).
μ_{max}	The maximum specific growth rate. The specific growth rate, μ, is the rate of growth per unit of time ($^1/_{day}$).
K_s	The half-saturation constant or shape factor of the Monod equation. K_s equals the substrate concentration (mg/L) at which μ equals 1/2 of μ_{max}.
q_N	The specific nitrification rate, which is measured by rate of NO_2^- +NO_3^- formation (mg NO_2^- + NO_3^--N/mg VSS/hour).
q_D	The specific denitrification rate, which is measured by rate of NO_2^- +NO_3^- removed (mg NO_2^- + NO_3^-N/mg VSS/hour).

2.3.2(c) Nitrification and Denitrification Rates

Although the kinetics of nitrification have been modeled by zero-order and first-order reactions, a Monod type equation expressing the effect of substrate concentration on the growth of nitrifying bacteria has been found to fit the data in most nitrification studies (Barnes and Bliss 1983). The effect of individual independent limiting substrates on the specific growth rate can also be expressed. Thus, the effects of NH4+-N and dissolved oxygen on the growth rate of Nitrosomonas are described as follows:

$$\mu_{corrected} = (\mu_{max}) \left(\frac{NH_4+}{K_N + NH_4+} \right) \left(\frac{DO}{K_{DO} + DO} \right)$$

where ;

μ_N = specific growth rate of *Nitrosomonas* (nitrifiers) (^{1}/hour);

μN_{max} = maximum specific growth rate of *Nitrosomonas* (nitrifiers) (^{1}/hour);

K_N = half-saturation constant for NH_4^+- N (mg/L);

DO = dissolved oxygen (mg/L); and

K_o = half-saturation constant for oxygen (mg/L).

Carlson (1971) and Christensen and Harremoes (1977) suggested that the kinetic reaction for denitrification by activated sludge can be expressed by:

$$\mathbf{dN/dT = q_D X}$$

where;

dN/dt = denitrification rate (mg NO_2^-+NO_3^--N/L/hour);

N = nitrite plus nitrate concentration (mg-N/L);

t = time (hour); and

q_D = specific denitrification rate (mg N/mg VSS/hour).

The experimental procedures for determining the nitrification and denitrification are attached in the Appendices.

2.4. DESIGN OF NITRIFICATION AND DENITRIFICATION

2.4.1. Introduction

Nitrification is a process of converting ammonia to nitrites by microorganism known as *Nitrosomonas*, followed by the oxidation of these nitrites into nitrates by microorganisms known as *Nitrobacter*.

Nitrification plays an important role in the removal of nitrogen from municipal wastewater (, 1991). There are several physical and chemical technologies available for nitrogen removal. This chapter provides an overview on the design of biological nitrogen removal only, which is via nitrification process due to its cost-effectiveness and ease of use.

Biological removal of nitrogeneous compounnds from typical municipal wastewater involves three basic processes, which are: (i) synthesis, (ii) nitrifcation, and (iii) denitrification. Synthesis is termed as incorporation of nitrogen into mirobial mass as a result of cell growth (Sedlak, 1991).

Denitrification is the reduction of nitrates back into nitrogen gas (N_2), completing the nitrogen cycle. If a sewage treatment plant requires nitrification, denitrification should be considered as well. Nitrification results in a loss of alkalinity and denitrification returns the alkalinity back to the activated sludge process. Other benefits of denitrification include protecting the quality of the receiving water, permit compliance, strengthening of the floc particles, control of undesired filamentous growth, and cost-savings for the treatment or degradation of cBOD (Gerardi, 2002).

2.4.2. Operating Strategy for Nitrification

This section discusses in brief the steps and calculation needed for nitrification to occur in the activated sludge system. The steps include: (i) calculation of oxygen required for nitrification, (ii) calculation of alkalinity required for nitrification, (iii) calculation of target Mean Cell Residence Time, (iv) calculation of current actual Mean Cell Residence Time, and (v) consideration of other nitrification factors.

2.4.2(a) Calculation of Oxygen Requirement for Nitrification

Nitrification starts when *Nitrosomonas* bacteria convert the ammonium ions to nitrite ions. During this stage, the amount of oxygen and alkalinity required to complete this process are 3.43 lb/lb N oxidized and 7.14 lb as $CaCO_3$/lb N oxidized respectively.

At the second stage, *Nictobacter* bacteria convert the nitrite ions produced from the first stage to nitrate ions. During this stage, the amount of oxygen required to complete this process is 1.14 lb/lb N oxidized. No alkalinity is required in this stage. Therefore, for both reactions, the total of oxygen and alkalinity required are 4.57 lb/lb N oxidized and 7.14 lb as $CaCO_3$/lb N oxidized respectively.

In order to calculate the oxygen requirement for nitrification, five data are required, which are: (i) flow rate of influent, (ii) TKN concentration in influent, (iii) BOD_5 concentration in influent, (iv) percent of TKN removal, and (v) percent of BOD_5 removal. The following equation is used in order to determine the oxygen required for the nitrification process. The result of is reported in the unit of pounds of oxygen per day (lb O_2/day).

$$\mathbf{O_2 = (Q_{influent})\ (TKN_{influent})\ (100\% - \%\ TKN\ removal)\ (4.57\ lbs\ of\ O_2)\ (8.34)} \quad (1)$$

2.4.2(b) Calculation of Alkalinity Required for Nitrification

As mentioned in section 6.5.1, the total alkalinity required for the nitrification process is 7.14 lb as $CaCO_3$/lb N oxidized. When adopting nitrification to a real plant, the alkalinity has to be calculated using the following equation. The result is reported in the unit of mg/l alkalinity as $CaCO_3$ consumed.

$$\textbf{Alkalinity} = \textbf{TKN}_{\textbf{effluent}} \textbf{ x 7.14 lb as } \textbf{CaCO}_3\textbf{/lb N oxidized} \quad (2)$$

Sufficient alkalinity must be present for nitrification to take place. Alkalinity must be controlled so that the value should not drop below 50 mg/l at any point in the process.

2.4.2(c) Calculation of Target Mean Cell Residence Time (MCRT)

Mean Cell Residence Time (MCRT) is the key factor in achieving nitrification. As temperature increases, nitrifier growth rate increases. Typical temperature is within the range of 4° C to 35° C. In addition, as nitrifier growth rate increases, required MCRT decreases. As the rule of thumb, for every 10° C increase in temperature, nitrifier growth rate doubles, required MCRT is cut in half and required MLSS concentration is also reduced (Gerardi, 2002).

The nitrifying bacteria are slow growers and require a much longer MCRT. Equation below is used to calculate the maximum rate of the nitrifier growth. Nitrifier growth rate is denoted by μ.

$$\mu_{max} = (0.65)\,(1.055)^{(T-25)} \quad (3)$$

T represents temperature in $^{\circ}$ C. The first step in determining the target MCRT is by calculating the nitrifier growth rate at the desired temperature. The unit for the equation is 1/day. Table 6.2 describes how the temperature affects the nitrification process, followed by Table 6.3, describing how temperature affects MCRT.

Table 2.3: Temperature and Nitrification

Temperature	Effect upon Nitrification
> 45° C	Nitrification ceases
28° C – 32° C	Optimal temperature range
16° C	Approximately 50% of nitrification rate at 30° C
10° C	Significant reduction in rate, approximately 20% rate at 30° C
< 5° C	Nitrification ceases

Table 2.4: Temperature and MCRT Required for Nitrification

Temperature	Mean Cell Residence Time (MCRT)
10° C	30 days
15° C	20 days
20° C	15 days
25° C	10 days
30° C	7 days

Once the maximum nitrifier growth rate is obtained, it is required to determine the minimum MCRT, which can be calculated by using the following equation:

$$\text{Minimum MCRT} = \frac{1}{\mu_{max} - k_d} \quad (4)$$

k_d is the endogenous decay coefficient, reported in the unit of 1/day. It accounts for the loss in cell mass due to oxidation of internal storage products for energy for cell maintenance, cell death, and predation by organisms higher in the food chain (Metcalf & Eddy, 2004). The value of k_d can be determined from the batch test or by using respirometer. The methods are attached in the Appendices. For a simplification, the value of k_d at 10° C is 0.02 1/day and the value decrease 0.01 for every 5° C increment of temperature. The next step is to calculate the corrected growth rate for ammonia and dissolved oxygen concentration before determining the target MCRT. Both corrected growth rates can be calculated in one single calculation as the following:

$$\mu_{corrected} = (\mu_{max})\left(\frac{NH_4+}{K_N + NH_4+}\right)\left(\frac{DO}{K_{DO} + DO}\right) \quad (5)$$

K_{DO} is half-saturation constant for dissolved oxygen and typical value used is 1.0 mg/L. K_N is half-saturation constant for ammonium. Stehr et al (1995) reported K_N is measured as half of the maximum oxidation rate, which is ranging from 0.42 to 1.05 mg/L. Oxidation rate is a measurement of how fast ammonium is oxidized to nitrate. The ammonium oxidation rates are commonly 1 - 3 mg/g/hour (Barnes and Bliss 1983). Sample procedure to determine the oxidation rate is attached in the appendices. Once the corrected nitrifier growth rate is obtained, the target MCRT can be calculated by using the following equation:

$$\text{Target MCRT} = \frac{1}{M_{corrected} - k_d} \quad (6)$$

As a guideline, the dissolved oxygen concentrations should not drop below 2.0 mg/L. Low dissolved oxygen readings can lead to loss of or inhibition of nitrification.

2.4.2(d) Calculation of Current Actual Mean Cell Residence Time (MCRT)

Practically, the current actual MCRT represents the average number of days the solids or biomass remain in the system. It can be determined by dividing the amount of biomass in the system with the amount of biomass wasted. The step by step of the calculation processes are described as the following:

$$\text{MCRT (days)} = \frac{\text{Biomass in system (lbs)}}{\text{Biomass wasted (lbs per day)}} \quad (7)$$

$$\text{Biomass in System (lbs)} = \text{Aeration Tank Volume (million gallons)} \times \text{MLSS (mg/L)} \times 8.34 \quad (8)$$

$$\text{Biomass Wasted} = Q_{WAS}\ (\text{mgd}) \times MLSS_{WAS}\ (\text{mg/L}) \times Q_{SecondaryEffluent}\ (\text{mgd}) \times TSS_{SecondaryEffluent}\ (\text{mg/L}) \times 8.34 \quad (9)$$

The abovementioned MCRT has to be calculated on the daily basis for at least a week. The daily MCRT results versus date need to be plotted so that the data could be studied. It should be bear in mind that the current actual MCRT must not rely on a single day's MCRT calculation as the variation would vary significantly.

It is advisable to use a running average over a period approximately equal to the MCRT. For example, if MCRT is about 7 days, use a 7-day running average. The purpose of having the running average is to smooth out spikes in the graph. Some programs that can be used include Microsoft Word or Visual Studio.

The current actual MCRT must be adjusted so that it could meet the designed target MCRT. The adjustment could be made either to the amount of biomass in the system or amount of biomass wasted from the system.

2.4.2(e) Consideration of Other Nitrification Factors

Five factors that affect MCRT, as discussed previously, include temperature, alkalinity, as well as ammonia and dissolved oxygen concentration. Besides MCRT, the design should be checked in terms of the other nitrification factors, which are, toxic compounds, pH, and cBOD removal.

Toxic Compound

The nitrifying bacteria will be the first to die off if the facility is impacted by toxic compounds such as heavy metals, cyanide and some organic chemicals. Nitrification can break down quickly and takes several days or weeks to re-establish. Thus, removal methods should be established to remove the toxic compound from the facility so that nitrification may take place efficiently. Besides, the application of flow equalization may mitigate the effects of the toxic compounds.

cBOD Removal

Soluble cBOD must be significantly reduced, typically down to 20-30 mg/L before nitrification can take place because of its ability to enter the cells of nitrifying bacteria and inactive their enzyme systems. This form of cBOD must be degraded significantly or completely by organotrophs in the aeration tank for the nitrifying bacteria to oxidize ammonium ions and nitrite ions (Gerardi, 2002)

pH

Nitrification proceeds much more slowly at low pH, but higher pH would adversely affect many organotrophs that are required to degrade cBOD (Gerardi, 2002). Nitrification works best at pH greater than 6.5. The optimum range is from 7.0 to 8.0. Inhibition can take place at pH is below 6.5 or above 8.0.

2.4.2(f) Sample of Calculation

This section provides a sample calculation to determine the target mean cell residence time in order to achieve nitrification. All the given data were assumed due to insufficient experimental data.

Assume: Plant Influent Flow = 10 mgd

Plant Influent TKN = 35 mg/l

Plant Influent BOD_5 = 180 mg/l

BOD_5 Removal in Primary Clarifier = 30%

TKN Removal in Primary Clarifier = 10%

Temperature = 30 °C

Effluent NH_4^+-N = 1 mg/L

DO = 3 mg/L

MLSS = 2200 mg/L

Aeration Tank Volume = 2 MG

1. Oxygen Required for Conversion of Ammonia to Nitrate

$O_2 = (Q_{influent})\ (TKN_{influent})\ (100\% - \%\ TKN\ removal)\ (4.57\ lbs\ of\ O_2)\ (8.34)$

$= (10\ mgd) \times (35\ mg/l) \times (0.9) \times (4.57) \times (8.34) = 12{,}006\ lbs\ O_2/day$

2. Alkalinity Consumed by Nitrification

$Alkalinity = TKN_{effluent} \times 7.14\ lb\ as\ CaCO_3/lb\ N\ oxidized$

$= (31.5\ mg/l) \times (7.14)$

$= 225\ mg/l\ alkalinity\ as\ CaCO_3\ consumed$

3. Target Mean Cell Residence Time

$$\mu_{max} = (0.65)\,(1.055)^{(T-25)}$$
$$= (0.65)\,(1.055)^{(30-25)}$$
$$= 0.15$$

$$\text{Minimum MCRT} = \frac{1}{\mu_{max} - k_d}$$
$$= \frac{1}{0.15 - 0.07}$$
$$= 12.5 \text{ days}$$

$$\mu_{corrected} = (\mu_{max}) \left(\frac{NH_4+}{K_N + NH_4+} \right) \left(\frac{DO}{K_{DO} + DO} \right)$$
$$= (0.15) \left(\frac{1}{0.45 + 1} \right) \left(\frac{3}{1 + 3} \right)$$
$$= 0.08$$

$$\text{Target MCRT} = \frac{1}{M_{corrected} - k_d}$$
$$= \frac{1}{0.08 - 0.07}$$
$$= 100 \text{ days}$$

2.4.3 Operating Strategies for Denitrification

In order to establish denitrification process in the activated sludge system, five factors are taken into consideration, which are: (i) design of anoxic zone, (ii) carbon source, (iii) nitrate recycle, (iv) dissolved oxygen, and (v) mixing equipment.

2.4.3(a) Design of Anoxic Zone

Denitrification is the process of converting nitrate into nitrogen gas. The key point to denitrify is by establishing the anoxic conditions in the activated sludge process, whether before or after the aeration tank. In UTP, the facility is designed for the pre-denitrification process, where anoxic zone is placed at the beginning of the activated sludge tanks. This type of layout is the most recommended one.

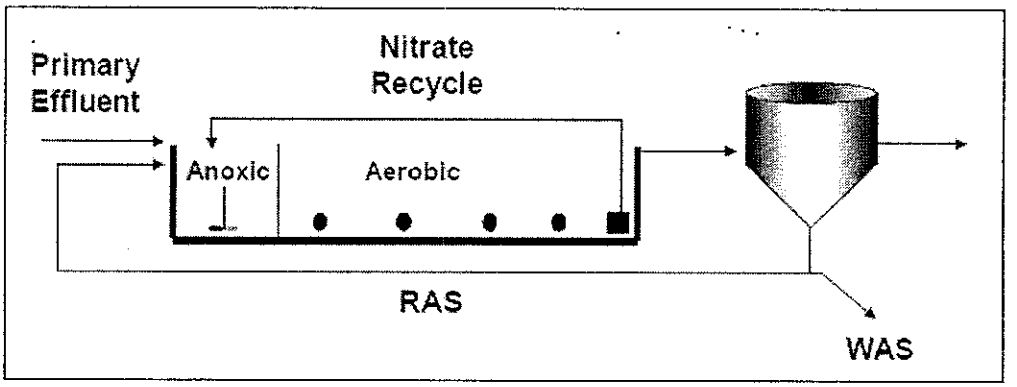


Figure 6: Layout of UTP's Anoxic Zone

In the aerobic zone, nitrification takes place and produces nitrate. A portion of the mixed liquor is returned to the head end of the anoxic zone for a source of nitrate. In the anoxic zone, the lack of elemental oxygen causes the bacteria to derive their oxygen chemically and they therefore convert the nitrate to nitrite and ultimately nitrogen gas.

The anoxic zone must be designed to meet the required anoxic volume. As the rule of thumb, the required anoxic zone volume will be about one third of the aerobic volume.

2.4.3(b) Carbon Source

In the anoxic zone, there must be a carbon source for denitrification to take place. Typically influent raw wastewater is used for this source. The carbon source is needed by the denitrifying bacteria as the source of energy for the denitrification process. Organic compounds like methanol and acetic acid can also be added to a denitrification tank to fully denitrify it (Gerardi, 2002).

2.4.3(c) Nitrate Recycle

An adequate supply of nitrate is needed in the anoxic zone. Thus, a portion of mixed liquor from the aeration tank must be recycled to the anoxic tank for the source of nitrate. The recycle rate of about 200% of the influent flow rate is needed, where it can remove 67% of nitrogen.

2.4.3(d) Dissolved Oxygen

Dissolved oxygen (DO) must be depleted in the denitrification process. The value should be below 0.3 mg/L as dissolved oxygen levels above 0.3 mg/L will start to inhibit the denitrification process. In order to achieve this, it is important to provide mixing in the anoxic zone, but not aeration. Low or cyclical aeration is acceptable. Cyclical aeration involves an on and off aeration.

2.4.3(e) Mixing Equipment

Denitrification requires a mixing to be established in the anoxic zone by the means of pulsed or cycled air, submersible mixers or vertical mixers. As the rule of thumb, the required mixing power will be about 1 HP per 15,000 gallons of anoxic zone volume. For an instance, 45,000 gallons of anoxic would require approximately 3.0 HP.

2.4.4 Facility Design

Sometimes, the design of MCRT cannot achieve the desired nitrification due to insufficient data or lack of time. Alternatively, nitrification may be achieved through a proper design to the facility. The facility design includes the modification or improvement made to the aerobic zone, anoxic zone, recycle pumping and the secondary clarifier.

2.4.4(a) Aerobic Zone

The design of the first aerobic zone may be viewed simply as the aeration basin for a nitrifying sludge system. The aeration tank must have an efficient oxygen transfer for nitrification to occur. Three types of aeration equipment normally used in activated sludge system are: (ii) mechanical surface aerators, (ii) fine or coarse bubble diffused air systems, and (iii) submerged turbine aerators.

Mechanical surface aerator offers little maintenance but it has a limited turndown capability. Diffused air system is well-suited to nitrification since it has wider turndown range. The sewage treatment system of UTP is currently using this type of system in its aeration tank. As an option, submerged turbine aerators can also be used. The advantage of this equipment over diffused air system is in terms of turndown capability. This type of aerator can easily be converted to a mixer by simply shutting off the air flow. This can provide additional system flexibility in a plug flow basin configuration by allowing adjustment of the aerobic and anoxic zone.

2.4.4(b) Anoxic Zone

Anoxic zone has two basic features, which are: (i) a basin of sufficient volume and (ii) sufficient mixing of the contents to maintain the microbial solids in suspension without transferring oxygen to the content (Sedlak, 1991).

Anoxic zone should be designed to allow floating solids to exit the system, not to simply trap them as it can result in significant accumulation of scum. The best way to achieve this is by installing a submerged turbine mixer in the anoxic zone. In such a design, floating solids can pass from one zone to another, finally exiting the aeration basin to be collected by the secondary clarifier.

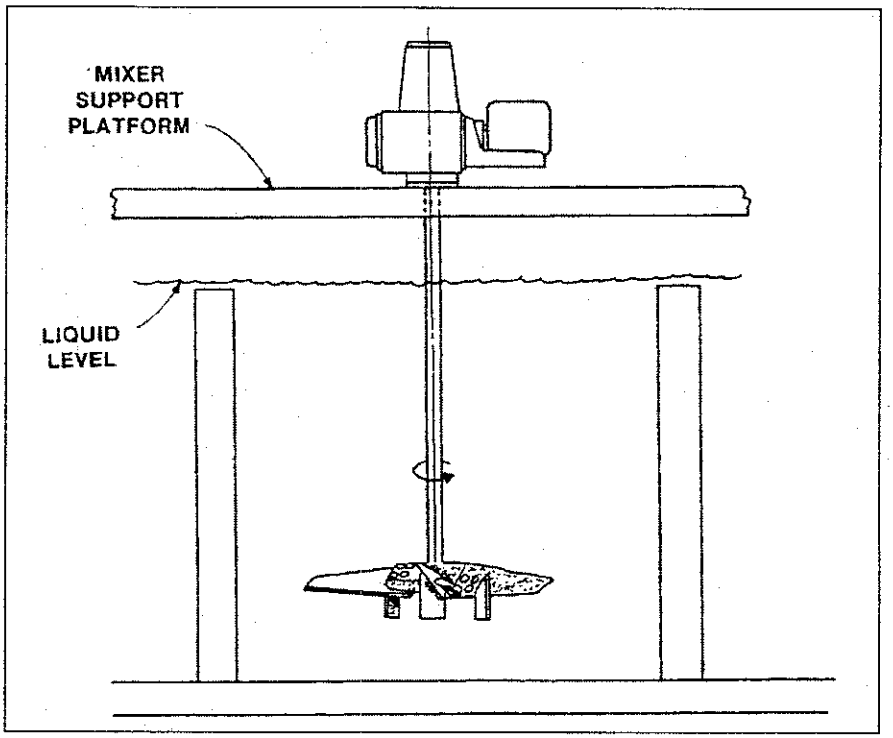


Figure 7: Typical Submerged Turbine Mixer

2.4.4(c) Recycle Pumping

The recycle of mixed liquor from the first aerobic zone to the first anoxic zone is generally accomplished by pumping. The pumps should be located near the downstream end of a plug flow aerobic chamber. The pumps should not be located immediately adjacent to an aeration device so that the amount of dissolved oxygen (DO) returned with the mixed liquor will be minimized (Sedlak, 1991).

