EFFECTIVENESS STUDY OF VERTICAL AND HORIZONTAL AERATED STEEL SLAG FILTER FOR NITROGEN REMOVAL FROM DOMESTIC WASTEWATER

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A thesis submitted in partial of fulfillment of the requirements for the award of the Master Degree of Civil Engineering

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AUGUST 2016
SPECIAL DEDICATION TO......

My beloved mum and dad, Puan Hjh Siti Habsah Abdullah and Hj. Ibrahim Ab. Kadir

My Husband,

Syahrul Nizam bin Maarup

My siblings,

Izzatul Aini Ibrahim, Izzani Naquieddin Ibrahim and Noradhiha

Farahin Ibrahim

For their love and support

And not forget to my supervisor and all my friends

For their support and help.
ACKNOWLEDGEMENT

First and foremost, I would like to express my special thanks to Allah S.W.T, the almighty of his Graciousness and Mercifulness that I'm able to complete this thesis appropriately. A very special thank and deepest appreciation to my honourable supervisor, PM. Dr. Rafidah Binti Hamdan for her valuable comments, advices, guidance and general supervision in preparing the whole thesis. I also want extend my special thanks to all staffs in Environmental Laboratory, Wastewater Engineering Laboratory, Analytical Laboratory FKAAS, and Chemical Engineering Laboratory FTK, UTHM who were very helpful from the initial project until during the data collecting. Their assistance was really appreciated. Always in my mind, thanks to my husband, Syahrul Nizam bin Maarup and all my friends who has given me support and valuable contribution, as well as ideas and cooperation in completing this project. Most importantly, I would like to thanks to my parents, who motivate me to pursue a Master Degree. They have supported and understood me everywhere and every time. Last but not least, my thanks also go to everyone who is involved directly or indirectly in the preparation of making this thesis successfully. The efforts from everyone who gives contribution in this thesis are highly appreciated. Thank you very much and may Allah bless you.
Nitrogen removal from wastewater often requires a highly cost of chemical treatment to prevent over loading of nutrient in effluent discharge to the surface water body. Rock filters (RF) emerged as one of attractive natural wastewater treatment method to treat wastewater high in nutrient. However, the application of RF in the removal of eutrophic nutrients and nitrogen is very limited under warm climate. Therefore, the aim of this study is to develop an aerated steel slag filter (ASSF) system design under Malaysia condition. The objective of this study are to optimize hydraulic loading rate (HLR) and aeration rate for the vertical flow aerated steel slag filter (VFASSF) system for ammonia nitrogen (AN) and total kjeldahl nitrogen (TKN) removal, identification of nitrifiers in VFASSF system, and comparison study of vertical and horizontal ASSF system on pollutant removal. Three pilot-scale VFASSF with 2.0 m H and 0.3 m D and a HFASSF with 1.0 m L and 0.3 m W and 0.5 m H has been developed at Taman Bukit Perdana Wastewater Treatment Plant (WWTP) Batu Pahat, Johor to optimize the HLRs range from 0.16 - 5.44 m³/m³.d and aeration rate of 3, 5 and 10 L/min for nitrogen removal from domestic wastewater. During the optimization study, the VFASSF influent and effluent daily composite sampling analysed for TKN, AN, DO, and temperature. Whilst, for monitoring the effectiveness of the VFASSF and HFASSF, influent and effluent twice a week grab samples have been collected and analysed for TKN, AN, BOD₅, COD, TSS, Alkalinity, Total coliform, pH, DO and Temperature. Furthermore, slime samples from the VFASSF system has been collected for nitrifying bacteria identification using SEM microscope analyses. From optimization study, the optimum value of HLR and aeration rate was 2.72 m³/m³.d and 10 L/min, respectively and has been further investigated in the ASSF monitoring study using VFASSF and HFASSF.
system. From the second experiment, it was found that the VFASSF system has outperformed as the removal efficiency of TKN, AN, TSS, and Total coliform were 89%, 97%, 86%, and 97%. The removal efficiency was slightly lower in the HFASSF as their removal were 78%, 71%, 88%, and 91% for TKN, AN, TSS, and Total coliform. Throughout the study, DO profile in VFASSF effluent consistently higher than in HFASSF as the value average at 5.20 mg/L and 3.75 mg/L, respectively. In addition, identification study using SEM and microscope analysis, it was confirmed that nitrifiers were present in VFASSF system with in rod-shape. In conclusion, it was indicated that most of ammonia nitrogen were converted to nitrate-nitrogen through nitrification process in the highly aerated VFASSF system than HFASSF system. More than 95% of AN were converted to NO₃-N in the system which is 18.65 mg/L where the limit is within in the permissible limit of Standard B which is 50 mg/L.
ABSTRAK

Penyingkiran nitrogen daripada air sisa sering memerlukan kos rawatan kimia yang tinggi untuk mengelakkan lebihan muatan nutrient dalam pelepasan efluen ke permukaan air. Penapis Batu (RF) muncul sebagai salah satu kaedah rawatan air sisa semula jadi yang menarik untuk merawat air kumbahan yang tinggi nutrient. Walau bagaimanapun, penggunaan RF dalam penyingkiran nutrient eutrofik dan nitrogen adalah sangat terhad di bawah iklim panas. Oleh itu, tujuan kajian ini adalah untuk membangunkan satu sistem reka bentuk penapis sanga besi (ASSF) di Malaysia. Objektif untuk kajian ini adalah untuk mengoptimumkan kadar beban hidraulik (HLR) dan kadar pengudaraan untuk sistem aliran menegak sanga besi berudara (VFASSF) bagi penyingkiran ammonia nitrogen (AN) dan jumlah kjeldahl nitrogen (TKN), mengenalpasti nitrifiers di dalam sistem VFASSF, dan untuk membandingkan kajian di antara sistem VFASSF dan HFASSF bagi penyingkiran bahan cemar. Tiga penapis berskala besar VFASSF dengan ketinggian 2.0 m dan diameter 0.3 m dan HFASSF dengan 1.0 m panjang dan 0.3 m lebar serta 0.5 m tinggi telah dibangunkan di Loji Rawatan Airsisa (WWTP) Taman Bukit Perdana, Batu Pahat, Johor bagi mengoptimumkn pelbagai HLRs dari 0.16 - 5.44 m³/m³.d dan kadar pengudaraan 3, 5 dan 10 L/min untuk penyingkiran nitrogen daripada air sisa domestik. Dalam kajian pengoptimuman, persampelan komposit harian bagi influen dan efluen VFASSF dianalisis untuk TKN, AN, DO, dan suhu. Sementara itu, untuk memantau keberkesanan VFASSF and HFASSF, influen dan efluen sampel cekau yang diambil dua kali seminggu telah dikumpulkan dan dianalisis untuk TKN, AN, BOD₅, COD, TSS, kealkalian, Total coliform, pH, DO, dan suhu. Tambahan pula, sampel lendir dari sistem VFASSF telah dikumpul untuk mengenal pasti bakteria nitrifying dengan menggunakan analisis SEM mikroskop. Daripada kajian pengoptimuman, nilai optimum HLR dan kadar pengudaraan masing-masing adalah
2.72 m³/m³.d dan 10 L/min, dan telah disiasat lanjut dalam kajian pemantauan ASSF dengan menggunakan sistem VFASSF dan HFASSF. Daripada eksperimen kedua, didapati bahawa sistem VFASSF telah mencapai prestasi dengan kecekapan penyaringan TKN, AN, TSS, dan Total coliform adalah 89%, 97%, 86%, dan 97%. Kecekapan penyaringan dalam HFASSF adalah rendah sedikit dengan penyaringan adalah 78%, 71%, 88%, dan 91% untuk TKN, AN, TSS, dan Total coliform.

