# AERATED ROCK FILTER AS A POLISHING UNIT FOR TOTAL NITROGEN & PHOSPHORUS REMOVAL FROM DOMESTIC WASTEWATER
# PART I

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# ABSTRACT

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. Therefore, in this study a pilot-scale vertical aerated rock filter (VARF) was principally design to remove total nitrogen from domestic wastewater. The influence of aeration flow rate at different filters depth has been studied. Wastewater from UTHM wastewater treatment plant has been collected to operate the VARF in the FKAAS Environmental Laboratory. Throughout the experimental period, the VARF influent and effluent samples have been sampling and analyzed for total nitrogen, ammoniacal nitrogen (AN), $BOD_5$, COD, TSS, turbidity, DO and pH for to monitor the filter effectiveness. From this study, it was indicated that most of ammoniacal nitrogen were converted to nitrate-nitrogen in the highly aerated VARF system. However, the rate was influenced by the airflow aeration rate. More than 90% of AN were converted to $NO_3$-N in the system at the filter depth of 0.75m and 1.0 m. Results from this study shows that at the filter depth 0.75m and air flow rate of 10 L/min has efficiently remove 50.4%, 51.9%, 74.7%, 99.2%, 96.2%, and 97.1% of COD, $BOD_5$, total nitrogen, ammoniacal nitrogen, TSS, and turbidity respectively compared to the air flow rate of 20 L/min at the same filter depth which is remove 42%, 72.1%, 54%, 95.1%, 92.4%, and 83.5% of COD, $BOD_5$, total nitrogen, ammoniacal nitrogen, TSS, and turbidity respectively. For pH and DO profiles, the effluent values was found to be higher at the air flow rate of 10 L/min, which is range between 8.4 to 9.5 and 7.6, 8.3 and 8.5 mg/L respectively. Meanwhile at air flow rate of 20 L/min is about 8.2 to 8.4 and 7.3, 8.1 and 7.0 mg/L respectively. By complying with Malaysian Environment Quality (sewage) Regulations 2009, the sample treated for all parameters are within permissible limit of standard B.

# ABSTRAK

Penyingkiran nitrogen daripada air sisa sering memerlukan kos rawatan kimia yang tinggi untuk mengelakkan lebih muatan nutrien dalam pelepasan efluen ke permukaan air. Oleh itu, dalam kajian ini penapis berudara menegak berskala kecil terutamanya direka bentuk untuk menyingkirkan jumlah nitrogen dari air sisa domestik. Pengaruh kadar aliran pengudaraan pada kedalaman penapis yang berbeza telah dikaji. Air sisa daripada loji rawatan kumbahan UTHM telah dikumpulkan untuk VARF beroperasi di Makmal Alam Sekitar FKAAS. Sepanjang tempoh eksperimen, sampel influen dan efluen VARF telah disampelkan dan dianalisis bagi jumlah nitrogen, ammonia nitrogen (AN), $BOD_5$, COD, TSS, kekeruhan, DO dan pH untuk memantau keberkesanan penapis. Daripada kajian ini, ia menunjukkan bahawa kebanyakan ammonia nitrogen telah ditukar kepada nitrate-nitrogen dalam sistem VARF berudara. Bagaimanapun, kadar tersebut telah dipengaruhi oleh kadar pengudaraan aliran udara. Lebih daripada 90% AN telah ditukar kepada $NO_3$-N dalam sistem pada kedalaman penapis 0.75m dan 1.0m. Hasil daripada kajian ini menunjukkan bahawa pada kedalaman penapis 0.75m dan kadar aliran udara 10 L/min telah menyingkirkan 50.4%, 51.9%, 74.7%, 99.2%, 96.2%, dan 97.1% masing-masing daripada COD, $BOD_5$, jumlah nitrogen, ammonia nitrogen, TSS, dan kekeruhan berbanding dengan kadar aliran udara 20 L/min pada kedalaman penapis yang sama yang menyingkirkan 42%, 72.1%, 54%, 95.1%, 92.4%, dan 83.5% masing-masing daripada COD, $BOD_5$, jumlah nitrogen, ammonia nitrogen, TSS, dan kekeruhan. Untuk pH dan DO profil, nilai efluen telah ditemui untuk menjadi lebih tinggi pada kadar aliran udara 10 L/min, yang merupakan julat antara 8.4 hingga 9.5 dan 7.6, 8.3 dan 8.5 mg/L masing-masing. Sementara itu, pada kadar aliran udara 20 L/min adalah antara 8.2 hingga 8.4 dan 7.3, 8.1, dan 7.0 mg/L. Dengan mematuhi

Kualiti Persekitaran Malaysia (Kumbahan) Peraturan 2009, sampel yang dirawat untuk semua parameter adalah dalam had yang dibenarkan standard B.