2.4.4(d) Secondary Clarification

Some nutrient removal systems have a tendency to develop a troublesome scum that can cause odour problems and degradation of the plant effluent quality (Nigel, 1994). Thus, the system should be designed to allow floating solids to pass to the secondary clarifier. The clarifier mechanism should include a full radius rotating skimmer device as a mean of the scum removal, as illustrated in Figure 16.

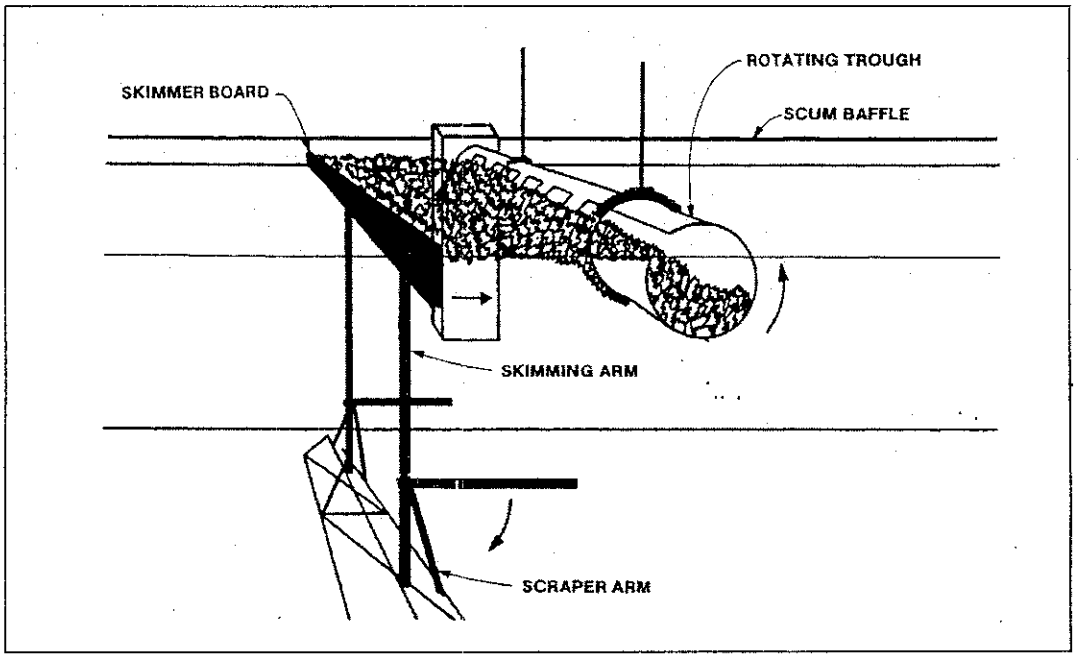


Figure 8: Typical Rotating Skimmer Device

This device includes a pipe with a slot cut along the centerline on one side to serve as a weir. As the full radius scum skimmer sweeps towards the pipe, the pipe rotates downward and a water mixture (scum) flows over the weir edge and into the pipe. The mixture then flows to one end of the pipe where it is discharged to the scum pumping facilities. Collected scum must be wasted from the system and not to be recycled.

CHAPTER 3
MATERIALS, EQUIPMENTS AND METHODOLOGY

3.1. MATERIALS AND EQUIPMENTS

3.1.1 Wastewater Sample

For the first part of this final year project, the characterization of wastewater required the raw samples of the wastewater influent, taken both from the UTP sewage treatment plant as well as the oxidation pond.

For the second part of the project, the samples were taken at five different points in the UTP's sewage treatment plant, which are at: (i) influent, (ii) anoxic inlet, (iii) aeration inlet, (iv) aeration outlet, and (v) effluent. Whenever the sewage treatment plant was closed for the rectification purpose, the samples were collected from the inlet and outlet of the oxidation pond.

3.1.2 Chemical Reagents

In order to identify the amount of Ammoniacal Nitrogen and Total Phosphorus that present in the wastewater samples, two sets of reagents were used, which are the Ammoniacal Nitrogen reagent set and the Total Phosphorus Test 'N Tube reagent set. Ammoniacal Nitrogen reagent set consists of the Nessler's reagent, mineral stabilizer, Polyvinyl Alcohol dispersing agent and the deionized water. However, during the second part of this project, the Ammoniacal Nitrogen in the wastewater samples was determined by using the ammonia probe. Chemical reagents that cooperated with the

probe include the Ammonia Ionic Strength Adjustor powder pillows and Nitrogen-Ammonia Standard Solutions (10 mg/L and 100 mg/L).
Total Phosphorus Test 'N Tube reagent set consists of PhosVer 3 Phosphate reagent powder pillows, Pottasium Persulfate powder pillows, 1.54 N Sodium Hydroxide solution, Total and Acid Hydrolyzable test vials and the deionized water.

The only chemical reagent that was used to determine the amount of nitrate in the wastewater samples is NitraVer 5 nitrate reagent powder pillow. All the reagents were ordered from the Hach Company.

3.1.3 Laboratory Apparatus

Like any other laboratory experiments, the basic apparatus that often be used include beakers, pipette and stirrer. In the experiment to determine the amount of Nitrate in the wastewater sample, square sample cells were used.

In the experiment to determine the amount of Total Phosphorus contained in the wastewater sample, Digital Reactor Block of DRB 200 type was used to heat the Total and Acid Hydrolyzable test vials so that the sample inside the vials could be digested.

Spectrophotometer of DR 2800 type was used at the end of each experiment in order to get the reading of the amount of Total Phosphorus, Ammoniacal Nitrogen and Nitrate contained in the wastewater samples. The square sample cell, spectrophotometer and Digital Reactor Block were ordered from the Hach Company as well.

3.2. METHODOLOGY

3.2.1 Sampling

Sampling was performed by grab sampling method. Grab sampling is collected at one time. It reflects performance only at the point in time that the sample was collected, and then only if the sample was properly collected. The samples were also collected by using the auto-sampler device every once in a while. The device will automatically collect the sample every hour for 24 hours. A minimum of 3 water samples for each analysis were taken to avoid any ambiguities during the analysis.

3.2.2 Preservation

Once the samples were taken, the analyses on the samples were carried out in the laboratory. When it is not possible to analyze the collected samples immediately, samples can be preserved up to 3 days by storing them at 4 °C. The sample was then being warmed to the room temperature.

3.2.3 Laboratory Analysis

Laboratory analysis was performed to analyze the amount of Total Phosphorus, Nitrate and Ammoniacal Nitrogen available in the wastewater samples. Brief descriptions for each experiment are explained in the next paragraphs. The detailed experimental works were carried out as illustrated in the diagrammatic standard operating procedures in the HACH Water Analysis Handbook, attached in the Appendices.

3.2.3(a) Total Phosphorus Procedure

The analysis for Total Phosphorus is based on Method 8190 in the Water Analysis Handbook, which is the PhosVer® 3 with Acid Persulfate Digestion Method. The analysis was carried out by diluting the wastewater samples first, so that a valid measurement can be made since the workable range often falls within only a few mg/L Phosphates present in the sample must be converted to reactive orthophosphate first by heating the sample with acid and persulfate (HACH, 2003).

3.2.3(b) Ammoniacal Nitrogen Procedure

During the first part of the final year project, the amount of Ammoniacal Nitrogen in the wastewater sample was determined by using the Nessler Method, as instructed in Method 8038 in the HACH Water Analysis Handbook. The addition of mineral stabilizer solution is to prevent cloudiness caused by the calcium and magnesium concentrations that may present in the samples. A yellow colour will develop if ammonia is present in the samples.

During the second half of the project, the analysis was carried out by using the ammonia probe. The analysis required the probe to be calibrated first by using the Ammonia Standard Solutions (10 mg/L and 100 mg/L), added with the Ammonia Ionic Strength Adjustor powder pillows. The same powder pillows were added into the samples before being read by the probe.

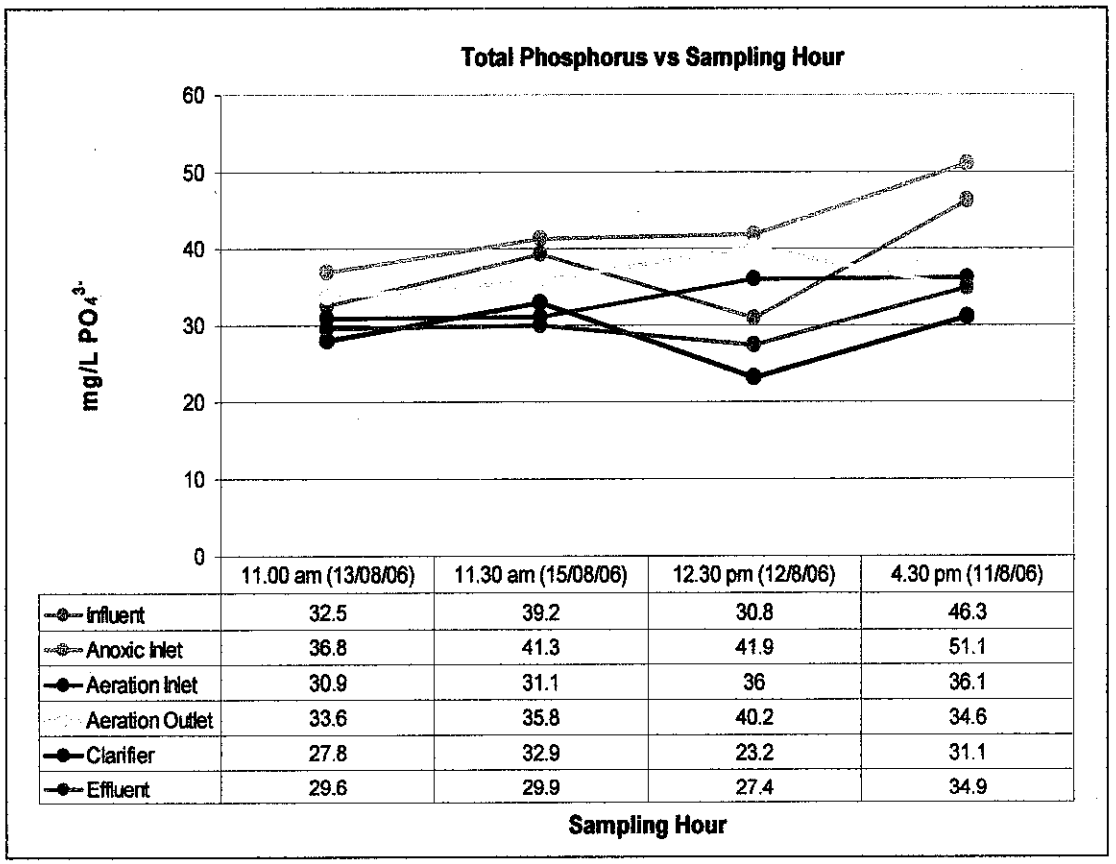
3.2.3(c) Nitrate Procedure

The analysis for Nitrate is based on Method 8039 in the Water Analysis Handbook, which is the Cadmium Reduction Method. It is a colorimetric method that involves contact of the nitrate in the sample with cadmium particles, which cause nitrates to be converted to nitrites. This method requires the samples being treated are clear. If a sample is turbid, it should be filtered through a 0.45-micron filter.

CHAPTER 4

RESULTS AND DISCUSION

4.1. TOTAL PHOSPHORUS



	11.00 am (13/08/06)	11.30 am (15/08/06)	12.30 pm (12/8/06)	4.30 pm (11/8/06)
Influent	32.5	39.2	30.8	46.3
Anoxic Inlet	36.8	41.3	41.9	51.1
Aeration Inlet	30.9	31.1	36	36.1
Aeration Outlet	33.6	35.8	40.2	34.6
Clarifier	27.8	32.9	23.2	31.1
Effluent	29.6	29.9	27.4	34.9

Figure 9: Graph of Total Phosphorus versus Sampling Hour before Rectification

Figure 2 shows the graph of Total Phosphorus at different sampling points versus the time (sampling hour) for the wastewater samples taken from the sewage treatment plant that had not been rectified yet.

From the graph, it can be seen that at every sampling date, the highest amount of Total Phosphorus were recorded at the samples taken from the anoxic inlet. It is due to the anoxic chamber that is the placed where the recycling of the return activated sludge takes place. All sediments entering the clarifier will be returned back at the head of the anoxic chamber, causing the amount of Total Phosphorus to be higher there.

The lowest concentration of Total Phosphorus in influent was recorded from the sample taken on 12/08/2006 at 12.30 pm. This indicates that discharges containing phosphate element were low between 9.00 am to 12.30 pm since the wastewater would take about three hours to reach the inlet of the sewage treatment plant. Students were normally having their lectures during that period of time. However, the concentration of the effluent was still lower then the influent's concentration during the same particular day.

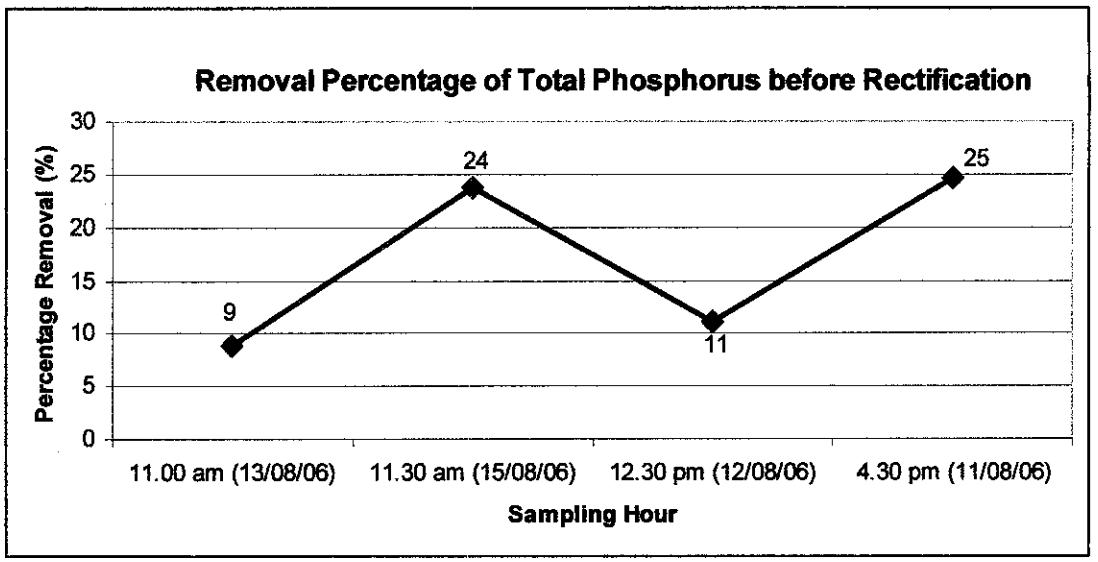
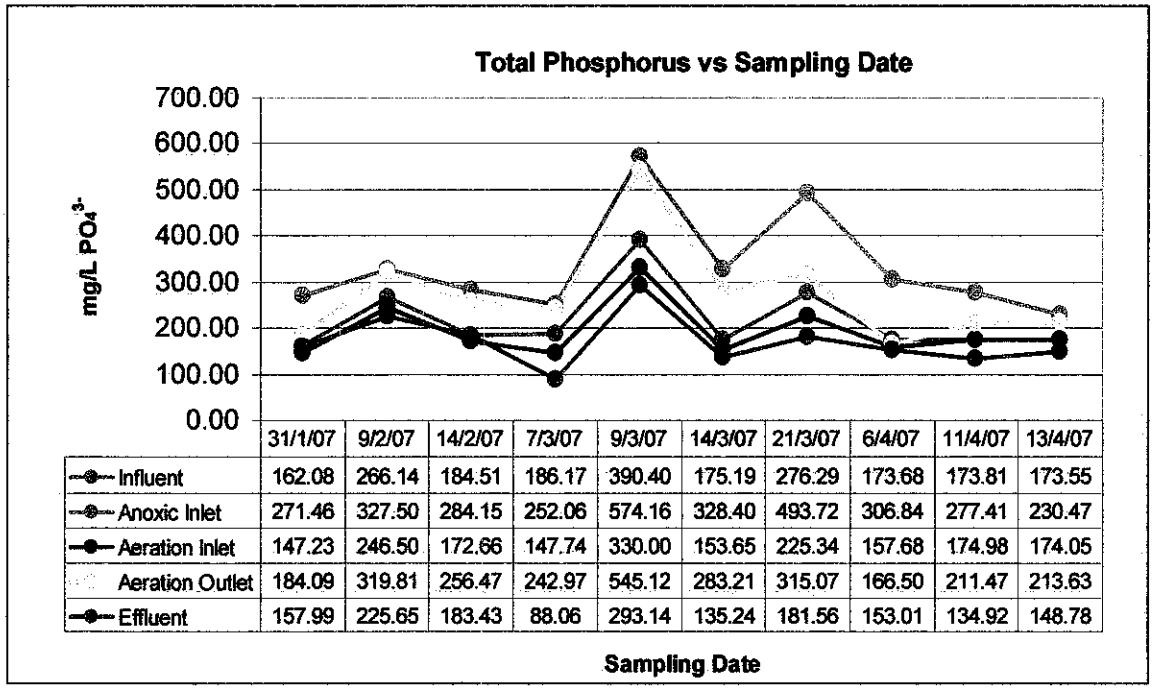


Figure 10: Percentage Removal of Total Phosphorus before Rectification

Figure 7 shows the removal percentage of Total Phosphorus for the samples taken before the rectification process of the sewage treatment plant. Removal percentage defines the difference in the concentration of contaminants between effluent and influent. The percentage was not constant. The highest removal percentage was recorded at 4.30 pm on 11/08/2006, which was 25% and the lowest percentage was 9%, recorded at 11.00 am on 13/08/2006.



	31/1/07	9/2/07	14/2/07	7/3/07	9/3/07	14/3/07	21/3/07	6/4/07	11/4/07	13/4/07
Influent	162.08	266.14	184.51	186.17	390.40	175.19	276.29	173.68	173.81	173.55
Anoxic Inlet	271.46	327.50	284.15	252.06	574.16	328.40	493.72	306.84	277.41	230.47
Aeration Inlet	147.23	246.50	172.66	147.74	330.00	153.65	225.34	157.68	174.98	174.05
Aeration Outlet	184.09	319.81	256.47	242.97	545.12	283.21	315.07	166.50	211.47	213.63
Effluent	157.99	225.65	183.43	88.06	293.14	135.24	181.56	153.01	134.92	148.78

Figure 11: Graph of Total Phosphorus versus Sampling Date after Rectification

Figure 3 shows the graph of the Total Phosphorus at different sampling points versus the time (sampling date) for the wastewater samples taken from the sewage treatment plant that had undergone a series of rectification processes.

Similar to Figure 2, the highest amount of Total Phosphorus at every sampling date were recorded at the samples taken from the anoxic inlet. However, after the rectification processes, the amount of Total Phosphorus at every sampling points were increasing tremendously which were approximately 6 to 8 times the values obtained before the rectification process. It shows that the current sewage treatment plant is not capable to remove Total Phosphorus from the system.

Experimental analysis carried out on 09/03/2007 and 21/03/2007 had resulted in very high concentrations of Total Phosphorus at every sampling point. It was due to the operator of the sewage treatment plant who closed the flow a day before each experiment was carried out. Total Phosphorus was accumulated for 2 days resulting in higher concentrations compared to the other sampling days.

Almost all organic and inorganic materials contain phosphate element. So, the sources of phosphorus contamination are very wide. These include food, supplement, cosmetics, toothpaste, pharmaceuticals products, fertilizers, household cleaning products, paint, lubricant emissions and human and animal waste. All these sources contribute to the high amount of Total Phosphorus.