Sepanjang kajian ini, profil DO di dalam efluen VFASSF mempunyai tinggi konsisten berbanding di dalam HFASSF di mana nilai purata masing-masing adalah 5.20 mg/L dan 3.75 mg/L. Di samping itu, kajian mengenalpasti menggunakan analisis SEM dan mikroskop, telah mengesahkan bahawa nitrifiers hadir dalam sistem VFASSF di dalam bentuk rod. Kesimpulannya, ia telah menunjukkan bahawa kebanyakan ammonia nitrogen telah bertukar kepada nitrat nitrogen melalui proses nitrifikasi dalam sistem VFASSF yang sangat berudara daripada sistem HFASSF. Lebih daripada 95% daripada AN telah ditukar kepada NO₃⁻N dalam sistem iaitu 18.65 mg/L di mana terletak dalam had yang dibenarkan oleh Piawaian B iaitu 50 mg/L.
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<tbody>
<tr>
<td>ANAMMOX</td>
<td>Anaerobic Ammonium Oxidation</td>
</tr>
<tr>
<td>AN</td>
<td>Ammonia Nitrogen</td>
</tr>
<tr>
<td>ARF</td>
<td>Aerated Rock Filter</td>
</tr>
<tr>
<td>BAFs</td>
<td>Biological Aerated Filters</td>
</tr>
<tr>
<td>BOD₅</td>
<td>5-days Biochemical Oxygen Demand</td>
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<td>CANON</td>
<td>Completely Autotrophic Nitrogen-removal Over Nitrite</td>
</tr>
<tr>
<td>COD</td>
<td>Chemical Oxygen Demand</td>
</tr>
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<td>CW</td>
<td>Constructed Wetland</td>
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<tr>
<td>DO</td>
<td>Dissolved Oxygen</td>
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<td><em>E</em>-coli</td>
<td>Escherichia coli</td>
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<td>HFARF</td>
<td>Horizontal Flow Aerated Rock Filter</td>
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<tr>
<td>HLR</td>
<td>Hydraulic Loading Rate</td>
</tr>
<tr>
<td>HRT</td>
<td>Hydraulic Retention Time</td>
</tr>
<tr>
<td>L</td>
<td>Liter</td>
</tr>
<tr>
<td>m</td>
<td>Meter</td>
</tr>
<tr>
<td>mg</td>
<td>Miligram</td>
</tr>
<tr>
<td>min</td>
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<tr>
<td>ml</td>
<td>Milimeter</td>
</tr>
<tr>
<td>N</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>N₂</td>
<td>Gaseous Dinitrogen</td>
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<tr>
<td>N₂O</td>
<td>Nitrous Oxide</td>
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<tr>
<td>NO</td>
<td>Nitric Oxide</td>
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<td>NO₂-N</td>
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<tr>
<td>NO₃-N</td>
<td>Nitrate-Nitrogen</td>
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<tr>
<td>OTE</td>
<td>Oxygen Transfer Efficiency</td>
</tr>
<tr>
<td>P.E</td>
<td>Population Equivalent</td>
</tr>
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<td>Description</td>
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<td>--------------</td>
<td>----------------------------------</td>
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<tr>
<td>Q</td>
<td>Wastewater</td>
</tr>
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<td>RF</td>
<td>Rock Filter</td>
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<tr>
<td>SEM</td>
<td>Scanning Electron Microscopy</td>
</tr>
<tr>
<td>TKN</td>
<td>Total Kjeldahl Nitrogen</td>
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<tr>
<td>TSS</td>
<td>Total Suspended Solid</td>
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<td>VFARF</td>
<td>Vertical Flow Aerated Rock Filter</td>
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<tr>
<td>WSP</td>
<td>Waste Stabilization Pond</td>
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<td>WWTP</td>
<td>Wastewater Treatment Plant</td>
</tr>
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<td>XRF</td>
<td>X-ray Fluorescence</td>
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CHAPTER 1

INTRODUCTION

1.1 Background of Research

Water is the most important source to all living things in the world. Nowadays, water resources become serious circumstances as a consequence of human activity, urbanization and industrial development where causes many challenges and contamination to wastewater discharges (Dan et al., 2011). Eutrophication is one of the major environmental problems in recent years due to high nutrient loading in surface water system.

Eutrophication is the process by which water bodies turn to be more eutrophic through an increasing of nutrient supply. Although this eutrophic is most commonly applied to lakes and reservoirs, it can also be applied to flowing waters, estuaries and coastal marine waters (Smith et al., 1999) because of their complex dynamics, which is longer water residence times and their role as a combining sink for pollutants from their drainage basins (WWAP, 2009). Previous study by Yang et al., (2008) have stated that the nutrient level of many lakes and rivers has increased dramatically over the past 50 years in response to an increased discharge of domestic wastes and non-point pollution from agricultural practices and urban development. In addition, eutrophication occurs naturally as lakes age and filled with sediments over the centuries (Chislock et al., 2013).
Other than that, human activities has found as one of contribution to
eutrophication where it increased the rate of nutrient input in a water body due to the
rapid urbanization, industrialization and agricultural production as reported in Yang
et al., (2008). Besides that, high nutrient in water body will causing detrimental
effects on the aquatic life, hence it will lose its primary functions and subsequently
influence sustainable development of society and world economy. Other problems
related with eutrophication include blooms of blue-green algae, contamination of
drinking water, degradation of recreational and hypoxia (Chislock et al., 2013).