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| | |
|---|---|
| AN | Ammonia Nitrogen |
| $BOD_5$ | 5-days Biochemical Oxygen Demand |
| COD | Chemical Oxygen Demand |
| DO | Dissolved Oxygen |
| L | Liter |
| m | Meter |
| min | Minit |
| mg | Miligram |
| ml | Milimeter |
| $NO_2$-N | Nitrite-Nitrogen |
| $NO_3$-N | Nitrate-Nitrogen |
| $N_{Tot}$ | Total Nitrogen |
| OTE | Oxygen Transfer Efficiency |
| Q | Flow rate |
| TSS | Total Suspended Solid |
| TKN | Total Kjeldhal Nitrogen |
| VARF | Vertical Aerated Rock Filter |

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# INTRODUCTION

## 1.1 Introduction

Water is the most important to all living things in the world. There are many uses of water in daily life including for drinking, washing, cleaning, cooking, and plant. Human need clean and fresh water to survive the life. The quality of water is very important to be cared in order to supply clean and fresh water for human. The water from toilet, sinks, washing machines, showers, industrial processes and agriculture liquid waste disposed from pipe or sewer was called wastewater or sewage. It contain of wastewater pollutant such as feces or urine. Therefore, the wastewater needs to be treated before it can be discharged into rivers or lakes.

Wastewater treatment is a multi-stage process to renovate wastewater before it can be used. The goal is to reduce or remove organic matter or existing contaminants from wastewater. There are three major stages involved in domestic wastewater treatment. It is primary treatment, secondary treatment and tertiary treatment. In primary treatment it is including large tanks commonly called ''pre-settling basins'' or ''primary clarifiers'', large rakes and skimming devices. Secondary treatment is the process after primary treatment and it is biological treatment. The last process is tertiary treatment and it was include advanced wastewater treatment before discharge to the receiving body such as river and lake. (Davis and Corwell, 2008).

Wastewater may contain high levels of the nutrients such as nitrogen and phosphorus, also called eutrophication which can encourage the overgrowth of weeds, algae, and cyanobacteria (blue-green algae). This may cause an algal bloom and may produce toxins that contaminate in drinking water. Therefore, the different treatment processes are required such as biological process to remove nitrogen and phosphorus (*Wikipedia)*. There are also physical and chemical processes which can remove nitrogen especially ammonia.

Aeration introduces air into a liquid, providing an aerobic environment for microbial degradation of organic matter. The increased organic loading on wastewater treatment plants using activated sludge process has necessitated changes in aeration systems to increase the oxygenation efficiencies in aeration tanks. The role of aeration in the activated sludge process is to provide oxygen to the microorganisms as they assimilate the organic carbon compounds and digest a portion of them to carbon dioxide and water, Sulfate and Nitrate compounds. Therefore, aeration is one of the most elemental techniques frequently employed in the improvement of the physical and chemical characteristics of water.

## 1.2 Problem Statement

During the last few decades, the importance of nutrient removal has increased as a result of the necessity to avoid eutrophication of water bodies receiving untreated wastewater and the effluent of wastewater treatment plant. Nitrogen can deplete dissolved oxygen in receiving waters, stimulate aquatic plant growth, exhibit toxicity toward aquatic life, present a public health hazard, and affect the suitability of wastewater for reuse purposes in various forms.

Demand of low-cost technology for treating high nutrient wastewater is increasing due to complex processes and expensive of conventional treatment for nutrient removal. From previous study, it has shown that it is not always favorable to treat different wastewaters together in one treatment work. Therefore, reactors for the effective and economic treatment of split flows are required which are operated either as a pre-treatment stage, before discharge to the sewer or rivers, or as a treatment stage for process wastewaters.

To comply with the latest Malaysian effluent discharge regulation post process units are needed. For this purpose, VARF reactor appears to be suitable method in removing nutrients from the biological process which is more effective than physicochemical treatments and thus has been used more often to achieve nitrogen removal from domestic wastewaters (Khin and Annachhatre, 2004). Besides that, the elimination of dissolved pollutants the suspended particles will be reduced evidently.

## 1.3 Objective of Study

The objective of this research is to study the effects of aeration in a pilot-scale VARF system in removing nitrogen from domestic wastewater.

## 1.4 Scope of Study

The scopes for this research are as the following:

a) To construct a pilot-scale VARF.
b) To study the performance of the VARF for nitrogen removal at different rate of aeration and different filter depths (10 L/min and 20 L/min; 0.5m, 0.75m and 1.0m).
c) To monitor the VARF performance by analyzed the selected parameters including COD, $BOD_5$, Nitrate and Nitrite, Ammonia Nitrogen, Suspended Solid, Dissolved Oxygen, pH, Turbidity and Total Nitrogen.