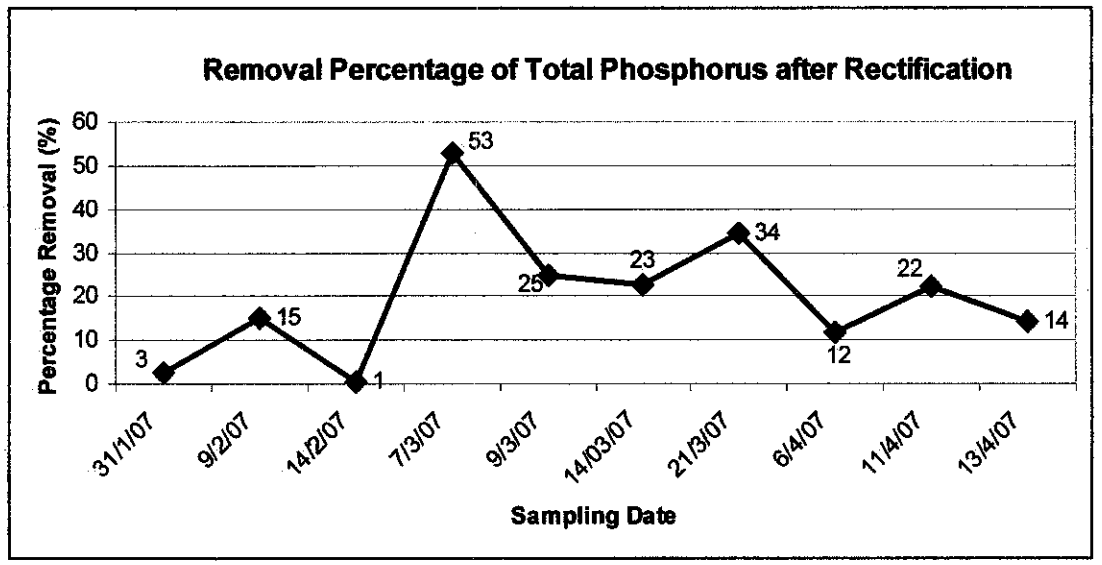
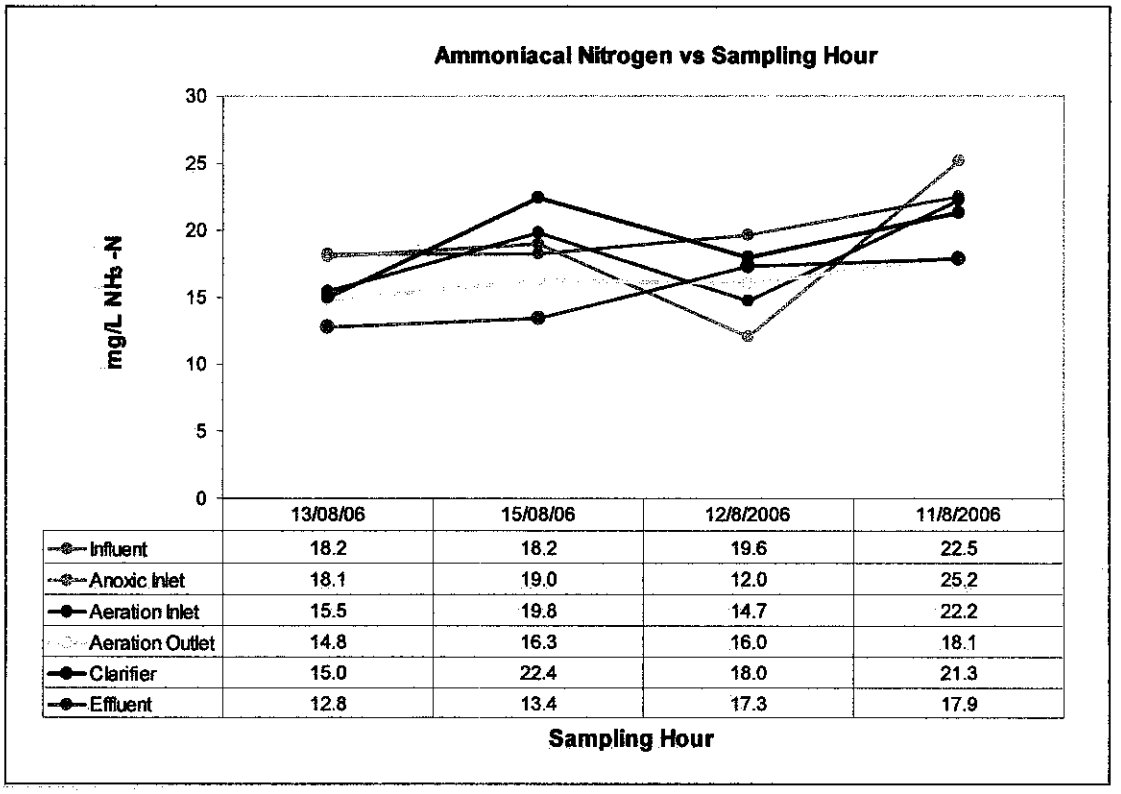


Figure 12: Percentage Removal of Total Phosphorus after Rectification

Figure 9 shows the removal percentage of Total Phosphorus for the samples taken after the rectification process of the sewage treatment plant. The highest removal percentage was recorded on 07/03/2007, which was 53% and the lowest percentage was 1%, recorded on 14/02/2007.

4.2. AMMONIACAL NITROGEN



	13/08/06	15/08/06	12/8/2006	11/8/2006
Influent	18.2	18.2	19.6	22.5
Anoxic Inlet	18.1	19.0	12.0	25.2
Aeration Inlet	15.5	19.8	14.7	22.2
Aeration Outlet	14.8	16.3	16.0	18.1
Clarifier	15.0	22.4	18.0	21.3
Effluent	12.8	13.4	17.3	17.9

Figure 13: Graph of Ammoniacal Nitrogen versus Sampling Hour before Rectification

Figure 5 shows the graph of Ammoniacal Nitrogen at different sampling points versus the time for the for the wastewater samples taken from the sewage treatment plant that had not been rectified yet.

For all these samples, the laboratory analysis was conducted by using the Hach Ammonia Reagents. For the second part of the project, the laboratory analysis for Ammoniacal Nitrogen was conducted by using the ammonia probe. The results were almost similar, but the procedures were quick and easier. For the first phase of the project, determination of the nitrification process was not the main concern due to the time constraint. However, it could be observed that there were not any nitrifications took place as the concentration of Ammoniacal nitrogen was almost constant throughout the analysis period. Ammonia was not converted to nitrate.

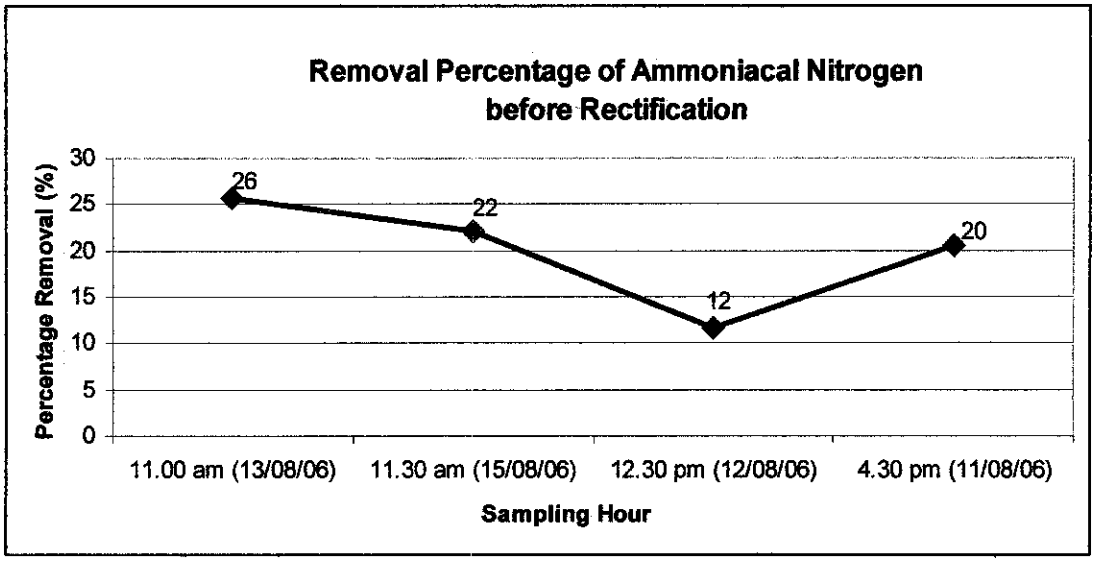
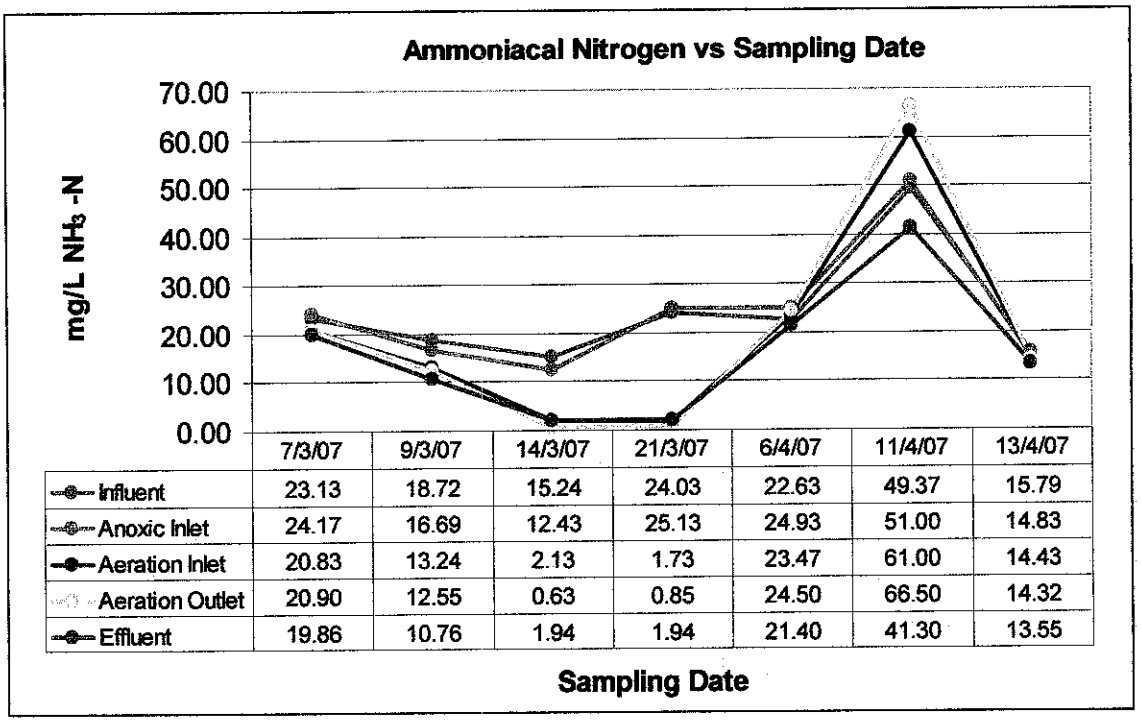


Figure 14: Percentage Removal of Ammoniacal Nitrogen before Rectification

Figure 11 shows the removal percentage of Ammoniacal Nitrogen for the samples taken before the rectification process of the sewage treatment plant. The highest removal percentage was recorded at 11.00 am on 07/03/2006, which was 26% and the lowest percentage was 12%, recorded at 12.30 pm on 12/08/2006.



	7/3/07	9/3/07	14/3/07	21/3/07	6/4/07	11/4/07	13/4/07
Influent	23.13	18.72	15.24	24.03	22.63	49.37	15.79
Anoxic Inlet	24.17	16.69	12.43	25.13	24.93	51.00	14.83
Aeration Inlet	20.83	13.24	2.13	1.73	23.47	61.00	14.43
Aeration Outlet	20.90	12.55	0.63	0.85	24.50	66.50	14.32
Effluent	19.86	10.76	1.94	1.94	21.40	41.30	13.55

Figure 15: Graph of Ammoniacal Nitrogen versus Sampling Date after Rectification

Figure 5 shows the graph of Ammoniacal Nitrogen at different sampling points versus the time for the for the wastewater samples taken from the rectified sewage treatment plant. The overall results followed the same pattern of fluctuation, where the highest values were recorded at the anoxic inlet, except for the last three points that gave a slight difference in the variation. This might due to the rectification progress carried out throughout the week.

The sewage treatment plant had managed to achieve nitrification for two consecutive days, which were on 14/03/07 and 21/03/07 respectively. Nitrification was indicated by the sudden drop in the amount of Ammoniacal Nitrogen from the aeration inlet and onwards. At the same time, there were sudden increments in the amount of Nitrate from the samples taken at the same points. It shows that ammonia had been converted to nitrate, which is a part of the nitrification process.

Besides, nitrification also when the effluent is equivalent to TSS = 50 mg/L, TCOD = 32 mg/L, SCOD = 18 mg/L, TOC = 18 mg/L and MLSS = 1235 mg/L at 21/03/07.

However, the facility had been closed for a few days for the rectification purposes. Experimental analysis carried out on 06/04/2007 was carried out 3 days after the facility was reopened. The rectification might have impacted the nitrifying bacteria. The nitrifying bacteria will be the first to die off if the facility is impacted by toxic compounds such as heavy metals, cyanide and some organic chemicals. Nitrification can break down quickly and takes several days or weeks to re-establish. It also explains why the concentration of Ammoniacal Nitrogen recorded on 11/04/2007 was increased tremendously.

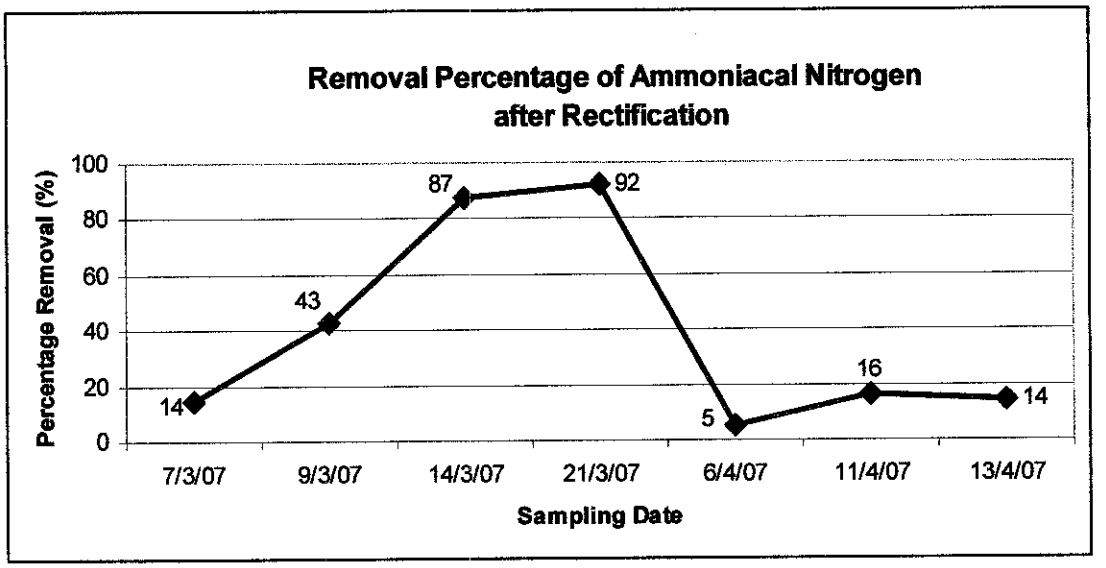
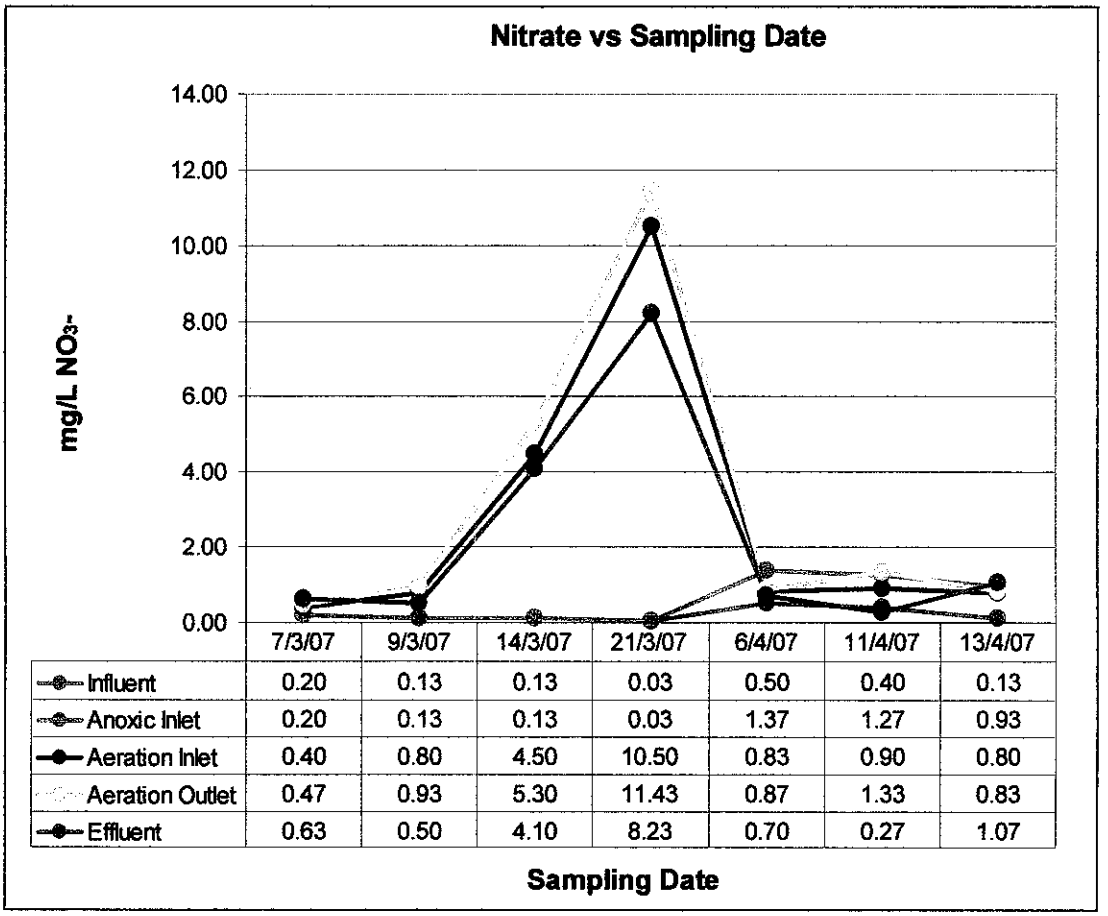


Figure 16: Percentage of Ammoniacal Nitrogen after Rectification

Figure 13 shows the removal percentage of Ammoniacal Nitrogen for the samples taken after the rectification process of the sewage treatment plant. The highest removal percentage was recorded on 21/03/2007, which was 92% and the lowest percentage was 5%, recorded on 06/04/2007. The highest removal percentage was due to the nitrification process that converted the ammonia to nitrate.

4.3. NITRATE



	7/3/07	9/3/07	14/3/07	21/3/07	6/4/07	11/4/07	13/4/07
Influent	0.20	0.13	0.13	0.03	0.50	0.40	0.13
Anoxic Inlet	0.20	0.13	0.13	0.03	1.37	1.27	0.93
Aeration Inlet	0.40	0.80	4.50	10.50	0.83	0.90	0.80
Aeration Outlet	0.47	0.93	5.30	11.43	0.87	1.33	0.83
Effluent	0.63	0.50	4.10	8.23	0.70	0.27	1.07

Figure 17: Graph of Nitrate versus Sampling Date after Rectification

Figure 2 shows the graph of Nitrate at different sampling points versus the time. The graph fluctuations follow the same pattern where the highest values were obtained at the aeration outlet.

From the graph, it can be seen that the anoxic inlet was not working properly from 07/03/2007 to 21/03/07, which were before rectification was made to the facility. It was indicated by the same values of concentration recorded at influent and the anoxic inlet during that period of time.

As mentioned earlier under Section 5.2, nitrification had occurred twice which were on 14/03/07 and 21/03/07 respectively. Nitrification was indicated by the sudden drop in the amount of Ammoniacal Nitrogen from the aeration inlet and onwards. At the same time, there were sudden increments in the amount of Nitrate from the samples taken at the same points. It shows that ammonia had been converted to nitrate, which is a part of the nitrification process.

Starting from 06/04/2007 and onwards, the concentrations of had gradually decreased, while the concentration of Ammoniacal Nitrogen was increased. It proves that the rectification process had inhibited the nitrification process, where the ammonia could not be converted to nitrate.

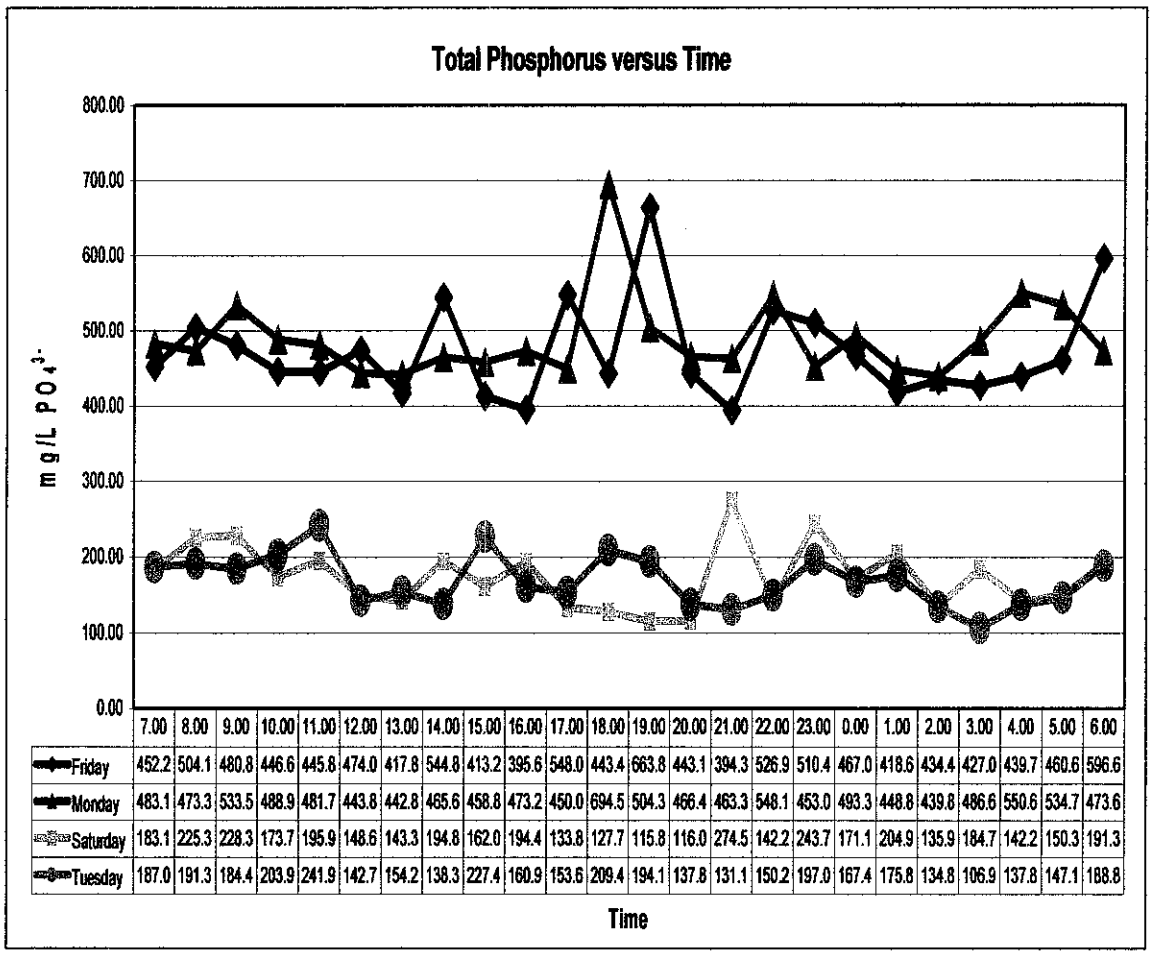
4.4. OXIDATION POND

Laboratory analysis for the grab samples taken at the oxidation pond was carried out only once, on the 28/03/2007 during the rectification of the sewage treatment plant. Table 5.1 below shows the summarized result for the samples taken at the inlet and outlet of the oxidation pond:

Table 4.1: Results of Samples Taken at Inlet and Outlet of Oxidation Pond

Location	Total Phosphorus (mg/L PO_4^{3-})	Ammoniacal Nitrogen (mg/L NH_3 –N)	Nitrate (mg/L NO_3-)
Influent	196.92	16.64	-0.23
Effluent	179.09	9.04	-0.9

The negative values indicate that the concentration of nitrate were very low and below the range detected by the spectrophotometer. The rest of the results discussed under this section were the results taken at the influent of the oxidation pond only by using the 24-hout automatic sampler. The samples were collected during the fasting month.