Wastewater generally contains high of nutrient; nitrogen and phosphorus,
whose removal has become a vital aspect of wastewater treatment. Thus, nitrogen in
wastewater may be removed by both biological and physicochemical treatment. As
land becomes limited space and more expensive, natural wastewater treatment has
proved more popular and economic system. Rock filter (RF), is an alternative natural
treatment method for treating wastewater in particular for nutrient removal as the
conventional system requires high capital, chemical costs, lack of treatment capacity,
efficiencies, stability and space requirements (Pramanik et al., 2012).

Furthermore, natural wastewater treatment systems are relatively simple,
cost-effective and efficient methods to purify the large amounts of wastewater
produced by society. These systems are competitive with conventional wastewater
treatment for small communities, as well as individual homes for the following
reasons: extreme simplicity in building, low first cost and the potential for having
very low operation and maintenance costs, low energy requirements, and, overall
‘low technology’ (Hamdan, 2010).

The concept of the rock filter was developed in Kansas in the early 1970’s as
one of the alternative treatment for removing algal suspended solids and biochemical
oxygen demand (BOD) from wastewater. This study has been designed to focus on
aerated system to enhance the removal of ammoniacal nitrogen as Middlebrooks
(1995) reported that unaerated system rapidly become anoxic after a certain period of
treatment and resulted high concentration of ammoniacal nitrogen in the RF effluent
could limit the application of the process. Based on previous research experienced in
temperate climate country that is United Kingdom, Johnson and Mara (2006) found
that aerated rock filter has been outperformed to the unaerated rock filter in removing
ammoniacal nitrogen from pond effluent. Furthermore, an extensive work on aerated
rock filter (ARF) has been carried out by Hamdan (2010) to develop a low cost ARF
system for the purpose of enhanced nutrient removal from waste stabilization (WSP) effluents, which also observed that nitrogen in forms of ammonia from wastewater has been well removed and propose to study the system under warm climate to wider the application of RF system globally.

Therefore, this present study has been design to develop an aerated rock filter system in warm climate condition as has been suggested to be further investigated by Hamdan and Mara (2013). The experimental works have been carried out to optimize the hydraulic loading rate (HLR) and aeration rate on nitrogen removal in terms of total kjeldhal nitrogen (TKN) and ammoniacal nitrogen (AN) using two different systems; vertical flow aerated steel slag filter (VFASSF) and horizontal flow aerated steel slag filter (HFASSF). Previous work carried out by Hamdan (2010) using the vertical-flow type of aerated rock filters has generally proved to provide the higher level of performance for nutrient removal as recommended by USEPA (2002).

In addition, the new stricter effluent requirements for nutrient removal in wastewaters are now applicable in Malaysia under the Environmental Quality Act (Sewage) Regulations, 2009 which the discharge of ammonia nitrogen is limited to 10 mg/L in Standard A and 20 mg/L in Standard B. It is expected that these permissible effluent concentrations would be lowered further in the near future.

1.2 Problem Statement

Domestic wastewater contains inorganic contaminant such as nutrient and heavy metals. In warm climates, wastewaters lose its content of dissolved oxygen, which turn nitrate to nitrogen. The continued discharge of wastewater effluent with high nutrients which does not meet the standard will caused damage to the environment and human health. In addition, excessive levels of nutrients in the water body will lead to eutrophication.

Discharge from incomplete treatment of nutrient from wastewater could be the main culprit of the above mentioned problem. However, to remove nutrient from wastewater conventionally, it requires advanced biological wastewater treatment system. In addition, for the development of advanced treatment process, wastewater
treatment plants (WWTPs) need to be more compact and low in operational costs to ensure the system are competitive.

In Malaysia, conventional treatment systems such as activated sludge, aerated lagoons, rotating biological contactor and trickling filters are commonly used to remove nutrients from domestic wastewater but this conventional treatment system have the weakness in terms of treatment capacity, efficiencies, stability, space requirements and also expensive in maintenance and need high operation skill in treating wastewater although this treatment processes are mostly reliable, well designed and tested. Furthermore, the demand of appropriate low-cost technology and an economic effective system are crucial as an improvement to the existing treatment systems for treating high nutrient wastewater and towards the new effluent discharge compliance. However, information on the performance of the ARF under various operating and environmental conditions is still lacking in terms of the impact different organic and HLR (Pramanik et al., 2012). Hence, this study was focused on the effect of HLR and aeration rate using a pilot-scale aerated steel slag filter system with steel manufacturing by product; steel slag as filter media in particular for nitrogen removal at WWTP at Bukit Perdana near Batu Pahat, Johor. This system is for polishing the effluent quality prior to be discharged to the nearest river to adhere the effluent requirements for nutrient removal in wastewaters under the Environmental Quality Act (Sewage) Regulations, 2009. In addition, the development of aerated rock filter is towards the sustainable and green environment as mentioned one of the area in National Key Results Areas (NKRAs).

1.3 Objectives of Study

The main objectives of this study are:

(a) To optimize the hydraulic loading rates (HLR) and the aeration rate in vertical flow aerated steel slag filter (VFASSF) system for ammoniacal nitrogen (AN) and total kjeldahl nitrogen (TKN) removal under warm climate (Malaysia).

(b) To identify the presence of nitrifiers bacteria.
(c) To compare the effectiveness VFASSF and HFASSF performance for pollutant removal from domestic wastewater and compare the effluent quality with the effluent of Malaysia Environmental Quality Act (sewage) Regulations 2009.

1.4 Scopes of Study

This study consists of field works and laboratory work. Field works was carried out at Taman Bukit Perdana Wastewater Treatment Plant (WWTP) in Batu Pahat, Johor. Field works started by designing and constructing the pilot-scale of vertical flow aerated steel slag filter (VFASSF) and horizontal flow aerated steel slag filter (HFASSF). This study is to determine the different range of twelve hydraulic loading rates (HLR); 0.16, 0.26, 0.34, 0.32, 0.52, 0.68, 1.04, 1.36, 2.08, 2.72, 4.16, 5.44 m³/m³.d. The range is multiplied until the systems become fails. Besides that, this study also is to optimize the range of aeration rate from 3, 5, and 10 L/min of the VFASSF and HFASSF. Performance of the VFASSF and HFASSF were monitored by analyzing laboratory work including COD, BOD₅, TKN, AN, Nitrate and Nitrite, Total Suspended Solid, Dissolved Oxygen, pH, Alkalinity, Temperature and Total Coliform. In conjunction with the site work, identification of nitrifying bacteria in steel slag slime sample collected from the VFASSF has been carried out by using Scanning Electron Microscopy (SEM) and microscope analysis.

1.5 Significance of Study

Generally, to remove nitrogen, heavy metals, suspended solids and organic matter from domestic wastewater required a tertiary wastewater treatment due to the effluent is a high standard and suitable for reuse. Unfortunately, there is no plan to build this treatment system in Malaysia. Therefore, it is essential to study and propose low-cost technology and an economic effective system such as pilot-scale
aerated rock filter using steel slag as filter media for removing nitrogen from domestic wastewater.