	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	22.00	23.00	0.00	1.00	2.00	3.00	4.00	5.00	6.00
Friday	452.2	504.1	480.8	446.6	445.8	474.0	417.8	544.8	413.2	395.6	548.0	443.4	663.8	443.1	394.3	526.9	510.4	467.0	418.6	434.4	427.0	439.7	460.6	596.6
Monday	483.1	473.3	533.5	488.9	481.7	443.8	442.8	465.6	458.8	473.2	450.0	694.5	504.3	466.4	463.3	548.1	453.0	493.3	448.8	439.8	486.6	550.6	534.7	473.6
Saturday	183.1	225.3	228.3	173.7	195.9	148.6	143.3	194.8	162.0	194.4	133.8	127.7	115.8	116.0	274.5	142.2	243.7	171.1	204.9	135.9	184.7	142.2	150.3	191.3
Tuesday	187.0	191.3	184.4	203.9	241.9	142.7	154.2	138.3	227.4	160.9	153.6	209.4	194.1	137.8	131.1	150.2	197.0	167.4	175.8	134.8	106.9	137.8	147.1	188.8

Figure 18: Graph of Total Phosphorus Nitrogen Concentration in Influent of Oxidation Pond versus Time during Fasting Month

Figure 7 shows the variation of Total Phosphorus with time for four wastewater sample, taken from the influent of the oxidation pond. Four samples were collected at different days by using the automatic sampler device.

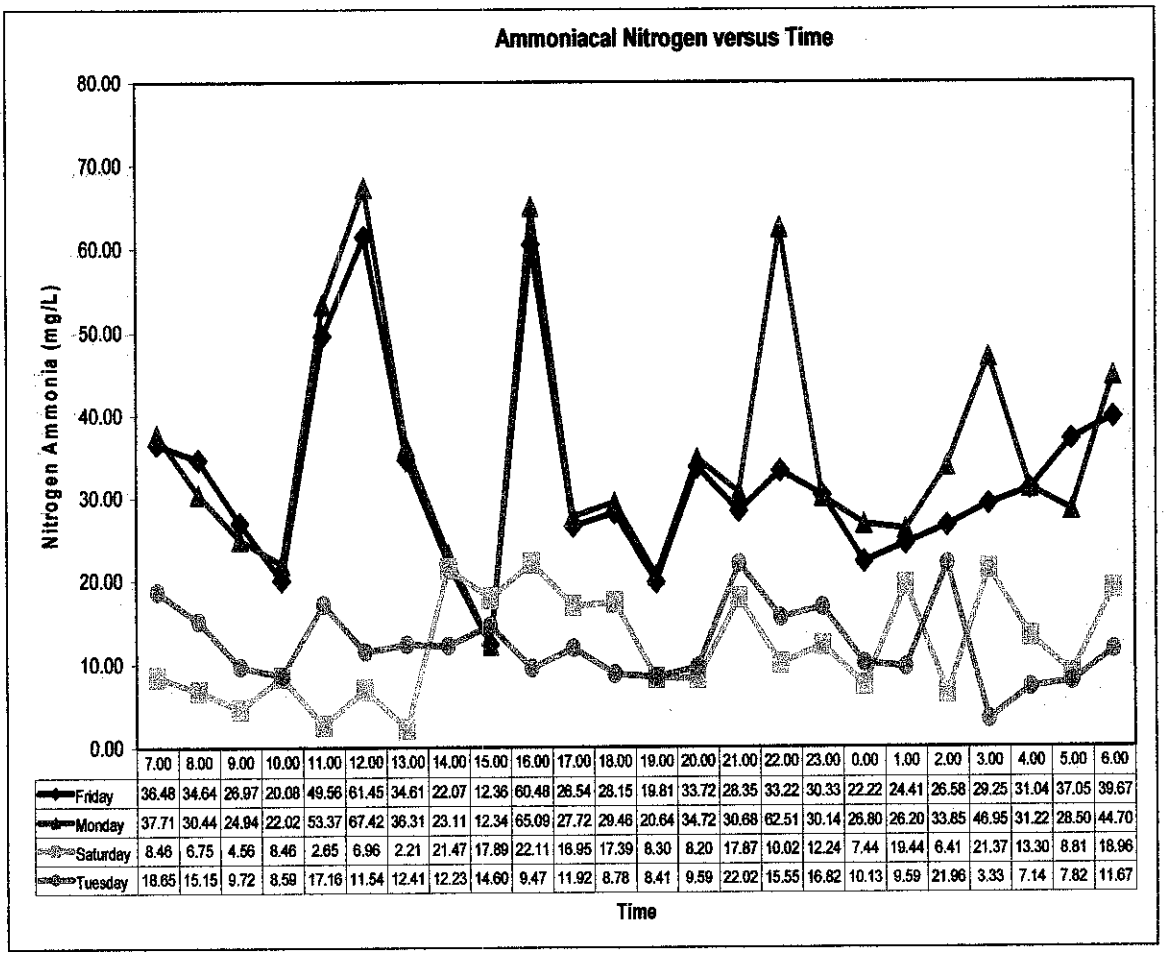
From the graph, the highest amount of Total Phosphorus is 694.8 mg/L which was recorded on Monday at 6 pm. It can be observed that the samples taken on Friday (6/10/2006) and Saturday (9/10/2006) were definitely going higher than the normal range.

Through the investigation carried out a day after the completion of this laboratory analysis, it was discovered that the upgrading works for the roadway system near the V4 field had been carried out starting from Monday, 2nd of October 2006. The upgrading works include the pavement of the grass area and the addition of road bumps. All the construction materials such as the asphalt and the paint used to mark the road would enter the sewage system, causing a higher amount of Total Phosphorus were recorded.

The other sources of Total Phosphorus that would affect the reading include the detergent from the laundry service and the food discharge from the cafeterias that served the food for the fast-breaking.

Through the statistical analysis carried out by using the T-Test, the t-value between Friday and Monday was 0.97, which is not very significant. The difference in variance was 1293.52.

The t-values between Friday and Saturday as well as Friday and Tuesday are significant, which are 18.90 and 20.26 respectively. The differences in variance were 2541.86 and 3138.41 respectively.



	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	22.00	23.00	0.00	1.00	2.00	3.00	4.00	5.00	6.00
Friday	36.48	34.64	26.97	20.08	49.56	61.45	34.61	22.07	12.36	60.48	26.54	28.15	19.81	33.72	28.35	33.22	30.33	22.22	24.41	26.58	29.25	31.04	37.05	39.67
Monday	37.71	30.44	24.94	22.02	53.37	67.42	36.31	23.11	12.34	65.09	27.72	29.46	20.64	34.72	30.68	62.51	30.14	26.80	26.20	33.85	46.95	31.22	28.50	44.70
Saturday	8.46	6.75	4.56	8.46	2.65	6.96	2.21	21.47	17.89	22.11	16.95	17.39	8.30	8.20	17.87	10.02	12.24	7.44	19.44	6.41	21.37	13.30	8.81	18.96
Tuesday	18.65	15.15	9.72	8.59	17.16	11.54	12.41	12.23	14.60	9.47	11.92	8.78	8.41	9.59	22.02	15.55	16.82	10.13	9.59	21.96	3.33	7.14	7.82	11.67

Figure 19: Graph of Ammoniacal Nitrogen Concentration in Influent of Oxidation Pond versus Time during Fasting Month

Figure 5 shows the variation of Ammoniacal Nitrogen with time for four wastewater sample, taken from the influent of the oxidation pond. From the graph, it can be observed that the readings recorded on Friday (6/10/2006) and Monday (9/10/2006) also went higher than the other readings. This proves that the theory that has been discussed for describing Figure 7 is acceptable.

Urban works could also lead to the production of high value of Ammoniacal Nitrogen. From the graph, the highest amount of Ammoniacal Nitrogen is 67.42 mg/L which was recorded on Monday at 12 pm.

Two other readings that gave high values of Ammoniacal Nitrogen were recorded on 4 pm and 10 pm, which gave the readings of 65.09 mg/L and 62.51 mg/L respectively.

The sudden increase in value of the Ammoniacal Nitrogen might due to the improper disposal of ammonia products from the laboratory. On that day, most of the final year students were having a laboratory experiments. This included the experiments to test the amount of ammonia in their samples. The other sources include operation of the SpeedKlean that does laundry service for the students.

Through the statistical analysis carried out by using the T-Test, the t-value between Friday and Monday was 0.86, which is not very significant. The difference in variance was 70.14.

The t-values between Friday and Saturday as well as Friday and Tuesday are significant, which are 7.37 and 7.68 respectively. The differences in variance were 97.54 and 115.74 respectively.

CHAPTER 5
CONCLUSION

Nitrification had occurred twice throughout the project, which are on 14/03/2007 and 21/03/2007 respectively. During nitrification, the removal percentages of Ammoniacal Nitrogen to Nitrate were 87% and 92% respectively. By combining the nitrification results with the other team mates, it was concluded that, nitrification took place when the effluent is equivalent to TSS = 50 mg/L, TCOD = 32 mg/L, SCOD = 18 mg/L, TOC = 18 mg/L and MLSS = 1235 mg/L at 21/03/2007. The amount of Total Phosphorus in the sewage treatment plant was constantly high. Rectifications made to the sewage treatment plant did not help in removing this high concentration of Total Phosphorus which was approximately 200 mg/L. Malaysia does not regulate any standard limit for Total Phosphorus, Ammoniacal Nitrogen and Nitrate yet. However, the amount of Ammoniacal Nitrogen and Nitrate in the effluent met the EPA's standard limit.

CHAPTER 6
RECOMMENDATIONS

It is recommended that a formal collaboration is made between the management of the Final Year Project and the contractor that operate the sewage treatment plant of UTP. There has been a lot of miscommunication between the students and the operators of the sewage treatment plant.

For the future work improvements, it is recommended that the future students will start applying the design of the nitrification and denitrification to the current system of UTP's sewage treatment plant by using the design and operating strategies for nitrification and denitrification, as explained in Chapter 6.

Besides, removal process for Total Phosphorus must immediately be implemented as the concentration of Total Phosphorus in the UTP's sewage treatment plant is significantly high.

REFERENCES

1. Metcalf & Eddy, 2004, "*Wastewater Engineering - Treatment and Reused*" Mc Graw Hill Publisher: New York

2. Barnes D, Bliss PJ, 1983, *"Biological Control of Nitrogen in Wastewater Treatment"* E and F N Spon: London

3. Sedlak, Richard, 1991, "*Phosphorus and Nitrogen Removal from Municipal Wastewater: Principles and Practices"* Lewis Publishers: New York.

4. Skinner, 1999, "*The Blue Planet: An Introduction to Earth System Science"* John Wiley and Sons: New York

5. Smil V., 2000, "*Cycles of Life"* Scientific American Library: New York

6. Campbell, N., & Reece, J. 2002, "*Biology: Sixth Edition*" Benjamin Cummings: San Francisco.

7. EPA, 1995, "*Draft Environmental Guidelines for Industry: Utilisation of Treated Effluent by Irrigation"* New South Wales Environment Protection Authority: Sydney

8. Swotinsky RB, Chase KH., 1990 *"Health Effects of Exposure to Ammonia: Scant*

9. *Information"*

10. Stehr G, Böttcher B, Dittberner P, Rath G, Koops HP, 1995 *"The Ammonia-Oxidizing Nitrifying Population of the River Elbe estuary"* FEMS Microbiol Ecol 17:177–186

APPENDIX I

(Data Tables)

Data Table for Total Phosphorus versus Time

	13/08/06 11.00 am (mg/L PO_4^{3-})	15/08/06 11.30 am (mg/L PO_4^{3-})	12/8/2006 12.30 pm (mg/L PO_4^{3-})	11/8/2006 16.30 pm (mg/L PO_4^{3-})
ore Anoxic Chamber	22.5	39.2	30.8	46.3
oxic Chamber	34.8	31.3	41.9	51.1
ation Tank	30.9	41.1	36.0	36.1
fore Clarifier	33.6	35.8	40.2	34.6
rifier	27.8	32.9	23.2	31.1
luent	36.6	29.9	31.4	34.9

Data Table for Ammoniacal Nitrogen versus Time

	13/08/06 11.00 am (mg/L NH_3-N)	15/08/06 11.30 am (mg/L NH_3-N)	12/8/2006 12.30 pm (mg/L NH_3-N)	11/8/2006 16.30 pm (mg/L NH_3-N)
fore Anoxic Chamber	17.2	17.2	19.6	22.5
oxic Chamber	18.1	19.0	12.0	25.2
ration Tank	15.5	19.8	14.7	22.2
fore Clarifier	14.8	13.4	18.0	18.1
rifier	15.0	22.4	16.0	21.3
luent	12.8	16.3	17.3	17.9

Data Table for Total Phosphorus and Ammoniacal Nitrogen 24-Hour Wastewater Sample

Point	Time	mg/L PO_4^{3-}	mg/L NH_3-N
1	18.00	47.2	17.5
2	18.30	40.4	15.6
3	19.00	40.4	10.7
4	19.30	46.6	21.8
5	20.00	45.3	24.2
6	20.30	36.9	10.6
7	21.00	37.9	12.0
8	21.30	41.4	14.9
9	22.00	38.4	11.7
10	22.30	33.9	17.1
11	23.00	40.1	6.2
12	23.30	43.2	16.2
13	12.00	31.0	14.5
14	12.30	38.1	17.1
15	1.00	42.1	16.6
16	1.30	39.4	22.6
17	2.00	36.5	19.0
18	2.30	36.5	16.1
19	3.00	40.1	21.8
20	3.30	39.0	13.8
21	4.00	42.1	14.3
22	4.30	45.3	12.9
23	5.00	42.7	18.4
24	5.30	46.7	16.3

Data Table for Total Phosphorus on 6/10/2006 (Friday)

Point	Time	Trial 1	Trial 2	Trial 3	Average
1	7.00	448.03	452.50	456.12	452.22
2	8.00	500.26	513.56	498.70	504.17
3	9.00	474.16	486.88	481.50	480.85
4	10.00	440.01	447.84	452.20	446.68
5	11.00	449.88	429.46	458.20	445.85
6	12.00	472.71	479.23	470.14	474.03
7	13.00	406.86	418.17	428.40	417.81
8	14.00	546.56	541.35	546.62	544.84
9	15.00	414.14	411.55	414.16	413.28
10	16.00	394.33	397.89	394.79	395.67
11	17.00	532.29	542.90	568.99	548.06
12	18.00	451.00	440.06	439.41	443.49
13	19.00	664.45	653.90	673.04	663.80
14	20.00	445.62	440.54	443.22	443.13
15	21.00	396.25	392.88	393.99	394.37
16	22.00	534.07	517.68	529.13	526.96
17	23.00	526.46	500.47	504.30	510.41
18	0.00	469.23	438.43	493.43	467.03
19	1.00	416.28	410.26	429.39	418.64
20	2.00	429.31	442.62	431.55	434.49
21	3.00	421.91	432.06	427.09	427.02
22	4.00	425.46	450.37	443.43	439.75
23	5.00	462.62	455.63	463.76	460.67
24	6.00	599.04	596.19	594.72	596.65

Data Table for Total Phosphorus on 9/10/2006 (Monday)

Point	Time	Trial 1	Trial 2	Trial 3	Average
1	7.00	475.85	495.38	478.35	483.19
2	8.00	465.80	484.19	470.12	473.37
3	9.00	509.59	555.25	535.67	533.50
4	10.00	491.88	484.88	490.05	488.94
5	11.00	465.13	491.91	488.32	481.79
6	12.00	446.12	440.10	445.23	443.82
7	13.00	446.27	440.05	442.21	442.84
8	14.00	463.52	468.25	465.23	465.67
9	15.00	439.89	470.47	466.05	458.80
10	16.00	485.35	456.55	477.85	473.25
11	17.00	450.63	448.57	450.99	450.06
12	18.00	694.43	695.32	693.98	694.58
13	19.00	492.63	519.74	500.77	504.38
14	20.00	469.06	464.88	465.33	466.42
15	21.00	440.54	483.51	465.89	463.31
16	22.00	545.57	551.04	547.71	548.11
17	23.00	460.91	447.13	451.16	453.07
18	0.00	500.71	483.40	496.06	493.39
19	1.00	449.41	448.21	448.88	448.83
20	2.00	442.11	437.53	440.03	439.89
21	3.00	495.02	476.25	488.55	486.61
22	4.00	575.98	595.68	480.26	550.64
23	5.00	546.71	527.53	530.11	534.78
24	6.00	483.09	465.73	472.01	473.61

Data Table for Total Phosphorus on 14/10/2006 (Saturday)

Point	Time	Trial 1	Trial 2	Average
1	7.00	182.12	184.20	183.16
2	8.00	225.06	225.71	225.39
3	9.00	229.95	226.67	228.31
4	10.00	171.25	176.29	173.77
5	11.00	199.95	191.85	195.90
6	12.00	149.31	147.93	148.62
7	13.00	140.45	146.16	143.31
8	14.00	194.18	195.56	194.87
9	15.00	163.93	160.22	162.08
10	16.00	194.71	194.18	194.45
11	17.00	132.26	135.33	133.80
12	18.00	129.81	125.68	127.75
13	19.00	118.28	113.33	115.81
14	20.00	115.68	116.49	116.09
15	21.00	279.51	269.58	274.55
16	22.00	136.49	148.00	142.25
17	23.00	233.38	254.18	243.78
18	0.00	169.04	173.20	171.12
19	1.00	203.20	206.74	204.97
20	2.00	134.11	137.83	135.97
21	3.00	180.11	189.37	184.74
22	4.00	144.77	139.70	142.24
23	5.00	150.31	150.34	150.33
24	6.00	190.95	191.67	191.31

Data Table for Total Phosphorus on 17/10/2006 (Tuesday)

Point	Time	Trial 1	Trial 2	Average
1	7.00	188.75	185.27	187.01
2	8.00	191.95	190.65	191.30
3	9.00	186.25	182.67	184.46
4	10.00	204.41	203.57	203.99
5	11.00	238.19	245.74	241.97
6	12.00	142.66	142.85	142.76
7	13.00	157.50	150.95	154.23
8	14.00	138.00	138.75	138.38
9	15.00	226.14	228.75	227.45
10	16.00	159.42	162.56	160.99
11	17.00	143.71	163.54	153.63
12	18.00	201.93	216.99	209.46
13	19.00	191.89	196.41	194.15
14	20.00	138.78	136.99	137.89
15	21.00	132.06	130.15	131.11
16	22.00	149.74	150.73	150.24
17	23.00	196.94	197.06	197.00
18	0.00	148.14	186.65	167.40
19	1.00	177.03	174.61	175.82
20	2.00	129.89	139.89	134.89
21	3.00	108.34	105.46	106.90
22	4.00	138.29	137.30	137.80
23	5.00	148.90	145.31	147.11
24	6.00	190.98	186.76	188.87

Data Table for Ammoniacal Nitrogen on 6/10/2006 (Friday)

Point	Time	Trial 1	Trial 2	Trial 3	Average
1	7.00	36.19	36.83	36.41	36.48
2	8.00	34.63	34.42	34.87	34.64
3	9.00	27.55	26.76	26.60	26.97
4	10.00	20.85	21.83	17.56	20.08
5	11.00	53.27	55.48	39.92	49.56
6	12.00	67.67	67.60	49.09	61.45
7	13.00	36.32	38.30	29.21	34.61
8	14.00	20.57	25.59	20.05	22.07
9	15.00	10.61	13.44	13.02	12.36
10	16.00	64.18	67.90	49.36	60.48
11	17.00	26.04	29.42	24.15	26.54
12	18.00	27.39	31.44	25.61	28.15
13	19.00	19.29	20.53	19.61	19.81
14	20.00	34.03	36.83	30.29	33.72
15	21.00	29.43	29.11	26.51	28.35
16	22.00	33.29	33.11	33.27	33.22
17	23.00	30.21	30.44	30.35	30.33
18	0.00	21.71	22.01	22.93	22.22
19	1.00	24.39	24.07	24.76	24.41
20	2.00	26.51	26.78	26.44	26.58
21	3.00	29.17	29.34	29.23	29.25
22	4.00	31.03	30.89	31.21	31.04
23	5.00	37.09	36.83	37.24	37.05
24	6.00	39.18	40.07	39.76	39.67

Data Table for Ammoniacal Nitrogen on 9/10/2006 (Monday)

Point	Time	Trial 1	Trial 2	Trial 3	Average
1	7.00	37.55	37.55	38.03	37.71
2	8.00	29.73	30.74	30.85	30.44
3	9.00	23.84	25.76	25.22	24.94
4	10.00	22.73	23.25	20.08	22.02
5	11.00	53.27	55.48	51.35	53.37
6	12.00	67.67	67.60	67.00	67.42
7	13.00	36.32	38.30	34.30	36.31
8	14.00	20.57	25.59	23.16	23.11
9	15.00	10.61	13.44	12.97	12.34
10	16.00	64.18	67.90	63.20	65.09
11	17.00	26.04	29.42	27.70	27.72
12	18.00	27.39	31.44	29.54	29.46
13	19.00	19.29	20.53	22.11	20.64
14	20.00	34.03	36.83	33.29	34.72
15	21.00	25.54	34.18	32.33	30.68
16	22.00	64.89	59.25	63.40	62.51
17	23.00	31.41	29.78	29.24	30.14
18	0.00	26.43	27.42	26.55	26.80
19	1.00	25.77	27.01	25.81	26.20
20	2.00	30.79	37.70	33.05	33.85
21	3.00	47.97	45.88	47.00	46.95
22	4.00	29.87	33.71	30.09	31.22
23	5.00	29.77	27.73	28.00	28.50
24	6.00	46.95	42.50	44.64	44.70

Data Table for Ammoniacal Nitrogen on 4/10/2006 (Saturday)

Point	Time	Trial 1	Trial 2	Average
1	7.00	8.70	8.21	8.46
2	8.00	6.48	7.01	6.75
3	9.00	4.71	4.40	4.56
4	10.00	8.58	8.33	8.46
5	11.00	2.29	3.01	2.65
6	12.00	6.83	7.09	6.96
7	13.00	2.28	2.14	2.21
8	14.00	21.36	21.57	21.47
9	15.00	17.66	18.11	17.89
10	16.00	22.42	21.79	22.11
11	17.00	17.86	16.03	16.95
12	18.00	17.52	17.25	17.39
13	19.00	8.34	8.26	8.30
14	20.00	8.27	8.12	8.20
15	21.00	17.90	17.84	17.87
16	22.00	10.20	9.84	10.02
17	23.00	12.24	12.23	12.24
18	0.00	7.31	7.56	7.44
19	1.00	19.49	19.38	19.44
20	2.00	6.82	5.99	6.41
21	3.00	21.91	20.83	21.37
22	4.00	14.28	12.31	13.30
23	5.00	8.90	8.72	8.81
24	6.00	19.03	18.88	18.96

Data Table for Ammoniacal Nitrogen on 17/10/2006 (Tuesday)

Point	Time	Trial 1	Trial 2	Average
1	7.00	18.89	18.41	18.65
2	8.00	15.01	15.28	15.15
3	9.00	9.94	9.49	9.72
4	10.00	8.42	8.75	8.59
5	11.00	17.04	17.28	17.16
6	12.00	11.71	11.36	11.54
7	13.00	12.05	12.77	12.41
8	14.00	12.00	12.45	12.23
9	15.00	14.74	14.45	14.60
10	16.00	9.78	9.15	9.47
11	17.00	12.20	11.64	11.92
12	18.00	8.34	9.22	8.78
13	19.00	8.57	8.24	8.41
14	20.00	9.37	9.80	9.59
15	21.00	21.36	22.67	22.02
16	22.00	15.77	15.33	15.55
17	23.00	17.33	16.3	16.82
18	0.00	9.76	10.50	10.13
19	1.00	9.31	9.86	9.59
20	2.00	21.09	22.83	21.96
21	3.00	3.47	3.18	3.33
22	4.00	7.06	7.21	7.14
23	5.00	7.60	8.03	7.82
24	6.00	11.31	12.03	11.67

FYP 2: Week 2

Date : 31/01/2007 (Wednesday)

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	68.29	68.32	68.31	68.31
2	Distribution Chamber	58.13	57.25	56.26	57.21
3	Aeration Chamber	69.25	70.16	70.45	69.95
4	Return Chamber	62.61	63.34	64.01	63.32
5	Effluent	65.59	66.21	64.89	65.56

Ammoniacal Nitrogen (mg/L NH_3 - N)

Point	Location	1	2	3	4	Average
1	Influent	35.70	23.60	32.30	32.30	30.98
2	Distribution Chamber	0.41				0.41
3	Aeration Chamber	31.70	21.80	22.80	20.00	24.08
4	Return Chamber	72.10				72.10
5	Effluent	35.00	33.40	22.40	34.30	31.28

Nitrate (mg/L NO_3)

Point	Location	1	2	3	4	Average
1	Influent	0.8	1.2	0.4	1.4	0.95
2	Distribution Chamber	-1.9				-1.90
3	Aeration Chamber	3.27	2.5	1.1	1.6	2.12
4	Return Chamber	1.06				1.06
5	Effluent	-2.37	-2.80	-2.40	0.00	-1.89

Date : 02/2/2007 (Friday)

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	160.77	162.21	163.26	162.08
2	Distribution Chamber	146.21	148.12	147.35	147.23
3	Aeration Chamber	273.92	271.04	269.41	271.46
4	Return Chamber	186.76	184.91	180.6	184.09
5	Effluent	158.08	156.75	159.15	157.99

FYP 2: Week 3

Date : 09/02/2007 (Friday)

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	269.98	264.71	263.73	266.14
2	Distribution Chamber	242.82	247.69	248.99	246.50
3	Aeration Chamber	329.27	325.69	327.54	327.50
4	Return Chamber	319.58	320.84	319.00	319.81
5	Effluent	226.98	225.8	224.17	225.65

Ammoniacal Nitrogen (mg/L NH_3 - N)

Point	Location	1
1	Influent	2.19
2	Distribution Chamber	3.84
3	Aeration Chamber	1.99
4	Return Chamber	1.78
5	Effluent	1.35

Nitrate (mg/L NO_3)

Point	Location	1	2	3	Average
1	Influent	0.2	0.5	0.5	0.40
2	Distribution Chamber	1.3	1.1	1.7	1.37
3	Aeration Chamber	5.0	5.6	5.4	5.33
4	Return Chamber	12.6	12.6	10.4	11.87
5	Effluent	4.1	4.6	4.8	4.50

FYP 2: Week 4

Date : 14/02/2007 (Wednesday)

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	186.74	186.33	180.46	184.51
2	Distribution Chamber	171.48	170.62	175.88	172.66
3	Aeration Chamber	285.49	283.24	283.73	284.15
4	Return Chamber	253.70	259.55	256.15	256.47
5	Effluent (Clarifier)	153.76	155.16	154.23	154.38
6	Effluent (RAS)	146.68	145.65	148.99	147.11
7	Effluent	181.46	183.27	185.57	183.43

Ammoniacal Nitrogen (mg/L NH_3 - N)

Point	Location	1	2	3	Average
1	Influent	0.7450	0.7470	0.7970	0.7630
2	Distribution Chamber	0.1366	0.1377	0.1415	0.1386
3	Aeration Chamber	0.0004	0.0006	0.0005	0.0005
4	Return Chamber	0.0001	0.0001	0.0001	0.0001
5	Effluent (Clarifier)	0.0001	0.0001	0.0001	0.0001
6	Effluent (RAS)	0.0000	0.0001	0.0001	0.0001
7	Effluent	0.0000	0.0000	0.0001	0.0000

Nitrate (mg/L NO_3)

Point	Location	1
1	Influent	0.3
2	Distribution Chamber	2.4
3	Aeration Chamber	2.8
4	Return Chamber	23.3
5	Effluent (Clarifier)	1.3
6	Effluent (RAS)	3.8
7	Effluent	2.5

FYP 2: Week 7

Date : 07/03/2007 (Wednesday)

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	188.22	187.60	182.68	186.17
2	Distribution Chamber	147.53	149.97	145.72	147.74
3	Aeration Chamber	250.70	253.24	252.23	252.06
4	Return Chamber	243.97	244.49	240.44	242.97
5	Effluent	86.03	89.32	88.84	88.06

Ammoniacal Nitrogen (mg/L NH_3 - N)

Point	Location	1	2	3	Average
1	Influent	23.00	23.00	23.40	23.13
2	Distribution Chamber	24.00	24.10	24.40	24.17
3	Aeration Chamber	20.59	20.90	21.00	20.83
4	Return Chamber	20.80	20.90	21.00	20.90
5	Effluent	19.87	19.98	19.72	19.86

Nitrate (mg/L NO_3)

Point	Location	1	2	3	Average
1	Influent	0.30	0.20	0.10	0.20
2	Distribution Chamber	0.20	0.10	0.30	0.20
3	Aeration Chamber	0.30	0.30	0.60	0.40
4	Return Chamber	0.30	0.50	0.60	0.47
5	Effluent	0.70	0.60	0.60	0.63

FYP 2: Week 8

Date : 09/03/2007 (Friday) - Mid-Term Break

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	386.77	391.44	392.98	390.40
2	Distribution Chamber	328.32	333.79	327.90	330.00
3	Aeration Chamber	572.20	578.0.	576.12	574.16
4	Return Chamber	542.20	542.71	550.45	545.12
5	Effluent	290.98	298.39	290.04	293.14

Ammoniacal Nitrogen (mg/L NH_3 - N)

Point	Location	1	2	3	Average
1	Influent	10.76	10.79	10.73	10.76
2	Distribution Chamber	16.70	16.69	16.68	16.69
3	Aeration Chamber	13.32	13.19	13.20	13.24
4	Return Chamber	12.51	12.60	12.55	12.55
5	Effluent	12.68	12.71	12.77	12.72

Nitrate (mg/L NO_3)

Point	Location	1	2	3	Average
1	Influent	0.10	0.10	0.20	0.13
2	Distribution Chamber	0.10	0.10	0.20	0.13
3	Aeration Chamber	0.60	0.90	0.90	0.80
4	Return Chamber	0.80	1.00	1.00	0.93
5	Effluent	0.50	0.60	0.40	0.50

Date : 14/03/2007 (Wednesday) - Mid-Term Break

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	173.45	175.66	176.47	175.19
2	Distribution Chamber	151.30	154.91	154.73	153.65
3	Aeration Chamber	327.46	325.91	331.82	328.40
4	Return Chamber	281.09	284.90	283.65	283.21
5	Effluent	134.94	136.36	134.41	135.24

Ammoniacal Nitrogen (mg/L NH_3 - N)

Point	Location	1	2	3	Average
1	Influent	15.42	15.02	15.27	15.24
2	Distribution Chamber	12.53	12.41	12.35	12.43
3	Aeration Chamber	2.12	2.15	2.11	2.13
4	Return Chamber	0.69	0.59	0.62	0.63
5	Effluent	1.92	1.98	1.93	1.94

Nitrate (mg/L NO_3)

Point	Location	1	2	3	Average
1	Influent	0.10	0.10	0.20	0.13
2	Distribution Chamber	0.20	0.10	0.10	0.13
3	Aeration Chamber	4.70	4.20	4.60	4.50
4	Return Chamber	5.20	5.10	5.60	5.30
5	Effluent	4.00	4.10	4.20	4.10

TYP 2: Week 9

Date : 21/03/2007 (Wednesday)

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	276.51	277.34	275.02	276.29
2	Distribution Chamber	224.55	228.36	223.11	225.34
3	Aeration Chamber	493.69	493.13	494.35	493.72
4	Return Chamber	311.89	313.30	320.01	315.07
5	Effluent	180.94	182.41	181.33	181.56

Ammoniacal Nitrogen (mg/L NH_3 - N)

Point	Location	1	2	3	Average
1	Influent	24.00	23.70	24.40	24.03
2	Distribution Chamber	25.10	25.20	25.10	25.13
3	Aeration Chamber	1.91	1.57	1.71	1.73
4	Return Chamber	0.89	0.80	0.85	0.85
5	Effluent	1.97	1.90	1.94	1.94

Nitrate (mg/L NO_3)

Point	Location	1	2	3	Average
1	Influent	0.10	0.00	0.00	0.03
2	Distribution Chamber	0.10	0.00	0.00	0.03
3	Aeration Chamber	10.60	10.20	10.70	10.50
4	Return Chamber	11.20	11.70	11.40	11.43
5	Effluent	8.30	8.20	8.20	8.23

FYP 2: Week 10

Date : 28/03/2007 (Wednesday) - Oxidation Pond

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	196.99	195.96	197.81	196.92
2	Distribution Chamber				
3	Aeration Chamber				
4	Return Chamber				
5	Effluent	179.50	177.61	180.15	179.09

Ammoniacal Nitrogen (mg/L NH_3 - N)

Point	Location	1	2	3	Average
1	Influent	16.72	16.65	16.55	16.64
2	Distribution Chamber				
3	Aeration Chamber				
4	Return Chamber				
5	Effluent	9.08	9.07	9.04	9.06

Nitrate (mg/L NO_3)

Point	Location	1	2	3	Average
1	Influent	-0.30	-0.30	-0.10	-0.23
2	Distribution Chamber				
3	Aeration Chamber				
4	Return Chamber				
5	Effluent	-0.90	-0.80	-1.00	-0.90

FYP 2: Week 11

Date : 06/04/2007 (Friday) - After rectification + After Johor trip

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	173.99	173.41	173.63	173.68
2	Distribution Chamber	157.71	155.42	159.92	157.68
3	Aeration Chamber	307.09	303.85	309.59	306.84
4	Return Chamber	164.15	167.46	167.89	166.50
5	Effluent	151.52	153.48	154.04	153.01

Ammoniacal Nitrogen (mg/L NH_3 - N)

Point	Location	1	2	3	Average
1	Influent	22.70	22.30	22.90	22.63
2	Distribution Chamber	24.90	24.80	25.10	24.93
3	Aeration Chamber	23.30	23.60	23.50	23.47
4	Return Chamber	24.30	24.50	24.70	24.50
5	Effluent	27.60	27.40	27.20	27.40

Nitrate (mg/L NO_3)

Point	Location	1	2	3	Average
1	Influent	0.40	0.60	0.50	0.50
2	Distribution Chamber	1.70	1.30	1.10	1.37
3	Aeration Chamber	0.90	0.90	0.70	0.83
4	Return Chamber	0.80	0.90	0.90	0.87
5	Effluent	0.80	0.60	0.70	0.70

Nitrite (mg/L NO_2)

Point	Location	1	2	3	Average
1	Influent				
2	Distribution Chamber				
3	Aeration Chamber	0.029	0.032	0.033	0.031
4	Return Chamber	0.033	0.036	0.033	0.034
5	Effluent	0.010	0.008	0.012	0.010

FYP 2: Week 12

Date : 11/04/2007 (Wednesday) - People cleaning up clarifier

Total Phosphorus (mg/L PO_4^{3-})

Point	Location	1	2	3	Average
1	Influent	175.02	172.17	174.23	173.81
2	Distribution Chamber	276.17	278.50	277.57	277.41
3	Aeration Chamber	173.88	176.05	175.00	174.98
4	Return Chamber	210.64	213.07	210.69	211.47
5	Effluent	139.09	130.93	134.74	134.92

Ammoniacal Nitrogen (mg/L NH_3 - N)

Point	Location	1	2	3	Average
1	Influent	48.00	49.70	50.40	49.37
2	Distribution Chamber	49.50	51.10	52.40	51.00
3	Aeration Chamber	59.10	61.80	62.10	61.00
4	Return Chamber	64.50	66.20	68.80	66.50
5	Effluent	38.30	42.40	43.20	41.30

Nitrate (mg/L NO_3)

Point	Location	1	2	3	Average
1	Influent	0.50	0.30	0.40	0.40
2	Distribution Chamber	1.20	1.20	1.40	1.27
3	Aeration Chamber	0.90	1.10	0.70	0.90
4	Return Chamber	1.40	1.30	1.30	1.33
5	Effluent	0.20	0.30	0.30	0.27

Nitrite (mg/L NO_2)

Point	Location	1	2	3	Average
1	Influent				
2	Distribution Chamber				
3	Aeration Chamber	0.012	0.012	0.014	0.013
4	Return Chamber	0.014	0.014	0.014	0.014
5	Effluent	0.006	0.006	0.006	0.006

Removal Percentage

Ammoniacal Nitrogen

	Influent	Effluent	I - E	%
11.00 am (13/08/06)	17.2	12.8	4.4	26
11.30 am (15/08/06)	17.2	13.4	3.8	22
12.30 pm (12/08/06)	19.6	17.3	2.3	12
4.30 pm (11/08/06)	22.5	17.9	4.6	20

	Influent	Effluent	I - E	%
7/3/07	23.13	19.86	3.28	14
9/3/07	18.72	10.76	7.96	43
14/3/07	15.24	1.94	13.29	87
21/3/07	24.03	1.94	22.10	92
6/4/07	22.63	21.40	1.23	5
11/4/07	49.37	41.30	8.07	16
13/4/07	15.79	13.55	2.24	14

Total Phosphorus

	Influent	Effluent	I - E	%
11.00 am (13/08/06)	32.5	29.6	2.9	9
11.30 am (15/08/06)	39.2	29.9	9.3	24
12.30 pm (12/08/06)	30.8	27.4	3.4	11
4.30 pm (11/08/06)	46.3	34.9	11.4	25

	Influent	Effluent	I - E	%
31/1/07	162.08	157.99	4.09	3
9/2/07	266.14	225.65	40.49	15
14/2/07	184.51	183.43	1.08	1
7/3/07	186.17	88.06	98.10	53
9/3/07	390.40	293.14	97.26	25
14/03/07	175.19	135.24	39.96	23
21/3/07	276.29	181.56	94.73	34
6/4/07	173.68	153.01	20.66	12
11/4/07	173.81	134.92	38.89	22
13/4/07	173.55	148.78	24.78	14

Statistical Analysis

Total Phosphorus

Fri	Mon	Sat	Tues
1	2	3	4
6/10/2006	9/10/2006	14/10/06	17/10/06
452.2167	483.19	183.16	187.01
504.1733	473.37	225.385	191.3
480.8467	533.50	228.31	184.46
446.6833	488.94	173.77	203.99
445.8467	481.79	195.9	241.965
474.0267	443.82	148.62	142.755
417.81	442.84	143.305	154.225
544.8433	465.67	194.87	138.375
413.2833	458.80	162.075	227.445
395.67	473.25	194.445	160.99
548.06	450.06	133.795	153.625
443.49	694.58	127.745	209.46
663.7967	504.38	115.805	194.15
443.1267	466.42	116.085	137.885
394.3733	463.31	274.545	131.105
526.96	548.11	142.245	150.235
510.41	453.07	243.78	197
467.03	493.39	171.12	167.395
418.6433	448.83	204.97	175.82
434.4933	439.89	135.97	134.89
427.02	486.61	184.74	106.9
439.7533	550.64	142.235	137.795
460.67	534.78	150.325	147.105
596.65	473.61	191.31	188.87

1 and 2
t-Test: Two-Sample Assuming Equal Variances

	38878	*38970*
Mean	472.9115	489.7022
Variance	4264.231	2970.712
Observations	24	24
Pooled Variance	3617.472	
Hypothesized Mean Difference	0	
df	46	
t Stat	-0.96707	
P(T<=t) one-tail	0.169284	
t Critical one-tail	1.67866	
P(T<=t) two-tail	0.338568	
t Critical two-tail	2.012896	

1 and 3
t-Test: Two-Sample Assuming Equal Variances

	38878	*14/10/06*
Mean	472.9115	174.3546
Variance	4264.231	1722.372
Observations	24	24
Pooled Variance	2993.301	
Hypothesized Mean Difference	0	
df	46	
t Stat	18.90352	
P(T<=t) one-tail	1.27E-23	
t Critical one-tail	1.67866	
P(T<=t) two-tail	2.55E-23	
t Critical two-tail	2.012896	

1 and 4
t-Test: Two-Sample Assuming Equal Variances

	38878	*17/10/06*
Mean	472.9115	169.3646
Variance	4264.231	1125.818
Observations	24	24
Pooled Variance	2695.024	
Hypothesized Mean Difference	0	
df	46	
t Stat	20.25513	
P(T<=t) one-tail	7.42E-25	
t Critical one-tail	1.67866	
P(T<=t) two-tail	1.48E-24	
t Critical two-tail	2.012896	

Ammoniacal Nitrogen

Fri	Mon	Sat	Tues
1	2	3	4
6/10/2006	9/10/2006	14/10/06	17/10/06
36.48	37.71	8.46	18.65
34.64	30.44	6.75	15.15
26.97	24.94	4.56	9.72
20.08	22.02	8.46	8.59
49.56	53.37	2.65	17.16
61.45	67.42	6.96	11.54
34.61	36.31	2.21	12.41
22.07	23.11	21.47	12.23
12.36	12.34	17.89	14.60
60.48	65.09	22.11	9.47
26.54	27.72	16.95	11.92
28.15	29.46	17.39	8.78
19.81	20.64	8.30	8.41
33.72	34.72	8.20	9.59
28.35	30.68	17.87	22.02
33.22	62.51	10.02	15.55
30.33	30.14	12.24	16.82
22.22	26.80	7.44	10.13
24.41	26.20	19.44	9.59
28.58	33.85	6.41	21.96
29.25	46.95	21.37	3.33
31.04	31.22	13.30	7.14
37.05	28.50	8.81	7.82
39.67	44.70	18.96	11.67

1 and 2
t-Test: Two-Sample Assuming Equal Variances

	38878	*38970*
Mean	32.04255	35.28486
Variance	137.4756	207.62
Observations	24	24
Pooled Variance	172.5478	
Hypothesized Mean Difference	0	
df	46	
t Stat	-0.85505	
P(T<=t) one-tail	0.198478	
t Critical one-tail	1.67866	
P(T<=t) two-tail	0.396956	
t Critical two-tail	2.012896	

1 and 3
t-Test: Two-Sample Assuming Equal Variances

	38878	*14/10/06*
Mean	32.04255	12.00583
Variance	137.4756	39.94223
Observations	24	24
Pooled Variance	88.70892	
Hypothesized Mean Difference	0	
df	46	
t Stat	7.369422	
P(T<=t) one-tail	1.28E-09	
t Critical one-tail	1.67866	
P(T<=t) two-tail	2.55E-09	
t Critical two-tail	2.012896	

1 and 4
t-Test: Two-Sample Assuming Equal Variances

	38878	*17/10/06*
Mean	32.04255	12.25729
Variance	137.4756	21.73586
Observations	24	24
Pooled Variance	79.60574	
Hypothesized Mean Difference	0	
df	46	
t Stat	7.681748	
P(T<=t) one-tail	4.37E-10	
t Critical one-tail	1.67866	
P(T<=t) two-tail	8.74E-10	
t Critical two-tail	2.012896	

APPENDIX II

(Standard Operating Procedures)

Nitrogen, Ammonia

Method 8038

Nessler Method

(0.02 to 2.50 mg/L NH_3–N

Scope and Application: For water, wastewater, and seawater; distillation is required for wastewater and seawater; USEPA accepted for wastewater analysis (distillation required); see Distillation on page 4 of this procedure.