This system was developed to determine the final effluent quality of vertical flow aerated steel slag filter (VFASSF) and horizontal flow aerated steel slag filter (HFASSF) as for comply to the new stricter effluent requirements for wastewater in Malaysia under Environmental Quality Act (sewage) Regulations, 2009 which is Standard A and Standard B. In addition, this application may be emerged as low-cost and green technology because the system has a great potential to be used as an alternative to the wastewater treatment for small community and small medium industries in removing nitrogen from wastewater.

1.6 Thesis Outline

This thesis is divided into five chapters and each chapter explains the sequence in this study.

(i) Chapter 1
Chapter 1 is focused on introduction. This chapter presents background of research, problem statement, objectives, scopes and significance of study. Background of research is review on occurrence of nutrients in water body, existing technologies of nutrient removal and pilot-scale method as an alternative technology for nutrient removal. Problem statement explain the major factor contribute to the environmental problem, disadvantages on using conventional methods and advantages on using pilot-scale method. This study was focused on four objectives that have been implementing and scope of study was discussed based on objective of this study. The significance of study refers to the potential of pilot-scale method in removing nitrogen from domestic wastewater.

(ii) Chapter 2
Chapter 2 presents a general review of nitrogen in ecosystem and their effect to the environment and humans. Besides, the treatment technologies for nitrogen
removal were discussed in detail. Next, this chapter covered on system of aerated rock filter for nitrogen removal, mechanism and the factors that affect performance on nitrogen removal. At the end of this chapter discussed about the presence of nitrifiers.

(iii) Chapter 3
Chapter 3 describes the methodology used in this study which is includes the details of construction of aerated rock filter (ARF), sampling method, materials, and preparation of slime from ARF media. This chapter also covers experimental set-up of ARF in Indah Water Konsortium treatment plant. Instruments such as SEM were discussed for nitrifiers identification.

(iv) Chapter 4
Chapter 4 focuses on analysis from data collection according to the objective of study. This chapter presents the results and discussion of optimization hydraulic loading rate and air flow rate and performance of treatment systems based on several parameters. All experimental results were performed in tables, figures, and graphs.

(v) Chapter 5
Chapter 5 focuses on analysis from data collection according to the objective of study. This chapter presents the data of monitoring vertical aerated rock filter (VFARF) and horizontal aerated rock filter (HFARF) performance based on several parameters. All experimental results were performed in tables, figures, and graphs.

(vi) Chapter 6
Chapter 6 presents the conclusion of the study based on the findings obtained in results and discussion. It also presents recommendations and future works for further studies. References and appendices are attached at the end of the thesis.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The discharge of untreated wastewater from households and industries is a threat to nature and humans because it causes adverse impact on environment, eutrophication of surface waters, and human health concerns. Therefore, wastewater need to be treated prior to reduce the harmful pollutants before finally discharging it into receiving waters such as lakes, reservoirs and river systems. The wastewater treatment systems include conventional, mechanical and natural treatment systems.

According to Indah Water Konsortium (2013), 38% of public wastewater treatment plants (WWTPs) in Malaysia are mechanical plants, at the same time as a secondary treatment. These plants operate using mechanical equipment that accelerates wastewater break down. To treat and remove nutrients such as nitrogen and phosphorus from wastewater requires an advanced wastewater treatment. Various methods of wastewater treatment systems have been developed over the last fifty years where it can be safely discharged to meet the need to protect public health and the environment. Furthermore, more recent developments in wastewater treatment have been to improve the reliability and efficiency of treatment systems to treat wastewater to meet standards and reduce the land area occupied by treatment works through accelerating natural treatment rates under controlled conditions.
In Malaysia, conventional treatment systems such as activated sludge, aerated lagoons, rotating biological contactor and trickling filters are commonly used to remove nutrients from domestic wastewater but this conventional treatment system have the weakness in terms of treatment capacity, efficiencies, stability, space requirements and also expensive in maintenance and need high operation skill in treating wastewater although this treatment processes are mostly reliable, well designed and tested. For the development of advanced biological treatment process, WWTP need to be more compact, low in operational costs and stable in operation while at the same time minimize the noise and odor, space requirements as well as generate high performance as reported by Pramanik et al., (2012).

In addition, natural wastewater treatment system is found as one of the low cost technologies that require no or very little electrical energy and they are more suitable for small communities also developing countries compared to the conventional wastewater treatment that requires large amounts of energy and bigger populations. Natural wastewater treatment systems such as waste stabilization pond (WSP) systems have been extensively used in France and Germany, where there are over 2500 and 3000 WSP systems respectively meanwhile United States is more than 7000 WSP systems, but in UK which has only ~40 systems as stated in Valero (2008). Nevertheless, WSP are not considered as reliable technical option for nutrient removal from domestic wastewater because of the nutrient removal often does not comply with the discharge permission. Therefore, the effluent from WSP requires further treatment specifically for nitrogen and phosphorus removal.

However, one of the advanced biological treatment system which is the biological aerated filters (BAFs) was proved to be more reliable due to the advantage of this BAFs are easy to operate, relatively compact, and may be more competent in removing ammonia and carbonaceous than activated sludge system as mentioned in previous study by Pramanik et al., (2012).

The overall aim of this study is to develop a low-cost, easy to operate and maintain method for such wastewater treatment for removing nitrogen from wastewater by using aerated rock filter (ARF) systems which is able to produce effluents that comply with the requirements under the Environmental Quality Act (Sewage) Regulation, 2009. Requirements to reduce nutrients from wastewater are directly addressed by Department of Environment (DOE) as shown in Table 2.1 for those receiving waters that are considered to be at risk from eutrophication. Two
types of ARF systems were designed to study the effectiveness of nutrients removal: a vertical flow aerated steel slag filter (VFASSF) and a horizontal flow aerated steel slag filter (HFASSF).

2.2 Nitrogen in Ecosystem

Nitrogen (N) is most important nutrient for organisms to survive because every living organism needs nutrients to grow and carry out life functions. Human activities have drastically impacted the global nitrogen cycle and excessive nitrogenous compounds released into the public water bodies not only resulting in direct toxicity to aquatic animals, but also increase the overgrowth of aquatic plants which cause eutrophication. Other than that, nitrogen pollution also has major effects on both human health and the ecological functions of natural ecosystems.

In most ecosystems, nitrogen is primarily stored in living and dead organic matter. This organic nitrogen is converted into inorganic forms when it re-enters the biogeochemical cycle via decomposition. Decomposers that found in the upper soil layer, chemically modify the nitrogen found in organic matter from ammonia (NH₃) to ammonium salts (NH₄⁺). Nitrogen can occur in many forms including ammonia, organic, nitrate and nitrite. Apart of that, nitrogen also include into organic compounds and inorganic compounds because its ability to easily form chemical bonds with other elements such as carbon, hydrogen, and oxygen where when elements bond together, the compounds are formed (Gerardi, 2002).
### Table 2.1 Environmental Quality (Sewage) Regulations 2009 (PU (A) 432))

#### SECOND SCHEDULE

*Regulation 7*

**ACCEPTABLE CONDITIONS OF SEWAGE DISCHARGE OF STANDARDS A AND B**

(i) New sewage treatment system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
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<th>Standard B</th>
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<td>Temperature</td>
<td>°C</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>pH Value</td>
<td></td>
<td>6.0-9.0</td>
<td>5.5-9.0</td>
</tr>
<tr>
<td>BOD5 at 20°C</td>
<td>mg/L</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>120</td>
<td>200</td>
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<tr>
<td>Suspended Solids</td>
<td>mg/L</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Oil and Grease</td>
<td>mg/L</td>
<td>5.0</td>
<td>10.0</td>
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<td>Ammonical Nitrogen (enclosed water body)</td>
<td>mg/L</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Ammonical Nitrogen (river)</td>
<td>mg/L</td>
<td>10.0</td>
<td>20.0</td>
</tr>
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<td>Nitrate – Nitrogen (river)</td>
<td>mg/L</td>
<td>20.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Nitrate – Nitrogen (enclosed water body)</td>
<td>mg/L</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Phosphorous (enclosed water body)</td>
<td>mg/L</td>
<td>5.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

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

#### 2.2.1 Nitrogen Cycle

The nitrogen cycle describes the movement of the element from the atmosphere into the biosphere and organic compound, and return back to the air in a continuing cycle as shown in Figure 2.1.
Figure 2.1 Nitrogen Cycle
(Source: Brandes et al., 2007)

The largest reservoir of N on Earth is triple-bonded N₂ gas where 78% consists of atmosphere and must be fixed by microorganisms before it is readily useable by other organisms (Francis et al., 2007). The nitrogen undergoes many different transformations in the ecosystem, changing from one form to another form as organisms that use it for growth and in some cases use for energy. This transformation can be carried out through biological and physical processes. There are five major transformations of nitrogen reactions which can be classified as a significant role in environment: fixation, nitrification, denitrification, assimilation, and ammonification (Hamdan, 2010). Other mechanism like uptake by plants, adsorption, and volatilization play a much less important role in this process (Ye and Li, 2009). In term of classic pathway, aerobic denitrification, heterotrophic
nitrification, CANON (Completely Autotrophic Nitrogen-removal Over Nitrite) and ANAMMOX (Anaerobic Ammonium Oxidation) are potentially important processes in nitrogen removal in constructed wetlands as indicated in Ostrowska et al., (2013).

The movement of nitrogen through the cycle involves a number of conversions namely oxidation and reduction reactions also a variety of bacteria. Naturally, nitrogen is constantly fixed from the atmosphere by exposing it to electrical discharge (lighting) or biological processes. $N_2$ is also fixed by biochemical processes solved by a group of unique bacteria and converted to ammonium ions. On the other hand, nitrogen fixation is the process of converting $N_2$ into biologically nitrogen by remineralization of organic matter and subsequent nitrification bacterial of ammonium to nitrate in oxic environments. Some nitrogen-fixing organisms are free-living under aerobic conditions or in anaerobic environment: some are phototrophic and others are chemotrophic means that they use chemicals as their energy source and not the light. Meanwhile, denitrification occurred when nitrate is in turn to $N_2$ gas under suboxic to anoxic conditions by denitrifiers (Francis et al., 2007).

2.2.2 Nitrogen in Wastewater

Human activities contribute excessive amounts of plant nutrients such as nitrogen and phosphorus. According to Lin et al., (2009) reported that nitrogen and phosphorus compounds are among the principal constituents of concern in wastewater because of their role in eutrophication, their effect on the oxygen content of receiving waters, and their toxicity to aquatic organisms. Nitrogen and phosphorus also cause sediment deposition on bottom of the natural water bodies, because they are quickly assimilated by plants due to their great mobility in plant and physical media (soil and water). This increased mobility make them limiting for plant growth within the boundaries of the water body (Bustamante et al., 2011).

Nitrogen in wastewater is present in a variety of forms because of the various oxidation states represented, and it can readily change from one state to another depending on the physical and biochemical conditions present. The total nitrogen concentration in typical municipal wastewaters ranges from about 15 to over 50
mg/L, which is approximately 60%, is in the ammonia form, and the rest being in organic form (Reed et al., 1995). Apart from that, nitrogen also originates from protein metabolism in the human body. In fresh wastewater systems, nitrogen was thought to be primarily inorganic but more recent studies have shown that the nitrogen transported in rivers is largely dissolved organic nitrogen.

A series of biochemical and physicochemical processes are involved in transforming one source of N to another source where the most important forms of inorganic N compounds include ammonium (NH$_4^+$), nitrite (NO$_2^-$), nitrate (NO$_3^-$), gaseous dinitrogen (N$_2$) and nitrous oxide (N$_2$O). These compounds are the end products of specific biological reaction. Typical concentrations for nitrogen constituents in domestic wastewater are given in Table 2.2 and Table 2.3.

### Table 2.2 Nitrogen in Domestic Wastewater Ranging from Weak to Strong
(Tchobanoglous et al., 2003)

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Concentration (mg/L as N or P)</th>
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<tbody>
<tr>
<td>Organic N</td>
<td>Soluble: 1 – 2</td>
</tr>
<tr>
<td></td>
<td>Particulate: 7 – 23</td>
</tr>
<tr>
<td>Ammonia/ammonium</td>
<td>Soluble: 12 – 45</td>
</tr>
<tr>
<td></td>
<td>Particulate: N/A$^*$</td>
</tr>
</tbody>
</table>

* N/A = not applicable

### Table 2.3 Typical composition of untreated domestic wastewater
(Metcalf and Eddy, 2003)

<table>
<thead>
<tr>
<th>Contaminants</th>
<th>Unit</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low strength</td>
</tr>
<tr>
<td>Nitrogen (total as N)</td>
<td>mg/L</td>
<td>20</td>
</tr>
<tr>
<td>Organic</td>
<td>mg/L</td>
<td>8</td>
</tr>
<tr>
<td>Free ammonia</td>
<td>mg/L</td>
<td>12</td>
</tr>
<tr>
<td>Nitrites</td>
<td>mg/L</td>
<td>0</td>
</tr>
<tr>
<td>Nitrates</td>
<td>mg/L</td>
<td>0</td>
</tr>
</tbody>
</table>

Enhancement nitrogen removal in treatment processes will have effluent concentrations of total nitrogen that vary from low, less than 3 mg/L to moderate 8 mg/L as N. In all cases, NH$_4^+$-N concentrations typically will be low, below 1 mg/L.
if the treatment plant is fully nitrifying. Nitrogen removal plant effluent typically will contain a combination of oxidized nitrogen, $\text{NH}_4^+$, and organic nitrogen.