Adapted from *Standard Methods for the Examination of Water and Wastewater 4500-NH_3 B & C.*

Before starting the test:

For more accurate results, determine a reagent blank value for each new lot of reagent. Follow the procedure using deionized water instead of the sample. Subtract the reagent blank value from the final results or perform a reagent blank adjust. See the user manual for more information.

Nessler Reagent contains mercuric iodide. Both the sample and the blank will contain mercury (D009) at a concentration regulated as a hazardous waste by the Federal RCRA. Do not pour these solutions down the drain. Refer to a current MSDS for safe disposal and handling instructions.

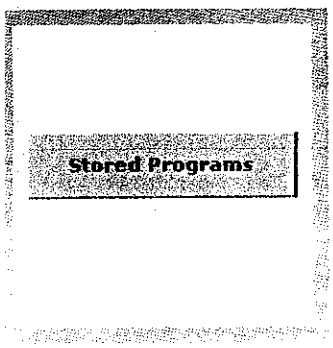
Collect the following items:	Quantity
Ammonia Nitrogen Reagent set	1
Deionized Water	25 mL
Graduated Mixing Cylinders	2
Sample Cells, 1-inch square, 10-mL	2
Serological Pipet, 1-mL	2

Note: *Reorder information for consumables and replacement items is on page 5.*

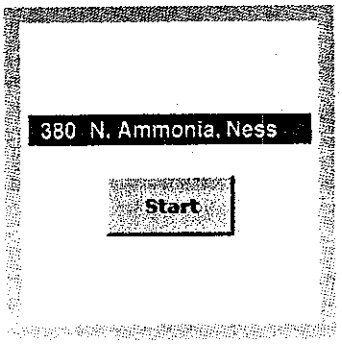
Note: *Nessler Reagent is toxic and corrosive. Pipet carefully, using a pipet filler. When dispensing reagent from a dropper bottle, hold the bottle vertically. Do not hold the bottle at an angle.*

Note: *A yellow color will develop if ammonia is present. (The reagent will cause a faint yellow color in the blank.)*

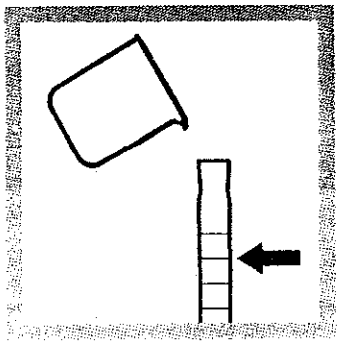
Nessler Method 8038



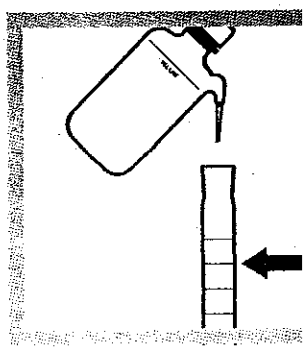
1. Press **STORED PROGRAMS.**



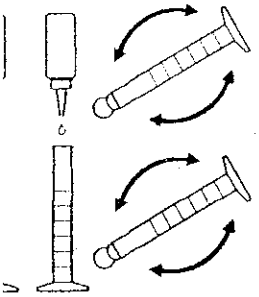
2. Select the test.



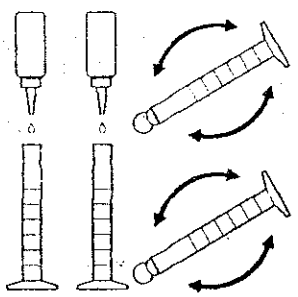
3. **Prepared Sample:** Fill a 25-mL mixing graduated cylinder to the 25-mL mark with sample.



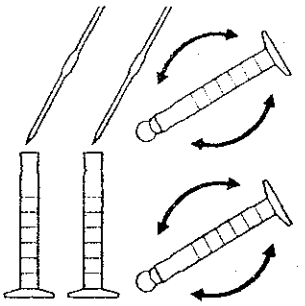
4. **Blank Preparation:** Fill a 25-mL mixing graduated cylinder to the 25-mL mark with deionized water.



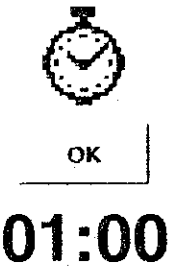
dd three drops
neral Stabilizer to
cylinder. Stopper and
several times to mix.



6. Add three drops of Polyvinyl Alcohol Dispersing Agent to each cylinder. Stopper and invert several times to mix.

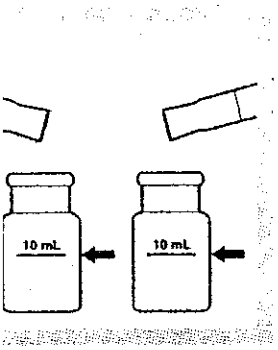


7. Pipet 1.0 mL of Nessler Reagent into each cylinder. Stopper and invert several times to mix.

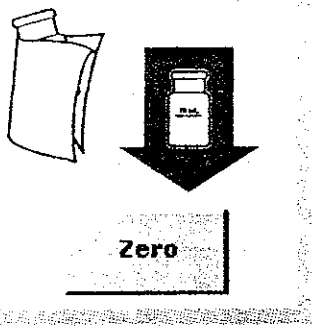


8. Press **TIMER>OK**.

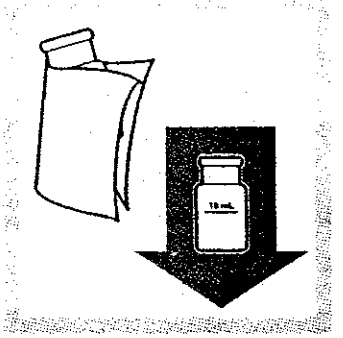
A one-minute reaction period will begin.



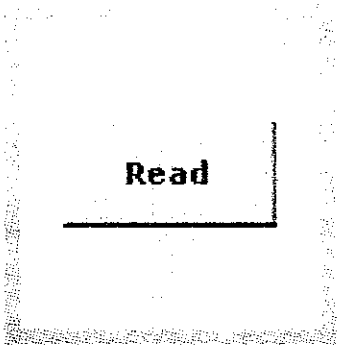
our 10 mL of each
on into a square
le cell.



10. When the timer expires, insert the blank into the cell holder with the fill line facing right. Press **ZERO**. The display will show:
0.00 mg/L NH_3 –N



11. Wipe the prepared sample and insert it into the cell holder with the fill line facing right.



12. Press **READ**.

Results are in mg/L NH_3–N.

rferences

Table 1 Interfering Substances and Levels

fering Substance	Interference Levels and Treatments
rine	Remove residual chlorine by adding 2 drops of sodium arsenite for each mg/L chlorine (Cl_2) from a 250 mL sample. Sodium thiosulfate can be used instead of sodium arsenite. See Sample Collection, Storage, and Preservation.
lness	A solution containing a mixture of 500 mg/L $CaCO_3$ and 500 mg/L Mg as $CaCO_3$ does not interfere. If the hardness concentration exceeds these concentrations, add extra Mineral Stabilizer.
	Interferes at all levels by causing turbidity with Nessler Reagent.
vater	May be analyzed by adding of 1.0 mL (27 drops) of Mineral Stabilizer to the sample before analysis. This complexes the high magnesium concentrations found in sea water, but the sensitivity of the test is reduced by 30 percent due to the high chloride concentration. For best results, perform a calibration, using standards spiked to the equivalent chloride concentration, or distill the sample as described below.
de	Interferes at all levels by causing turbidity with Nessler Reagent.

Table 1 Interfering Substances and Levels (continued)

nterfering Substance	Interference Levels and Treatments
Glycine, various aliphatic and aromatic amines, organic chloramines, acetone, aldehydes and alcohols	May cause greenish or other off colors or turbidity. Distill the sample if these compounds are present.

Sample Collection, Storage, and Preservation

Collect samples in clean glass or plastic bottles. If chlorine is present, add one drop of 0.1 N Sodium Thiosulfate* for each 0.3 mg/L Cl_2 in a 1-liter sample. Preserve the sample by reducing the pH to 2 or less with sulfuric acid (at least 2 mL). Store at 4 °C (39 °F) or less. Preserved samples may be stored up to 28 days. Warm samples to room temperature and neutralize with 5 N Sodium Hydroxide* before analysis. Correct the test result for volume additions.

Accuracy Check

Standard Additions Method (Sample Spike)

1. After reading test results, leave the sample cell (unspiked sample) in the instrument.
2. Press **OPTIONS>MORE**. Press **STANDARD ADDITIONS**. A summary of the standard additions procedure will appear.
3. Press **OK** to accept the default values for standard concentration, sample volume, and spike volumes. Press **EDIT** to change these values. After values are accepted, the unspiked sample reading will appear in the top row. See the user manual for more information.
4. Snap the neck off a Nitrogen Ammonia Voluette® Ampule Standard, 50-mg/L NH_3–N.
5. Prepare three sample spikes. Fill three mixing cylinders with 25 mL of sample. Use the TenSette® Pipet to add 0.1 mL, 0.2 mL, and 0.3 mL of the 50 mg/L standard, respectively to each sample and mix thoroughly.
6. Analyze each sample spike as described in the procedure above, starting with the 0.1 m sample spike. Accept each standard additions reading by pressing **READ**. Each addition should reflect approximately 100% recovery.
7. After completing the sequence, press **GRAPH** to view the best-fit line through the standar additions data points, accounting for the matrix interferences. Press **IDEAL LINE** to view the relationship between the sample spikes and the "Ideal Line" of 100% recovery.

Standard Solutions Method

1. To check accuracy, use a 1.0-mg/L Nitrogen Ammonia Standard Solution. Or, prepare a 1.0-mg/L ammonia nitrogen standard solution by pipetting 1.00 mL of Nitrogen Ammonia Voluette® Ampule Standard, 50-mg/L, into a 50-mL volumetric flask. Dilute to the mark with deionized water. Prepare this solution daily. Perform the Nessler procedure as described above.

See Optional Reagents and Apparatus on page 5.

2. To adjust the calibration curve using the reading obtained with the standard solution, press **OPTIONS>MORE** on the current program menu. Press **STANDARD ADJUST**.

3. Press **ON**. Press **ADJUST** to accept the displayed concentration. If an alternate concentration is used, press the number in the box to enter the actual concentration, then press **OK**. Press **ADJUST**.

tillation

1. Measure 250 mL of sample into a 250-mL graduated cylinder and pour into a 400-mL beaker. Destroy chlorine, if necessary, by adding 2 drops of Sodium Arsenite Solution per mg/L Cl_2.

2. Add 25 mL of Borate Buffer Solution and mix. Adjust the pH to about 9.5 with 1 N sodium hydroxide solution. Use a pH meter.

3. Set up the General Purpose Distillation Apparatus as shown in the *Distillation Apparatus Manual*. Pour the solution into the distillation flask. Add a stir bar.

4. Use a graduated cylinder to measure 25 mL of deionized water into a 250-mL Erlenmeyer flask. Add the contents of one Boric Acid Powder Pillow. Mix thoroughly. Set the flask under the still drip tube. Elevate so the end of the tube is immersed in the solution.

5. Turn on the heater power switch. Set the stir control to 5 and the heat control to 10. Turn on the water and adjust to maintain a constant flow through the condenser.

6. Turn off the heater after collecting 150 mL of distillate. Immediately remove the collection flask to avoid sucking solution into the still. Measure the distillate to ensure 150 mL was collected (total volume = 175 mL).

7. Adjust the pH of the distillate to about 7 with 1 N sodium hydroxide. Use a pH meter.

8. Pour the distillate into a 250-mL volumetric flask; rinse the Erlenmeyer with deionized water. Add the rinsings to the volumetric flask. Dilute to the mark. Stopper. Mix thoroughly. Analyze as described above.

nmary of Method

The Mineral Stabilizer complexes hardness in the sample. The Polyvinyl Alcohol Dispersing Agent aids the color formation in the reaction of Nessler Reagent with ammonium ions. A yellow color is formed proportional to the ammonia concentration. Test results are measured at 425 nm.

onsumables and Replacement Items

equired Reagents

lescription	Quantity/Test	Unit	Cat. No.
ammonia Nitrogen Reagent Set, includes:	—	—	24582-00
Nessler Reagent	2 mL	500 mL	21194-49
Mineral Stabilizer	6 drops	50 mL SCDB	23766-26
Polyvinyl Alcohol Dispersing Agent	6 drops	50 mL SCDB	23765-26
Vater, deionized	25 mL	4 L	272-56

equired Apparatus

)escription	Quantity/Test	Unit	Cat. No.
Cylinder, graduated, mixing, 25-mL	2	each	20886-40
Pipet, serological, 1-mL	2	each	9190-02
Pipet Filler, safety bulb	1	each	14651-00
Sample Cells, 1-inch square, 10-mL, matched pair	2	2/pkg	24954-02

ecommended Standards and Apparatus

)escription	Unit	Cat. No.
Flask, volumetric, Class A, 50 mL	each	14574-41
Nitrogen, Ammonia Standard Solution, 1-mg/L NH_3–N	500 mL	1891-49
Nitrogen, Ammonia Standard Solution, 10-mL Voluette® Ampule, 50-mg/L NH_3–N	16/pkg	14791-10
Pipet, TenSette® 0.1 - 1.0 mL	each	19700-01
Pipet Tips, for TenSette Pipet 19700-01	50/pkg	21856-96
Pipet Tips, for TenSette Pipet 19700-01	1000/pkg	21856-28
Pipet, volumetric, Class A, 1.00 mL	each	14515-35
Wastewater, Effluent Inorganics, for NH_3–N, NO_3–N, PO_4, COD, SO_4, TOC	500 mL	28332-49

ptional Reagents and Apparatus

)escription	Cat. No.
Distillation Apparatus, General	22653-00
Heater and Support Apparatus, 115 VAC, 60 Hz	22744-00
Heater and Support Apparatus, 230 VAC, 50 Hz	22744-02
Mixing Cylinders	20886-40
Pour-Thru Cell Kit	59404-00
Sodium Thiosulfate, 0.1 N	323-32
Sodium Hydroxide, 5 N	2450-32

Phosphorus, Tota

Method 8190

PhosVer® 3 with Acid Persulfate Digestion Metho

t 'N Tube™ Vials

(0.06 to 3.50 mg/L PO_4^{3-} or 0.02 to 1.10 mg/L P

pe and Application: For water, wastewater, and seawater; USEPA Accepted for reporting tewater analyses

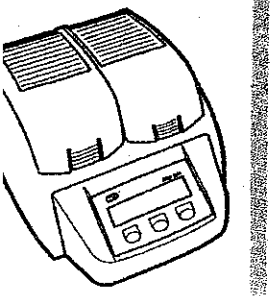
Tips and Techniques

more accurate results, determine a reagent blank value for each new lot of reagent. Follow the procedure using deionized er in place of the sample. Subtract the reagent blank value from the final results or perform a reagent blank adjust. See the ·ument manual for more information on *Running a Reagent Blank*.

test range for total phosphate is limited to 0.06 to 3.5 mg/L PO_4^{3-}. Values greater than 3.5 mg/L may be used to estimate ion ratios, but should NOT be used for reporting purposes. If the value is greater than 3.5 mg/L, dilute the sample and repeat digestion and the colorimetric test.

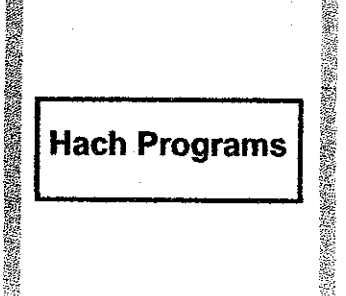
l samples will contain molybdenum. In addition, final samples will have a pH less than 2 and are considered corrosive (D002) ıe Federal RCRA.

Test 'N Tube Method 8190



urn on the DRB 200 or. Heat to 150 °C.

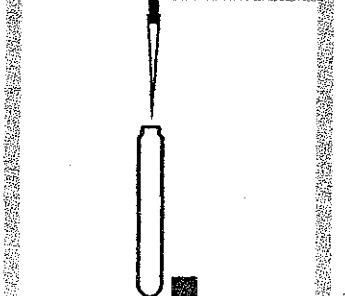
See the DRB 200 User al for selecting ogrammed temperature ations.



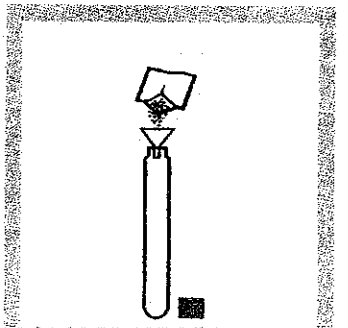
2. Touch **Hach Programs.**

Select program **536 P Total/AH PV TNT.**

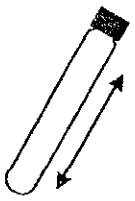
Touch **Start.**



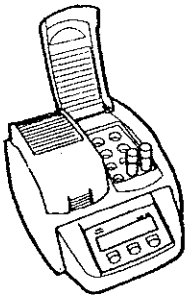
3. Use a TenSette® Pipet to add 5.0 mL of sample to a Total and Acid Hydrolyzable Test Vial.



4. Use a funnel to add the contents of one Potassium Persulfate Powder Pillow for Phosphonate to the vial.



Cap tightly and shake issolve.

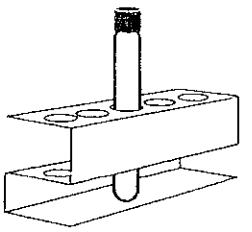


6. Place the vial into the DRB 200 Reactor.

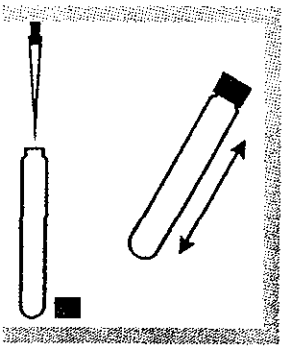
7. Touch the timer icon.

Touch **OK**.

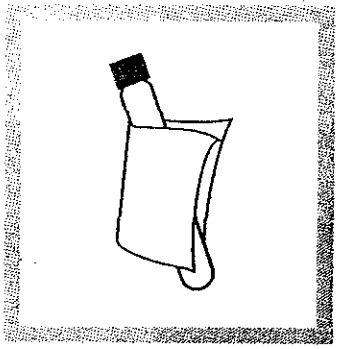
A 30-minute heating period will begin.



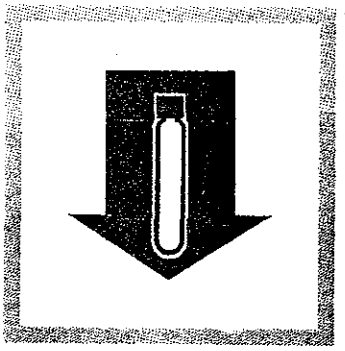
8. When the timer beeps, carefully remove the hot vial from the reactor. Place it in a test tube rack and cool to room temperature.



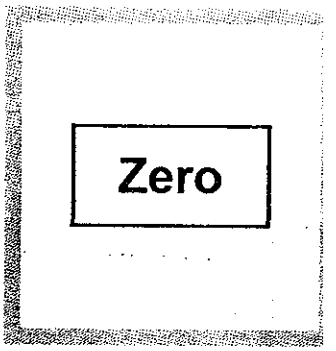
Use a TenSette Pipet dd 2 mL of 1.54 N ium Hydroxide dard Solution to the Cap and mix.



10. Wipe the outside of the vial with a damp cloth followed by a dry one, to remove fingerprints or other marks.



11. Place the vial into the cell holder.

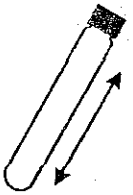


12. Touch **Zero**.

The display will show:

0.00 mg/L PO_4^{3-}

Use a funnel to add contents of one sVer 3 Powder Pillow ıe vial.



14. Cap tightly and shake to mix for 10–15 seconds.

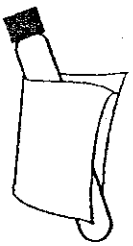
The powder will not dissolve completely.

15. Touch the timer icon.

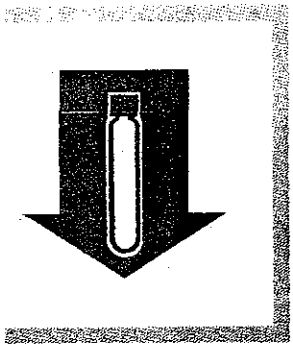
Touch **OK**.

A two-minute reaction period will begin.

Read the sample within 2–8 minutes after the timer beeps.



16. After the timer beep wipe the outside of the vial with a damp cloth followed by a dry one, t remove fingerprints or other marks.



Place the prepared ıple vial into the cell der.

ults will appear in /L PO_4^{3-}.

ıterferences

ıminum	Greater than 200 mg/L
senate	Interferes at any level
ıromium	Greater than 100 mg/L
ıpper	Greater than 10 mg/L
ın	Greater than 100 mg/L
ckel	Greater than 300 mg/L
l, excess buffering	Highly buffered samples or extreme sample pH may exceed the buffering capacity of the reagents and require sample pretreatment.
ica	Greater than 50 mg/L
icate	Greater than 10 mg/L
ılfide	Greater than 90 mg/L
rbidity (large amounts) color	May cause inconsistent results because the acid in the powder pillow may dissolve some of the suspended particles and because of variable desorption of orthophosphate from the particles.
ıc	Greater than 80 mg/L

mple Collection, Storage, and Preservation

Collect samples in plastic or glass bottles that have been acid washed with 1:1 Hydrochloric Acid Solution (Cat. No. 884-49) and rinsed with deionized water. Do not use commercial detergents containing phosphate for cleaning glassware used in this test.

Analyze the samples immediately for the most reliable results. If prompt analysis is not possible, samples may be preserved up to 28 days by adjusting the pH to 2 or less with concentrated Sulfuric Acid (about 2 mL per liter) (Cat. No. 979-49) and storing at 4 °C. Warm the sample to room temperature and neutralize with 5.0 N Sodium Hydroxide (Cat. No. 2450-53) before analysis. Correct for volume additions: see *Section 3.1.3 Correcting for Volume Additions* on page *23*.