In Rajasthan, India the raw wastewater has a BOD of 600 – 800 mg/L and a $\text{NH}_4^+$-N concentration of 80 – 110 mg/L received at the activated sludge plant during the summer when water shortage was critical (Breisha, 2010). Effluent from septic tanks generally contain high ammonia concentration and the effluent usually discharged to aerobic seepage fields where the ammonia and organic nitrogen transformed into nitrate which may be flow into the groundwater (Breisha, 2010). In addition, the effluent also flows to subsequent treatment such as aerobic treatment or directly to the soil treatment unit where the biological and chemical processes occur; soil adsorption, filtration, and transformation (Hazen and Sawyer, 2009). Table 2.4 summarizes the total Kjeldahl nitrogen (TKN) and ammonia nitrogen (AN) concentrations found in domestic wastewaters in different countries during the recent years.

**Table 2.4 Concentrations of TKN and AN in different domestic wastewaters**

*(Adopted from Breisha, 2010)*

<table>
<thead>
<tr>
<th>Country</th>
<th>Description</th>
<th>TKN (mg/L)</th>
<th>AN (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>Collected domestic wastewater samples for a period of 450 days</td>
<td>40</td>
<td>24 ± 11</td>
</tr>
<tr>
<td>Australia</td>
<td>Weekly collected domestic wastewater samples after on-site primary sedimentation and pre-denitrification treating</td>
<td>43</td>
<td>-</td>
</tr>
<tr>
<td>China</td>
<td>Domestic wastewater derived mainly from restaurants and dormitories</td>
<td>70</td>
<td>40</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Samples collected from a septic tank</td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td>China</td>
<td>Samples collected from a septic tank</td>
<td>85</td>
<td>79</td>
</tr>
</tbody>
</table>
2.2.3 Ammonia Toxicity

The need to remove the point source discharge of nutrients (both phosphorus and nitrogen) from domestic wastewater plant effluents prior to receiving waters has been recognized due to ammonia is in the form of free or unionized (NH₃-N) fraction has toxicity effects to aquatic life. The fraction of unionized NH₃-N in water increases with increasing of temperature and pH. Besides that, the discharge from ammonia into the receiving water will undergo the oxidation process in the presence of dissolved oxygen (DO) and bacteria that will cause a depletion of dissolved oxygen which is available to sustain the aquatic life.

Meanwhile, nitrate (NO₃-N) discharged will promote to the algae growth in receiving waters which is leading to associated problems of DO depletion, algae blooms and odors. Nevertheless, nitrate and nitrite (NO₂-N) discharged also become a concern if the receiving stream is to be used as a source for drinking water because the safe drinking water act (SDWA) amendments of 1986 require a maximum contaminant levels (MCL) is <10 mg/l for both total nitrate and nitrite nitrogen (USEPA, 1990).

Research from El-Shafai et al., (2004) stated that ammonia is toxic not only to fish but also to all aquatic life especially in pond aquaculture at low concentrations of dissolved oxygen. The problem of this toxicity as stated in same journal is relevant to the fish farming practice due to the growth yield may be depressed by usual ambient ammonia concentrations, under intensive farming conditions and also in aquaculture sewage-fed.

The major factors which is responsible for mortality in sewage-fed fish ponds was high in ammonia and low dissolved oxygen concentration during the summer and spring as reported by Wrigley et al., (1998) whilst the others reported that ammonia toxicity was the main source of fish mortality in sewage oxidation ponds (El-Shafai et al., 2004).
2.2.4 Wastewater Treatment Technology for Nitrogen Removal

There are many wastewater treatment technology developed in removing nitrogen from wastewater and can potentially be used as a sustainable strategy in yielding a product that meet water quality regulations, being at the same time efficient in terms of resource inversion. All treatment can meet the limits of nutrient effluent where currently applicable in almost all countries in the world due to global environmental problems.

Untreated wastewater can be divided into three types; physical, chemical and biological. Physical constituents are color, taste and odor, temperature, turbidity and solids content. Meanwhile, chemical constituents include nutrients and heavy metals then biological constituents are coliforms, fecal coliforms, pathogens and viruses. These constituents need to be removed for various reasons as shown in Table 2.5.

Table 2.5 Principle constituents of concern in wastewater treatment*

*(Adopted from Stovall, 2007)

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Reason for concern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total suspended solids</td>
<td>Sludge deposits and anaerobic conditions</td>
</tr>
<tr>
<td>Biodegradable organics</td>
<td>Depletion of natural oxygen resources and the development of septic conditions</td>
</tr>
<tr>
<td>Dissolved inorganics (e.g., total dissolved solids)</td>
<td>Inorganic constituents added by usage. Recycling and reuse applications</td>
</tr>
<tr>
<td>Heavy – metals</td>
<td>Metallic constituents added by usage. Many metals are also classified as priority pollutants</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Excessive growth of undesirable aquatic life, eutrophication, nitrate contamination or drinking water</td>
</tr>
<tr>
<td>Pathogens</td>
<td>Communicable diseases</td>
</tr>
<tr>
<td>Priority organic pollutants</td>
<td>Suspected carcinogenicity, mutagenicity, teratogenicity, or high acute toxicity. Many priority pollutants resist convention treatment methods (known as refractory organics)</td>
</tr>
</tbody>
</table>
Conventional treatment systems have three stages. In the first stage is primary treatment where the solids settle out of the wastewater. The solids are known as sludge and usually taken to the landfill. The second stage is secondary treatment, where the function is to remove dissolved or suspended matter. Besides that, secondary treatment may require a separation process to remove the microorganisms from the treated water. The next stage is tertiary treatment where the nutrients such as nitrogen and phosphorus, toxic substances including heavy metals are removed. Finally, the water is disinfected usually with chlorine and ultraviolet light (IWK, 2013).

Apart of that, conventional treatment systems also refer as mechanical systems. Tanks, pumps, blowers, screens, grinders, and other mechanical components are used by mechanical treatment technologies to treat wastewaters. Activated sludge, sequencing batch reactor, trickling filter and rotating biological contactor are four of the most common types of conventional treatment systems. These treatment systems are effective where land is limited, but they are more expensive to build and require more skilled personnel to operate them. It is prove in the literature by Jenssen et al., (2010) that stated the use of conventional treatment systems becomes very expensive due to topography and long distances between the connected facilities in Nordic countries. Although small-scale conventional systems like activated sludge or rotating biological contactors with chemical precipitation are options, but current investigations shows that they have difficulties in meeting the limit of discharges especially for phosphorus (Jenssen et al., 2010).

Constructed wetlands system (CW) is one of the natural wastewater treatment systems where it increasingly applied worldwide for the domestic wastewater treatment in isolated villages and rural areas as reported in (Yang et al., 2012) because CW are an inexpensive and technologically appropriate solution for wastewater treatment in developing countries (Belmont et al., 2004). According to Ostrowska et al., (2013) noted that CW enable long-term removal of contaminants with a stable efficiency and at low exploitation costs. A CW systems media is typically gravel of different sizes with larger gravel being near the bottom of the wetland and fine gravel being near the water surface for plant growth and roots. Most systems have been designed to treat municipal sewage and are generally efficient in removal of organic matter such as biochemical oxygen demand (BOD) and suspended solids (SS), but the removal of nitrogen and phosphorus is often relatively
poor. Nevertheless, nitrogen undergoes several transformations in wetlands, including ammonification, nitrification, denitrification, adsorption, bacteria, and plant uptake (Mburu et al., 2013).

Natural wastewater treatment systems are specifically designed to obtain the intended waste treatment goal by utilizing natural responses to the maximum possible with the minimum use of electromechanical treatment. They are more appropriate for small communities and developing countries. Natural wastewater treatment systems are anaerobic or aerobic, and some have both aerobic and anaerobic zones. They require a greater volume or area of land than wastewater treatment plant to enable wastewater treatment proceed to the level required because they are not energy-intensive processes. Besides that, natural treatment systems are capable of producing an effluent quality equal to that of mechanical treatment systems.

2.3 Aerated Rock Filter System

Aeration system is condition where air is introduces into a liquid, to provide the aerobic environment to microbial for degradation of organic matter. In wastewater treatment, the purpose of aeration used is to transferring oxygen in order to enhance the biological treatment process and to ensure continued aerobic conditions for the microorganism to degrade the organic matters. Besides that, aeration systems are among the most energy intensive operations in wastewater treatment systems as consuming between 50-90% of total energy costs of typical municipal installations as reported in Ashley et al., (1991).

There are few methods in aeration process but the main principle for aeration process is to deliver sufficient oxygen to the aeration tank. The oxygen can be supply into the aeration tank with two methods; it is from the top of surface aeration tank and at the bottom of aeration tank. Furthermore, there are many of aeration instruments to supply oxygen from the surface of aeration tank which can be classified to mechanical aerators, surface aerator, brush aerator and direct drive surface aerators. Meanwhile, method to supply oxygen from the bottom of aeration tank called diffused aeration where normally air compressor (blower) is the main
equipment followed by air piping system and diffuser. Oxygen transfer takes place from the rising bubbles to the mixed liquor to supply the oxygen requirements for the biological process. The air will break into the bubbles and dispersed through the aeration tank within this system.

In this present study, method of aeration used is diffused aeration because oxygen supplied from the bottom of rock filter. Diffused aeration process consists of contacting gas bubbles with water for the purpose of transferring gas to the water. For a good performance, the rate of supply of dissolved oxygen should be equal to the rate of oxygen consumption imposed by the mixed liquor under any set of circumstances (Al-Ahmady, 2006). Diffused aeration systems are classified as coarse or fine-pore diffuser. In this study, fine-pore diffusers is defined as a diffuser system in order to supply oxygen in the rock filter because they have higher efficiencies on the basis of specific energy consumption compared to other technologies (Rosso et al., 2013). Fine-pore diffusers are constructed from a range of materials including ceramics, porous plastics and perforated membranes. Size of the bubble range is 0.5mm to 5mm, but the common used of in wastewater treatment is 2mm.

Besides that, fine-pore diffuser is selected mainly due to the efficiency of oxygen transfer efficiency (OTE) into the aeration tank compared to the other method. OTE of an aeration system is the ratio of the amount of oxygen that actually dissolves into the water to the total amount of oxygen pumped into the water (OTE = O₂ transferred/O₂ fed) (Stenstrom et al., 2006). The OTE depends on many factors including the type, size and shape of the diffuser, the air flow rate, the depth of submersion, tank geometry, and wastewater characteristics, partial pressure of oxygen in atmosphere, and the corresponding equilibrium concentration in water, as has been discussed elsewhere (Ashley et al., 1991; Al-Ahmady, 2006).

Moreover, the depth of aerator submergence in the filter tank will have an effect on the overall OTE system (Al-Ahmady, 2006). The major effect is caused due to the greater length of the path of bubbles in the tank. Increasing the depth of water will increase bubble residence time in the filter since the ascension speed of bubbles which accordingly results in a longer time of bubble-water contact. The effect of time in operation on fine bubble diffusers may affect the ability of the aeration system to perform efficiently or at all (Rosso et al., 2013). Hence, the OTE of a diffuser system is a function of its depth.
In addition, atmospheric pressure and maximum allowable oxygen saturation are important factor in determining how much oxygen can be transferred into the tank due to the fact as the liquid depth increases, the saturation concentration of oxygen in the liquid also increases. The following equation was used to calculate the DO saturation at different depth (Hamdan, 2010):

\[ C_S = \text{atmospheric saturation (mg/L) x } [1 + (\text{depth (m)} / 10.3 \text{ m})] \]  \hspace{1cm} (2.1)

Where at 1 atm = 14.7 psi which is equivalent to 10.3 m of water.

The oxygen deficit (\(D\)), is the amount by which the actual dissolved oxygen concentration is less than the saturation value with respect to oxygen in the air. The oxygen deficit is one of the driving forces for the replenishment of oxygen used up in polluted water. The greater of oxygen deficit will give the greater transfer rate of oxygen into the water. The equation (2.2) shows the oxygen deficit calculation. The previous study of aeration in removing nitrogen has been summarized in Table 2.6.

\[ D = \text{DO}_S \text{ or } C_S - \text{DO or C} \]  \hspace{1cm} (2.2)

Where \(D\) = oxygen deficit (mg/L)

\(\text{DO}_S\) or \(C_S\) = saturation concentration of dissolved oxygen at the temperature

\(\text{DO or C}\) = actual concentration of dissolved oxygen

<table>
<thead>
<tr>
<th>Authors</th>
<th>Performance Removal Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuquerque et al., (2012)</td>
<td>74% of ammonia nitrogen removal</td>
</tr>
<tr>
<td>Farbregoli et al., (2009)</td>
<td>96% of ammonia nitrogen removal</td>
</tr>
<tr>
<td>Pan et al., (2012)</td>
<td>&gt;85% of ammonia nitrogen removal</td>
</tr>
<tr>
<td>Li et al., (2008)</td>
<td>97% of COD, 94% of TN and 97% of TP</td>
</tr>
</tbody>
</table>

2.3.1 Effect of Aeration Rate on Nitrogen Removal

Aeration is the process by which air mixed or dissolved air in a liquid or substances. Through this process, the area contact between water and air is increased. The role of
Aeration in the wastewater treatment process is to provide oxygen to microorganisms as they assimilate the organic carbon compounds and digest a portion of them to carbon dioxide, sulphate, and nitrate compounds.