:curacy Check

Standard Additions Method (Sample Spike)

1. Clean glassware with 1:1 Hydrochloric Acid Standard Solution. Rinse agai with deionized water. Do not use phosphate detergents to clean glassware
2. After reading test results, leave the sample cell (unspiked sample) in the instrument. Verify the chemical form.
3. Touch **Options**. Touch **Standard Additions**. A summary of the standard additions procedure will appear.
4. Touch **OK** to accept the default values for standard concentration, sample volume, and spike volumes. Touch **Edit** to change these values. After value are accepted, the unspiked sample reading will appear in the top row. See *Section 3.2.2 Standard Additions* on page *26* for more information.
5. Open a Phosphate 10-mL Ampule Standard, 50-mg/L as PO_4^{3-}.
6. Prepare three sample spikes. Fill three Mixing Cylinders (Cat. No. 1896-40) with 25 mL of sample. Use the TenSette Pipet to add 0.1 mL, 0.2 mL, and 0.3 mL of standard, respectively, to each sample and mix thoroughly.

7. Analyze each standard addition sample as described above (use a 5-mL aliquot of the spiked sample as the sample). Accept each standard addition reading by touching **Read**. Each addition should reflect approximately 100% recovery.
8. After completing the sequence, touch **Graph** to view the best-fit line through the standard additions data points, accounting for matrix interferences. Touch **View: Fit**, then select **Ideal Line** and touch **OK** to view the relationship between the sample spikes and the "Ideal Line" of 100% recovery.

See *Section 3.2.2 Standard Additions* on page *26* for more information.

Standard Solution Method

1. Use a 1.0-mg/L phosphate standard solution in place of the sample. Perform the procedure as describe above.
2. To adjust the calibration curve using the reading obtained with the 1.0-mg/L PO_4^{3-} Phosphate Standard Solution, touch **Options** on the current program menu. Touch **Standard Adjust**.
3. Touch **On**. Touch **Adjust** to accept the displayed concentration (the value depends on the selected chemical form). If an alternate concentration is used, touch the number in the box to enter the actual concentration, then touch **OK**. Touch **Adjust**.

For more information, see *Section 3.2.4 Adjusting the Standard Curve* on page *29*.

ethod Performance

Precision

Standard: 3.00 mg/L PO_4^{3-}

536	2.90–3.10 mg/L

See *Section 3.4.3 Precision* on page 33 for more information, or if the standard concentration did not fall within the specified range.

Sensitivity

Portion of Curve	ΔAbs	Δ Concentration
Entire range	0.010	0.06 mg/L PO_4^{3-}

See *Section 3.4.5 Sensitivity* on page *34* for more information.

mmary of Method

Phosphates present in organic and condensed inorganic forms (meta-, pyro-, or other polyphosphates) must be converted to reactive orthophosphate before analysis. Pretreatment of the sample with acid and heat provides the condition for hydrolysis of the condensed inorganic forms. Organic phosphates are converted to orthophosphates by heating with acid and persulfate.

Orthophosphate reacts with molybdate in an acid medium to produce a mixed phosphate/molybdate complex. Ascorbic acid then reduces the complex, giving an intense molybdenum blue color. Test results are measured at 880 nm.

hosphorus, Total

equired Reagents

escription	Quantity Required Per Test	Unit	Cat.
tal Phosphorus Test 'N Tube™ Reagent Set		50 tests	27426
cludes:			
PhosVer® 3 Phosphate Reagent Powder Pillows	1	50/pkg	21060
Potassium Persulfate Powder Pillows	1	50/pkg	20847
Sodium Hydroxide Solution, 1.54 N	2 mL	100 mL	27430
Total and Acid Hydrolyzable Test Vials	1	50/pkg	
ater, deionized		4 liters	272-

equired Apparatus

RB 200 Reactor, 110 V, 15 x 16 mm	1	each	LTV082.52.400
RB 200 Reactor, 220 V, 15 x 16 mm	1	each	LTV082.52.400
nnel, micro	1	each	25843-3
pet, TenSette®, 1 to 10 mL	1	each	19700-1
pet Tips, for 19700-10 TenSette® Pipet	1	1000/pkg	21856-2
st Tube Rack	1	each	18641-0

equired Standards

osphate Standard Solution, 10-mL Voluette® Ampule, 50-mg/L as PO_4^{3-}		16/pkg	171-1
osphate Standard Solution, 1-mg/L as PO_4^{3-}		500 mL	2569-
astewater Standard, Effluent Inorganics, for NH_3–N, NO_3–N, PO_4, COD, SO_4, TOC		500 mL	28332-

Not sold separately.

HACH®
FOR TECHNICAL ASSISTANCE, PRICE INFORMATION AND ORDERING:
In the U.S.A. – Call toll-free 800-227-4224
Outside the U.S.A. – Contact the HACH office or distributor serving you.
On the Worldwide Web – www.hach.com; E-mail – techhelp@hach.com

HACH COMPANY
WORLD HEADQUART
Telephone: (970) 669-
FAX: (970) 669-2932

APPENDIX III

(Biological Kinetic Parameter Estimation)

Required Kinetic Parameters

The important kinetic parameters required for biological phosphorus removal process design include the following.

- Y The cell yield coefficient defined as the mass of activated sludge or biomass produced per unit of substrate removed (mg VSS/mg COD).
- k_d The endogenous decay rate or mass of cells lost during endogenous respiration per unit of time (^{1}/day).
- μ_{max} The maximum specific growth rate. The specific growth rate, μ, is the rate of growth per unit of time ($^1/_{day}$).
- K_s The half-saturation constant or shape factor of the Monod equation. K_s equals the substrate concentration (mg/L) at which μ equals 1/2 of μ_{max}.
- q_N The specific nitrification rate, which is measured by rate of NO_2^-+NO_3^- formation (mg NO_2^- + NO_3^--N/mg VSS/hour).
- q_D The specific denitrification rate, which is measured by rate of NO_2^-+NO_3^- removed (mg NO_2^- + NO_3^-N/mg VSS/hour).

The theories and experimental procedures for determining the biological kinetic parameters defined above are discussed in this section. Also discussed are the measurement methods of phosphorus release and uptake rates. Although phosphorus release and uptake rates are not used in the design equations, the rates can provide insight into the design of BPR systems. Therefore, their measurement techniques are presented here.

Theoretical Base of the Kinetic Equations

The cell yield coefficient, Y, is one of the most important parameters used in biological kinetic models. It represents the mass of biomass produced per substrate removed. The endogenous decay rate, k_d, represents the rate of biomass loss due to endogenous respiration. The cell yield coefficient, Y, and endogenous decay rate, k_d, are critical for the prediction of waste-activated sludge production. In a BPR process, phosphorus is removed in the form of waste activated sludge. The stoichiometry between the organic substrate consumed and microorganisms produced can be expressed as:

$$\frac{dX}{dt} = Y\frac{dS}{dt} - k_d X \qquad (3)$$

where

X = concentration of mixed liquor volatile suspended solids (MLVSS) (mg/L);

t = time (day);

S = substrate concentration (mg/L);

Y = yield coefficient; mass of cells produced per unit mass of substrate utilized (mg VSS/mg COD); and

k_d = fraction of MLSS or cells oxidized by endogenous respiration per unit of time (^{1}/day).

This equation can be rewritten after dividing Equation 3 by X:

$$\frac{dX}{Xdt} = Y\frac{dS}{Xdt} - k_d \qquad (4)$$

It can then be rewritten on a finite time and mass basis:

$$\frac{\Delta X}{X\Delta t} = Y\frac{\Delta S}{X\Delta t} - k_d \qquad (5)$$

where

$\frac{\Delta X}{X\Delta t}$ = amount of specific cell mass produced over unit time, ($_1$/day); and

$\frac{\Delta S}{X\Delta t}$ = specific substrate utilization rate, U ($_1$/day).

The growth rate of microbial mass ($\frac{\Delta X}{\Delta t}$) is expressed as the specific growth rate, μ(i.e., the rate of growth per average unit of biomass during the time interval). Thus,

$$\mu = Y_x U - k_d \qquad (6)$$

Y and k_d Determination by Batch Test

It is difficult and time consuming to obtain Y and k_d by a conventional method that calls for operating at least four bench-scale, continuous-flow, biological reactors at different sludge ages. These parameters mainly affect activated sludge production and have relatively little effect on predicted effluent quality. However, phosphorus removal in a BPR process occurs through activated sludge wasting; therefore, Y and k_d are important for BPR design.

It is easy to determine Y and k_d by running a batch test, which is similar to the procedure used for T_bOD determination. Therefore, from the same batch test, T_bOD, Y, and k_d can be determined simultaneously. Since there is little difference in Y and k_d values (VSS basis) for conventional and phosphorus-removing treatment plants (McClintock et al. 1992), it may not be necessary to acclimate biomass for phosphorus removal in Y and k_d determination.

Data Analysis:

Some experimental runs may suffer from variability in VSS analyses used to measure biomass growth. If the samples are not carefully taken, the variability in the VSS measurements at each time may be even greater than the net growth of microorganisms, making the kinetic study inaccurate. Thus, the reactor contents must be mixed vigorously to disperse the mixture uniformly before taking samples. Triplicate VSS and duplicate COD samples should be analyzed. It may be desirable to increase the F/M above typical values. In this way, a more noticeable biomass growth may be attained. Idealized cell growth and substrate removal curves are shown in Figure 5. In experimental runs with municipal wastewater,

the net growth of microorganisms begins to decrease after several hours and becomes negative after the substrate is consumed. The experimental data are plotted and a smooth "best fit" curve is drawn through the points to average out some of the variability in the test data. These curves can either be drawn by hand or using a computer program to generate a best fit line through the data.

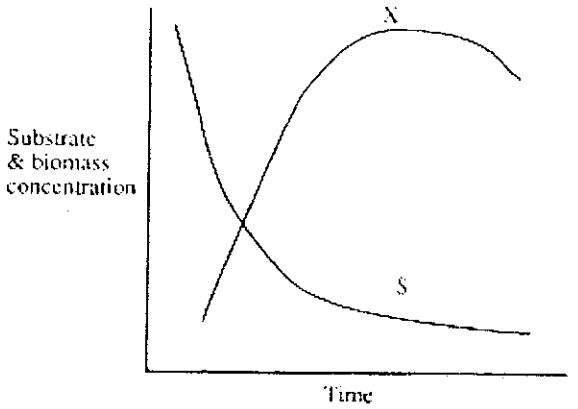


Figure 5. Generalized substrate consumption and biomass growth with time.

Values of S and X are chosen from the initial portion of the curve where the biomass is in the logarithmic growth phase.

These data are transformed into estimates of U, the substrate utilization rate, and μ, the specific growth rate, for each time period (Δt from i - 1 to i) using the following equations:

$$U_i = \frac{(S_{i-1} - S_i)/\Delta t_i}{(X_{i-1} + X_i)/2} \qquad (7)$$

$$\mu_i = \frac{(X_i - X_{i-1})/\Delta t_i}{(X_i + X_{i-1})/2} \qquad (8)$$

Based on Equation 6, μ and U can be plotted and a regression line can be drawn as shown in Figure 6. The endogenous decay rate, k_d, is the Y-intercept. Since k_d is extremely sensitive to the variability of the data points, it may be difficult to determine a reasonable value for k_d using this method. However, k_d can be obtained independently from a respirometer experiment that will be described in the section on "k_d Determination by Electrolytic Respirometer." Forcing a regression line to fit through the independently determined k_d makes the resulting slope a more reliable estimate of Y.

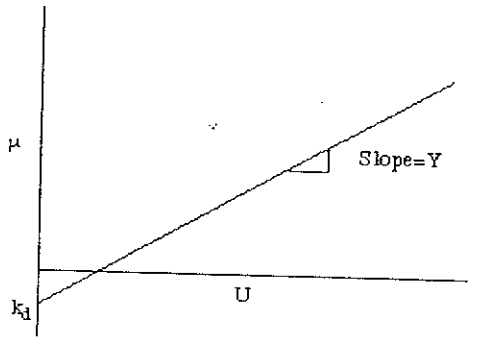


Figure 6. Plot of specific growth rate (u) with specific substrate utilization rate (U)

An example illustration of Y and k_d determination from an μvs. U plot is provided in Figure 7. The values of Y and k_d are determined to be 0.65 mg VSS/mg COD and 0.0026 ^{1}/hour (or 0.07 ^{1}/day), respectively.

Personhours needed: 24 hours + acclimation time (0-30 hours depending on wastewater).

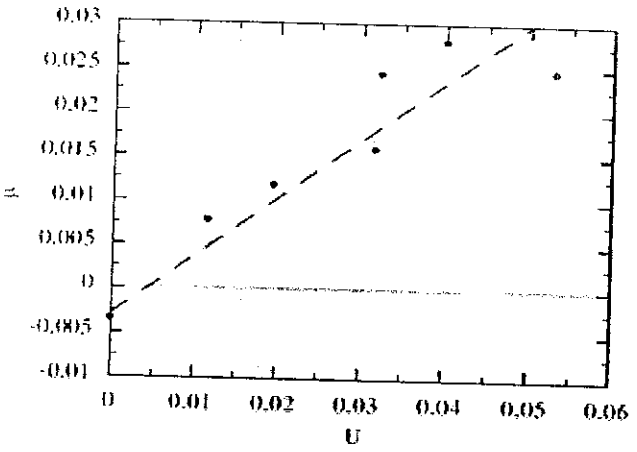


Figure 7. Y and K_d determination from μvs. U plot.

$_{max}$ and k_s Determination by Electrolyic Respirometer

e electrolytic respirometer is a very useful tool for determining the biokinetic growth constants, μ_{max} and K_s, used in the nod equation for non-inhibitory wastewater:

$$= \frac{\mu_{max} S}{(K_s + S)} \qquad (9)$$

where

μ_{max} = maximum specific growth rate (^{1}/hour); and

K_s = half-saturation constant or substrate concentration when $\mu = \mu_{max}/2$ (mg/L).

If the wastewater shows inhibition, the Haldane equation should be used. Once the relationship between μ and S is quantified, μ_{max} and K_s in the Monod model can be determined graphically or statistically.

Apparatus:

Electrolytic respirometer

COD measurement apparatus

VSS measurement apparatus

Filtration apparatus

A typical electrolytic respirometer is shown in Figure 8.

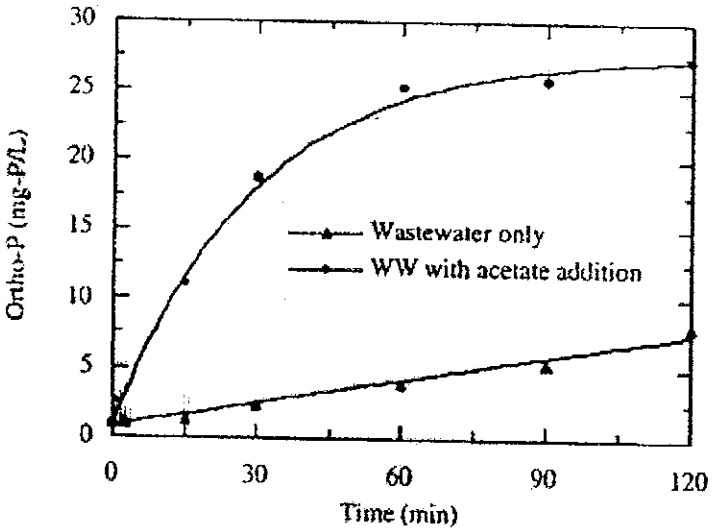


Figure 8: Electrolytic respirometer.

Procedure:

The procedures to run an electrolytic respirometer may vary slightly, depending on the manufacturer. Basically, the wastewater concentration is diluted by addition of washed activated sludge and added to each reactor cell. Each cell is prepared at a different F/M ratio, and contains a different initial mixed wastewater concentration (S_o). The activated sludge should be washed using the following procedure to remove any soluble and adsorbed substrate:

1. Settle the mixed liquor suspended solids.
2. Decant the supernatant.
3. Fill remaining volume with BOD_5 nutrient dilution water containing phosphate buffer, $MgSO_4$, $CaCl_2$, and $FeCl_3$ solution (17 mg of KH_2PO_4, 43.5 mg of K_2HPO_4, 66.8 mg of $NaHPO_4.7H_2O$, 3.4 mg of NH_4Cl, 45 mg of $MgSO_4$, 55 mg of $CaCl_2$, and 0.5 mg of $FeCl_3.6H_2O$ in 2 L of distilled water).
4. Mix gently and settle activated sludge.
5. Repeat step 2 through step 4 three times.

The oxygen uptake rate is automatically recorded by a computer data acquisition system. The initial mixed wastewater COD concentration (S_o) is used to calibrate the Monod equation. The initial mixed liquor VSS concentration (X_o) and the initial mixed wastewater COD concentration in each reactor cell must be analyzed. If an electrolytic respirometer is not available, a series of batch tests (see "Determination of the COD Fractions") for T_bOD determination may be conducted under several different F/M ratios.

Data Analysis:

The electrolytic respirometer's data acquisition system records the accumulated oxygen consumption vs. time, which then can be translated into biomass growth data. A typical plot of O_2 accumulation over time is shown in Figure 9.

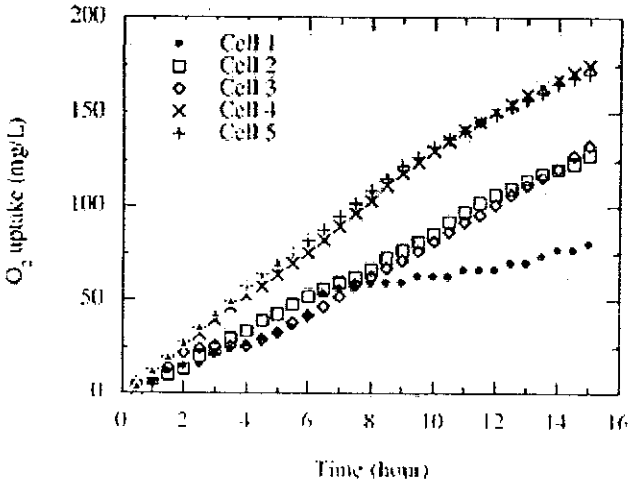


Figure 9. Typical O_2 accumulated overtime.

Oxygen uptake data can be converted into biomass growth curves using the following equation (Rozich and Gaudy 1992):

$$X_t = X_o + \frac{O_2 \text{ uptake}}{1/Y - f_{cv}} \qquad (10)$$

where

O_2 uptake = oxygen consumed by biomass (mg/L);

X_t = mixed liquor VSS concentration at time t in each reactor cell (mg/L); and

X_o = mixed liquor VSS concentration at time 0 in each reactor cell (mg/L).

This equation allows the indirect estimation of biomass concentrations over time.

To convert O_2 uptake data to biomass data using Equation 10, values for Y and f_{cv} must be determined. Y can be determined from the kinetic tests described in the section on "Y and k_d Determination by Batch Test." The values of f_{cv} can be assumed to be 1.42 - 1.48 mg COD/mg VSS. It should be noted that Y and f_{cv} in Equation 10 are assumed to be constant over time under declining substrate concentration conditions. The growth rate is obtained from the following equation:

$$\mu = \frac{\ln(X_2 - X_1)}{(t_2 - t_1)} \qquad (11)$$

Thus, when plotting the calculated X with time on a semi-logarithmic paper, the specific growth rate (μ) is the slope of the line. The typical plot of lnX vs. time is shown in Figure 9. The slopes in Figure 9 represent μvalues at different substrate concentrations. Table 10 lists the results of specific growth rate (μ) obtained from Figure 9 corresponded with the total substrate concentrations (S), which are predetermined from wastewater in each cell of the electrolytic respirometer. If a lag, stationary, or declining phase is shown in the ln X vs. time plot, the points in these phases should be excluded in the regression analysis. Because of this, only data points up to 10 hours from Figure 9, were used to determine μvalues in Figure 10.

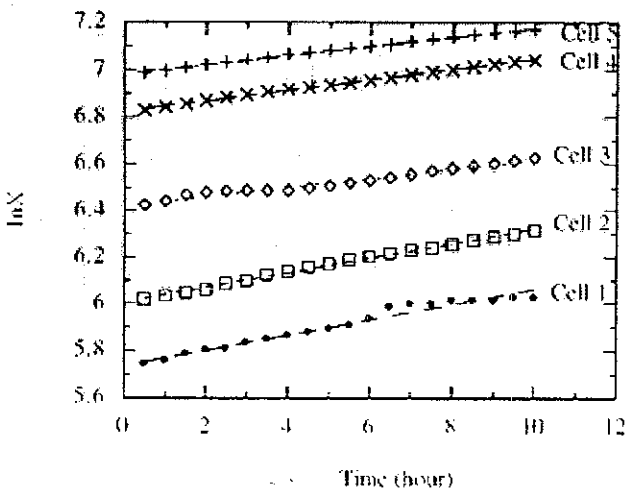


Figure 10. Typical ln X vs. time plot.

Table 10. Results of μ and S determination.

Cell #	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5
S (mg/L COD)	81	162	244	366	460
μ(1/hour)	0.0083	0.0151	0.0191	0.0216	0.0230

Assuming a wastewater is not inhibitory, the growth rate data (μ vs. S) are fitted to the Monod equation (Equation 9) to determine the values of the biokinetic constants m_{max} and K_s. An example illustration of a μvs. S plot used to determine μ_{max} and K_s is provided in Figure 11. Use of statistical computer software is highly recommended for parameter estimation. The curve was obtained from a nonlinear least squares method. The μ_{max} and K_s values were 0.034 ^{1}/hour and 209 mg/L, respectively, with the correlation coefficient of 0.99.

Personhours needed: 6 hours.