Aeration rate is needed in wastewater treatment system because to make sure the dissolved oxygen (DO) is adequate to microorganism to survive. During the aeration periods, DO is high then aerobic nitrifiers oxidize ammonium nitrogen to nitrite and then oxidize to nitrate (Li et al., 2008).

Previous study by Li et al., (2008) in their research effect of aeration rate on nutrient removal from slaughterhouse wastewater in intermittently aerated sequencing batch reactors (SBRs) has found that the optimum aeration rate of 0.8 L/min produced the best system performance where the removals of COD and TN were up to 97% and 94% that met the emission standards in temperate climate. The effects of the aeration rate on the performance of the SBRs were due to different DO concentrations during the aerobic periods in the reactors.

In contrast, previous study by Ibrahim (2012) in warm climate has found that the optimum aeration rate of 10 L/min produced the best system performance in removing nitrogen removal and organic matters in domestic wastewater where the removals of COD is 50.4% and AN is 99.2%.

2.3.2 Aerated Rock Filter for Nitrogen Removal

The aerated rock filter used in this study was similar in basic processes to a biological aerated filter (BAF) as both systems are wastewater treatment units that provide carbon oxidation, nitrification and denitrification (Hamdan, 2010). Aeration of the rock filter plays an important role as it transfers oxygen to the wastewater and mixes the liquid content to permit microorganisms use the organic material for growth and as a source of energy in the purification of wastewater (Hamdan, 2010). The main purpose of ARF is to remove algae solids and associated biochemical oxygen demand (BOD) in effluents. Other than that, aeration also eliminates H₂S generation, significantly improves BOD and TSS removals and also provides the condition for nitrification occur (Mara, 2007). In Malaysia, aerated rock filter still a new systems, however it have been used for around 30 years in the United States.
However, they also been used elsewhere, for example in Brazil as reported in Mara and Johnson (2006).

Aerated rock filter is classified into two types: unaerated and aerated rock filter (Mara, 2007). The aerated and unaerated rock filter has two general types; vertical aerated rock filter (VARF) and horizontal aerated rock filter (HARF). The VARF is called because wastewater is fed at the bottom of VARF inlet and flows vertically through the media bed whereas in the HARF, the wastewater is fed at the inlet and flows horizontally through the media bed to the HARF outlet. In addition, the rock filter was introduced with aerated system where it particularly for ammonia removal but they rapidly become anoxic and unable to remove ammonia through nitrification as found in previous study by Mara and Johnson (2006). They have done an aerated rock filter for enhanced ammonia and fecal coliform removal from facultative pond effluents in year 2005. Consequently the aerated rock filter (ARF) is principally designed in the present study in combination of reactive filter media particularly for nitrogen and phosphorus removal from various types of wastewater. An aerated rock filter (ARF) system is a very simple technology, which is relatively easy to install at existing facilities and which requires low initial costs.

However, high ammonia nitrogen concentration in rock filter effluent could limit the application of the process (Middlebrooks, 1995), but if nitrification could be induced in the rock filter, the effluents would have a lower ammonia nitrogen concentrations than in the influents. This would be beneficial because this upgrading is required to reduce the concentration of ammonia discharged not only for rock filters treating pond effluents, but also for any small wastewater treatment plant (Mara and Johnson, 2006).

2.3.3 Rock Filter Media in Nitrogen Removal

Rock filter media is a filtration process where wastewaters are percolating through some naturally occurring substrate or media. Medium selection of a suitable rock filter media is important to achieve effluent quality requirements and the media play an important role in maintaining a high amount of active biomass and a variety of microbe populations (Liu et al., 2010). Besides that, rock filter media can be
differentiated further by media type and size where size of rock filter media has a strong influence on process performance and it should be carefully selected for different applications (Pramanik et al., 2012). The smaller size media gives a greater surface area per unit volume for biofilm development and a medium larger than 6 mm may be preferable for a roughing stage prior to full secondary treatment (He et al., 2007). On the other hand, media roughness also affects the performance of the reactor.

The performance of removal efficiency from various types of filter media that has been done by previous study was summarized in Table 2.7. However, in this present study, aeration rate is given more focus than the filter media in removing nitrogen from domestic wastewater.

<table>
<thead>
<tr>
<th>Filter media</th>
<th>Performance of removal efficiency</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast furnace slag (aerated system)</td>
<td>94% of TKN and 97% of ammonia nitrogen</td>
<td>Hamdan and Mara (2013)</td>
</tr>
<tr>
<td>Zeolite (aerated system)</td>
<td>84.63-93.11% of COD and 85.74-96.26% of NH₃N</td>
<td>He et al., (2007)</td>
</tr>
<tr>
<td>Expanded clay (aerated system)</td>
<td>82.34-93.71% of COD and 85.06-93.20% of NH₃N</td>
<td></td>
</tr>
<tr>
<td>Oyster shell (aerated system)</td>
<td>85.1% of COD, 98.1% of NH₃N and 23.2% of TP</td>
<td>Liu et al., (2010)</td>
</tr>
<tr>
<td>Plastic ball (aerated system)</td>
<td>80.0% of COD, 93.7% of NH₃N and 21.7% of TP</td>
<td></td>
</tr>
<tr>
<td>Haydite (aerated system)</td>
<td>75.62%-42.23% of ammonia nitrogen</td>
<td></td>
</tr>
<tr>
<td>Grain-slag (aerated system)</td>
<td>90.63%-63.46% of ammonia nitrogen</td>
<td>Feng et al., (2010)</td>
</tr>
</tbody>
</table>

### 2.3.4 Design Consideration for Rock Filter

Conventionally, rock filter was often used to remove algae from lagoon effluents where the systems consist of submerged beds of rocks, 75 to 200 mm (3 to 8 in) in size through which lagoon effluent is passed horizontally or vertically (U.S. EPA, 2002); the larger values reduce the surface exposure area, while smaller values can
REFERENCES


U. S. Environmental Protection Agency (2002). *Rock Media Polishing Filter for Lagoons (Wastewater Technology Fact Sheet No. EPA 832-F-02-023)*. Washington, DC; US Environmental Protection Agency.