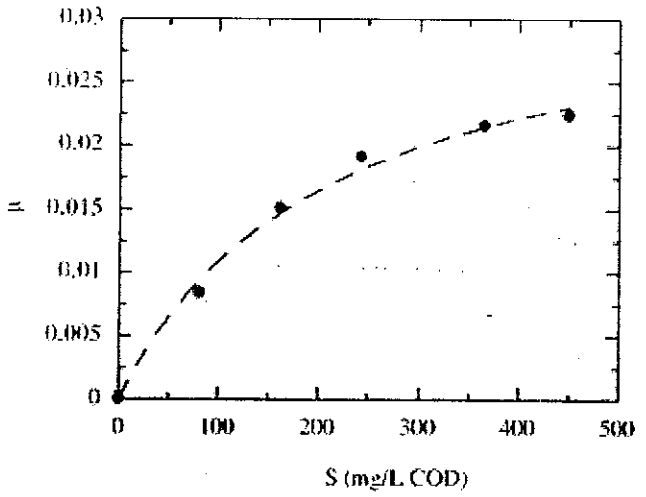


Figure 11. μvs. S plot to determine μ_{max} and K_s.

k_d Determination by Respirometer

Theory:

The oxygen consumption rate can be corrected for activated sludge concentration as follows:

$$\frac{dO}{dt} = 1.42 k_d X \qquad (12)$$

The endogenous decay rate, k_d, is defined as the rate of cell mass decrease per unit of mass:

$$k_d = -\frac{dX}{XdX}$$

which can be transformed into

$$X_t = X_o e^{-k_d t} \qquad (13)$$

where

X_t = cell mass at time t (mg VSS/L); and

X_o = initial cell mass (mg VSS/L).

Substituting Equation 13 into Equation 12 yields

$$\frac{dO}{dt} = 1.42 k_d X_o e^{-k_d t} \qquad (14)$$

Taking the natural logarithm, Equation 14 becomes

$$\ln\left(\frac{dO}{dt}\right) = \ln(1.42 k_d X_o) k_d t \qquad (15)$$

In Equation 15, k_d is the slope of the ln (dO/dt) vs. time plot. The dO/dt (rate of oxygen consumption) data can be generated by an electrolytic respirometer.

Apparatus:

Electrolytic respirometer

Procedure

The experimental method to determine k_d by electrolytic respirometer is straight forward. An activated sludge sample is aerated for one day and washed three times with BOD5 nutrient solution to remove any adsorbed and soluble substrate. Oxygen consumption is measured with washed activated sludge in an electrolytic respirometer, and the rate of oxygen consumption (dO/dt) is obtained.

Data Analysis:

Figure 12 shows an example of the results of a k_d determination using an electrolytic respirometer. The results indicated there was still residual substrate left in the first 12 hours. The slope of ln (dO/dt) vs. time plot after 12 hours will indicate the endogenous decay constant, k_d. If the activated sludge is washed well after one day aeration without feed, the sharp oxygen uptake rate at the initial phase will be minimized as shown in another run (Figure 13).

Personhours needed: 6 hours.

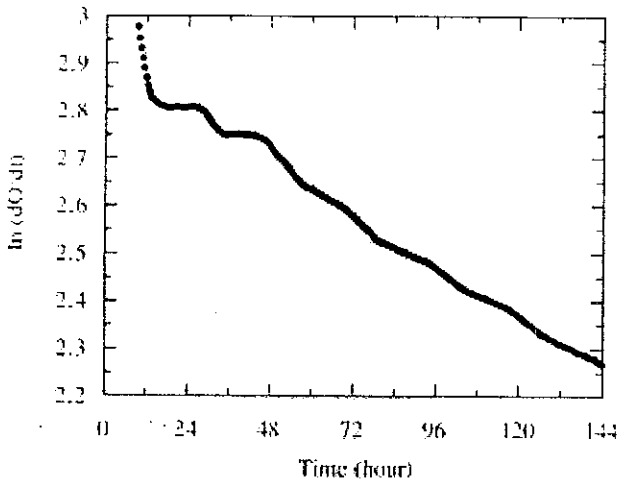


Figure 12. Endogenous decay rate, k_d, determination without well washed activated sludge.

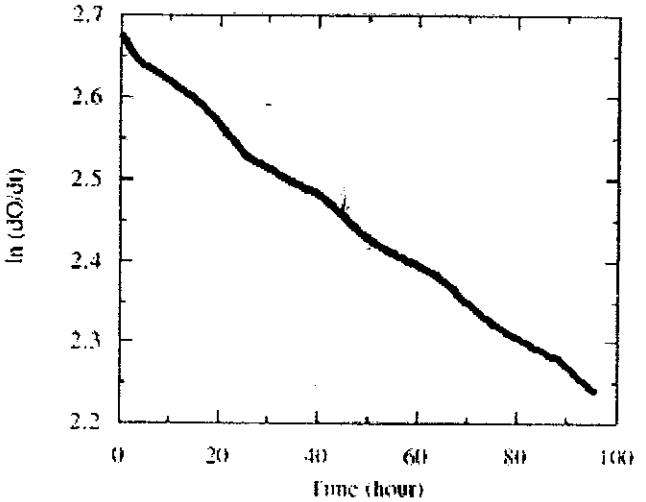


Figure 13. Endogenous decay rate, k_d, determination with well washed activated sludge.

Nitrification and Denitrification Rates Measurement

Nitrification Rate

Theory:

Although the kinetics of nitrification have been modeled by zero-order and first-order reactions, a Monod type equation expressing the effect of substrate concentration on the growth of nitrifying bacteria has been found to fit the data in most nitrification studies (Barnes and Bliss 1983). The effect of individual independent limiting substrates on the specific growth rate can also be expressed. Thus, the effects of NH_4^+-N and dissolved oxygen on the growth rate of *Nitrosomonas* are described as follows:

$$\mu_N = \mu_{N\max}\left[\frac{NH_4^+ - N}{K_N + NH_4^+ - N}\right]\left[\frac{DO}{K_o + DO}\right] \qquad (16)$$

where

μ_N = specific growth rate of *Nitrosomonas* (nitrifiers) (^{1}/hour);

μN_{max} = maximum specific growth rate of *Nitrosomonas* (nitrifiers) (^{1}/hour);

K_N = half-saturation constant for NH_4^+- N (mg/L);

DO = dissolved oxygen (mg/L); and

K_o = half-saturation constant for oxygen (mg/L).

Similar relationships can be written for the oxidation of nitrite to nitrate in terms of *Nitrobacter* and with NO_2^--N as substrate. Because it is generally the rate-limiting reaction, the nitrifier growth rate can be modeled based on the conversion of ammonium to nitrite by *Nitrosomonas*.

The ammonium oxidation rate can be measured to quantify how fast ammonium is oxidized to nitrate. It should be noted that over 99% of the total ammonia nitrogen (NH_3+NH_4^+-N) in normal domestic wastewater pH of 7 is in the form of ammonium (NH_4^+-N). The ammonium oxidation rate (q_N) for activated sludge is often expressed in units of mg NH_4^+-N removed per hour for each g MLVSS in the aeration tank as follows (Barnes and Bliss 1983):

$$\frac{d(NH_4^+ - N)}{dt} = q_N X \qquad (17)$$

The ammonium oxidation rates (q_N) are commonly 1 - 3 mg/g/hour (Barnes and Bliss 1983).

Apparatus:

A 10 L bottle (reactor)

Diffuser

Pipettes

DO meter

NH_3+NH_4^+-N and NO_2-+NO_3-N measurement apparatus

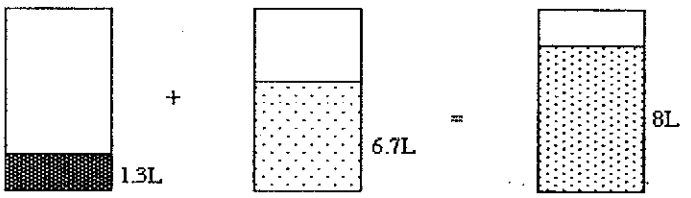
VSS measurement apparatus

Filtration apparatus

Procedure:

The procedure to determine the ammonium oxidation rate (q_N) is:

1. Obtain 8 L of wastewater sample.
2. Obtain 8 L of acclimated activated sludge.
3. Place a portion of the wastewater and activated sludge into an 8 L reactor. The dilution ratio used can be the same as the F/M ratio at the treatment plant of interest. For example, the Ashland treatment plant has an F/M = 0.67; thus, 1.3 L of activated sludge with VSS of 1,840 mg/L can be mixed with 6.7 L raw sewage with BOD_5 of 240 mg/L to obtain a F/M ratio of 0.67 in an 8 L reactor.



4. Measure VSS of mixture.
5. Aerate the reactor to reach a DO level of approximately 2 mg/L. If an air pump with a diffuser does not provide sufficient mixing, add a mechanical mixer.
6. Determine concentrations of total ammonia (NH_3+NH_4+-N), nitrite and nitrate (NO_2-+NO_3- -N) over time (at 0, 0.5, 1, 1.5, 2, 2.5, 3, 4, 5 hours) in filtrate passed through 0.45 μm membrane filters.
7.

Data Analysis:

Since the organic nitrogen will be transformed by bacteria to form total ammonia nitrogen, it is recommended to measure nitrite and nitrate production rates as the indicator of the ammonium oxidation rate. Table 11 and Figure 14 show an example of an ammonium oxidation rate determination. Even though a single sample is analyzed in this example, duplicated sample analysis is recommended.

Table 11. Example of nitrification determination.

Time (hr)	NH_3 + NH_4^+-N (mg/L)	Average NH_3 + NH_4^+-N (mg/L)	NO_2^-+ NO_3^- -N (mg/L)	Average NO_2^-+ NO_3^--N (mg/L)
0				
0		33.5		19.8
0.5				
0.5		31.8		20.8
1				
1		30.5		21.4
1.5				
1.5		30.0		22.7
2				
2		29.5		23.7
2.5				
2.5		28.0		24.0
3				
3		27.2		25.0
4				
4		26.8		25.6
5				
		25.2		27.6

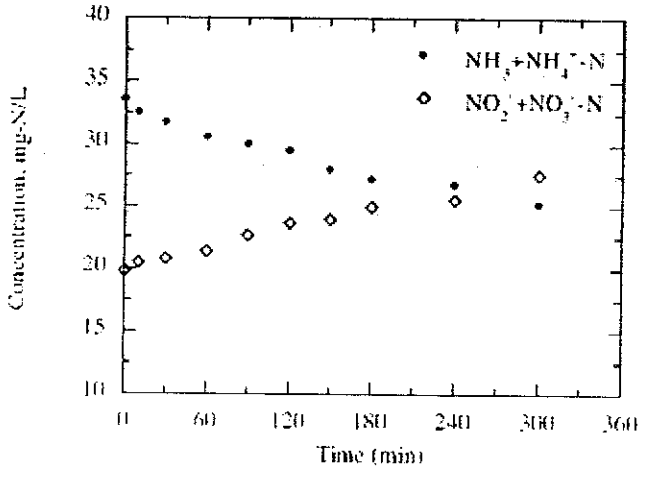


Figure 14. Ammonium oxidation rate determination.

The ammonium oxidation rate is:

(27.6 - 19.8 mg NO_2^-+NO_3^- /L) / 5 hours / 2,454 mg/L = 6.4 x 10^{-4} mg/mg/hour

where the initial biomass (MLVSS) in the batch reactor = 2,454 mg/L.

Personhours needed: 5 hours + acclimation time (~30 hours depending on wastewater).

Denitrification Rate

Theory:

Carlson (1971) and Christensen and Harremoes (1977) suggested that the kinetic reaction for denitrification by activated sludge can be expressed by:

$$\frac{dN}{dt} = q_D X \qquad (18)$$

where

dN/dt = denitrification rate (mg NO_2^-+NO_3^--N/L/hour);

N = nitrite plus nitrate concentration (mg-N/L);

t = time (hour); and

q_D = specific denitrification rate (mg N/mg VSS/hour).

This indicates that the denitrification rate is independent of the nitrate concentration and only a function of the volatile suspended solids concentration.

Apparatus:

Magnetic stirrer, stirring bar, and pipettes

DO meter

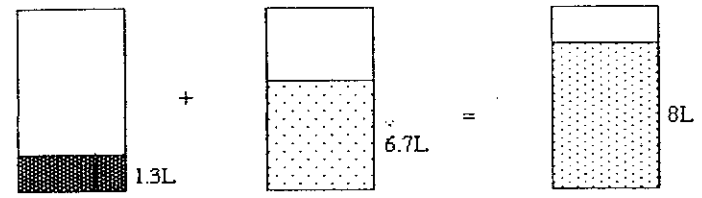
Filtration apparatus

NH_3+NH_4^+-N and NO_2^-+NO_3^--N measurement apparatus

Procedure

The procedure to determine the specific denitrification rate (q_D) is:

1. Obtain 8 L of wastewater sample.
2. Obtain 8 L of acclimated activated sludge.
3. Place a portion of the wastewater and activated sludge in an 8 L reactor. The dilution ratio used can be the same as the F/M ration at the treatment plant of interest. For example, the Ashland treatment plant has the F/M ratio of 0.67; thus, 1.3 L of activated sludge with VSS of 1,840 mg/L can be mixed with 6.7 L raw sewage with BOD_5 of 240 mg/L to obtain the F/M ratio of 0.1 in an 8 L reactor.



- ☐ Measure VSS of mixture.
- ☐ Mix the reactor with a magnetic stirrer and measure DO to ensure a DO level of < 0.1 mg/L.
- ☐ Add sodium nitrate ($NaNO_3$), if necessary, to provide an initial nitrate concentration of about 25 mg/L.
- ☐ Determine concentrations of total ammonia (NH_3+NH_4^+-N), nitrite and nitrate (NO_2^-+NO_3^--N) over time (at 0, 0.5, 1, 1.5, 2, 2.5, 3, 4, 5 hours) for the filtrate passed through 0.45 mm membrane filters.

Data Analysis:

Table 12 and Figure 15 show an example of a denitrification rate determination. Even though a single sample is analyzed in this example, duplicated sample analysis are recommended.

From Figure 15, the denitrification rate is estimated to be:

(40.2 - 26.6 mg NO_2^-+NO_3^--N /L) / 5 hours / 2,260 mg/L = 1.2×10^{-3} mg/mg/hour

where the initial biomass (MLVSS) in the batch reactor = 2,260 mg/L.

Personhours needed: 5 hours + acclimation time (~30 hours depending on wastewater).

Table 12. Example of denitrification determination.

Time (hr)	NH_3 + NH_4^+-N (mg/L)	Average NH_3 + NH_4^+-N (mg/L)	NO_2^-+ NO_3^- -N (mg/L)	Average NO_2^-+ NO_3^--N (mg/L)
0		6.6		40.2
0				
0.5		7.0		37.4
0.5				
1		7.5		35.3
1				
1.5		7.7		33.7

1.5 2 2	7.5	32.1
2.5 2.5	7.5	30.7
3 3	7.4	29.3
4 4	7.8	28.4
5 5	7.5	26.6

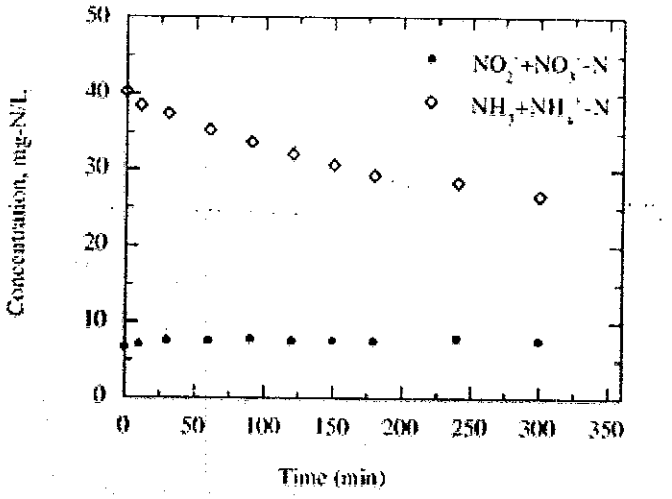


Figure 15. Denitrification rate determination.

Phosphorus Release and Update Rates Measurement

In a biological phosphorus removal process, phosphorus will be released by phosphorus-removing microorganisms under anaerobic conditions and taken up under aerobic conditions. The measurement of phosphorus release/uptake rates is meaningful only when phosphorus-removing microorganisms have been selected. An enhanced culture that removes phosphorus can either be obtained from a full scale BPR plant directly or produced in a laboratory reactor by using enrichment culture techniques.

A sequential batch reactor (SBR) can be used to develop the enhanced culture in a laboratory. The operational conditions for SBR to develop the enhanced culture depend on wastewater characteristics. The key feature of a SBR is its flexibility to adjust the anaerobic/aerobic retention time depending on the type of wastewater. Figure 16 shows a typical SBR configuration that controls the anaerobic/aerobic stage by a timer.

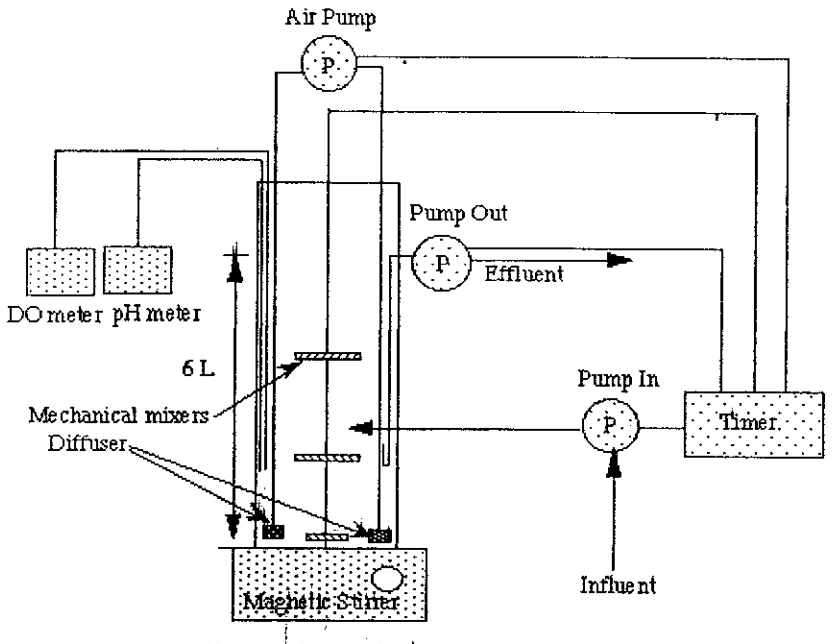


Figure 16. A typical SBR configuration.

Operational conditions of the SBR are as follows:

- reactor volume of 6 L; 4 L of fill and withdraw per cycle;
- wastewater feed in 10 minutes at each cycle;
- anaerobic/aerobic retention time = 2 hours/5 hours; 1 hour settling and decanting;
- 8 hours/cycle, 3 cycle/day.

When average COD and phosphorus concentrations in the influent are 200 mg/L and 9 mg-P/L, respectively under the above conditions, the effluent phosphorus concentrations were lower than 0.5 mg/L after 14 days of operation at room temperature. Once activated sludge containing phosphorus-removing microorganisms are obtained, phosphorus release/uptake rates can be measured as follows:

1. For the simulation of the anaerobic conditions, add wastewater and activated sludge to the reactor at a predetermined ratio and mix for a period of time corresponding to the hydraulic retention time of the anaerobic zone of the SBR or full-scale treatment plant. Take samples every 5 to 10 minutes for 0.5-1 hour and analyze for orthophosphate.

2. At the time corresponding to the hydraulic retention time of the anaerobic zone, supply the air using a fine pore diffuser placed at the bottom of the reactor. Take samples every 10 to 20 minute for 3-4 hours and analyze for orthophosphate.

In order to evaluate the effect of denitrification on phosphorus removal, total ammonia, nitrite, and nitrate concentrations are usually monitored. The rates of phosphorus release and uptake are simply expressed by the increase or decrease in phosphorus concentration per unit biomass per unit time (mg-P/g VSS/min).

The Ashland wastewater was used as an example to determine the phosphorus release/uptake rate. An aliquot of 500 ml of activated sludge from the laboratory SBR, where phosphorus-removing microorganisms were developed, was added to 500 ml of the Ashland composite wastewater to simulate a reaction of influent wastewater with 100% sludge recycle. The activated sludge were taken from the aerobic zone of the laboratory SBRs. The F/M ratio was 0.3. The NO_2^-+NO_3^--N concentration in the initial sludge and in the combined solution were 5 and 2 mg-N/L, respectively. The initial MLVSS was 880 mg/L. Samples were taken every 10 minutes during the anaerobic condition and every 20 minutes during the aerobic condition. This experiment was conducted under room temperature condition. The profile of phosphorus release and uptake is shown in Figure 17.

The phosphorus release was slow in the initial 30 minutes and rapid in the following 20 minutes. For the next 10 minutes, the phosphorus released was taken up slightly (approximately 0.2 mg-P/L). The specific phosphorus release rate was 0.064 mg-P/g VSS/min [(4.7 - 1.3)/60/0.880], and the specific phosphorus uptake rate was 0.034 mg-P/g VSS/min [(4.7 - 1.1)/120/0.880]. The total phosphorus released was obtained from the difference between the initial phosphorus concentration and the phosphorus concentration at the end of anaerobic stage. Even though it is uncertain what causes the lag and bump in the phosphorus release and uptake, the phosphorus release rates are comparable with reported values ranging from 0.042 to- 0.056 mg-P/g VSS/mir (Kang et al. 1991).

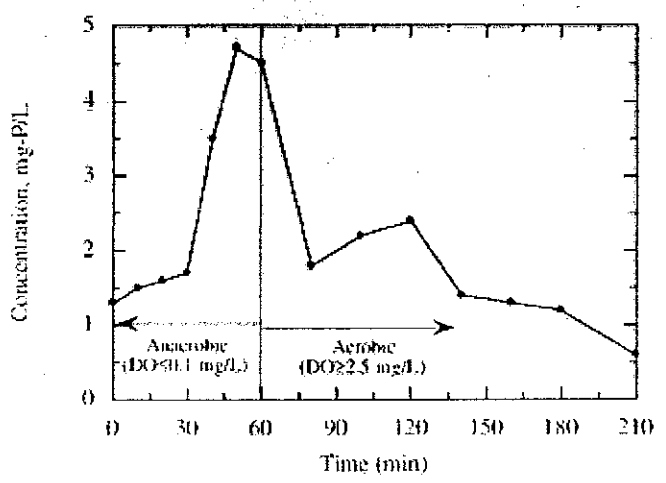


Figure 17. Phosphorus release/uptake profile of Ashland wastewater.