## 1.5 Limitation of Work

The sample is taken from domestic wastewater treatment plant at Tun Fatimah Residential College in UTHM. This study is to focus on aeration rate at different depth based on a pilot scale vertical aerated rock filter and to monitor the parameter of wastewater.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Water

Water is essential element of earth's natural environment. Without water there is no life and industry could not operate. Different with other raw materials, there are no materials that can be used to replace the water (Ruslan Hassan, 1988). Water is a liquid and can be solid such ice at once level of temperature and gases when evaporated. Hydrological water traces the successive changes of water as it moves from the ocean through precipitation, transpiration, infiltration, run-off and back to the sea.

There are many type of water, such as surface water and groundwater. Surface water includes river, sea, rainfall and lake. Surface water generally are replenished naturally by precipitation and lost through discharge to evaporation and subsurface seepage into groundwater. Groundwater is water that located beneath the ground surface in soil pore spaces and in the fractures of rock formations.

Other than that, water is used for drinking water and it is essential for human, animal, plants to survive the life. Clean and fresh water are important for avoid from diseases. Besides that, water also uses for human activity daily for example washing, cooking, shower, industrial and others. The water must be had a treatment process to get the good quality of water before use.

## 2.2 Forms of Nitrogen

Nitrogen can occur in many forms in wastewater and undergo numerous transformations throughout the wastewater treatment process. Although, nitrogen is an essential nutrient for plant and algae growth, wastewater effluent containing too much nitrogen can have adverse effects on receiving waters. In order to control nitrogen concentrations in wastewater effluent, it is vital to understand the forms of nitrogen found in wastewater influent and at various stages in the wastewater treatment process.

Nitrogen is found in wastewater in two basic forms, they are unoxidized and oxidized nitrogen as shown in Table 2.1 below.

Table 2.1: Unoxidized and Oxidized Nitrogen

| **Unoxidized Forms** | **Oxidized Forms** |
|---|---|
| • Ammonia ($NH_3$) | • Nitrite ($NO_2$) |
| • Organic nitrogen (Org-N) | • Nitrate ($NO_3$) |
| • Nitrogen gas ($N_2$) | • Nitrous oxide ($N_2O$) |

Nitrogen typically enters a wastewater treatment plant as unoxidized nitrogen, in the form of organic nitrogen (Org-N) and ammonia. The combination of ammonia and Org-N concentrations is reported as total Kjeldahl nitrogen (TKN).

Many processes have been explored for the removal of nitrogen from water and wastewater. Those applied to wastewater are reported in Table 2.2. The four principal methods found feasible are biological nitrification, followed by denitrification, air stripping of ammonia at high pH, removal of nitrate or ammonia by ion exchange, and breakpoint chlorination. Only two methods will be discussed in depth in this review. They are nitrification and denitrification.

Table 2.2: Effect of Various Treatment Processes on Nitrogen Compounds

| **Treatment operations and processes** | **Nitrogen compound** | | | **Removal of total nitrogen entering process, %** |
|---|---|---|---|---|
| | **Organic nitrogen** | **$NH_3^-$ $NH_4^+$** | **$NO_3^-$** | |
| **Conventional treatment** | | | | |
| 1. Primary | 10-20% removed | No effect | No effect | 5-10 |
| 2. Secondary | 15-50% removed urea + $NH_3^-NH_4^+$ | <10% removed | Slight | 10-30 |
| **Biological processes** | | | | |
| 1. Bacterial assimilation | No effect | 40-70% removed | Slight | 30-70 |
| 2. Denitrification | No effect | No effect | 80-90% removed | 70-95 |
| 3. Harvesting of algae | Partial transformation to $NH_3^-NH_4^+$ | → Cells | → Cells | 50-80 |
| 4. Nitrification | 10-50 | → $NO_3^-$ | No effect | 5-20 |
| 5. Oxidation ponds | Partial transformation to $NH_3^-NH_4^+$ | Partial removal by stripping | Partial removal by nitrification-denitrification | 20-90 |

| | | | | |
|---|---|---|---|---|
| **Chemical processes** | | | | |
| 1. Breakpoint chlorination | Uncertain | 90-100% removed | No effect | 80-95 |
| 2. Chemical coagulation | 50-90% removed | Slight | Slight | 20-30 |
| 3. Carbon sorption | 30-50% removed | Slight | Slight | 10-20 |
| 4. Selective ion exchange for ammonium | Slight, uncertain | 80-97% removed | No effect | 70-95 |
| 5. Selective ion exchange for nitrate | Slight | Slight | 75-90% removed | 70-90 |
| **Physical operations** | | | | |
| 1. Ammonia stripping | No effect | 60-95% removed | No effect | 50-90 |
| 2. Electrodialysis | 100% of suspended organic N removed | 30-50% removed | 30-50% removed | 80-90 |
| 3. Filtration | 30-100% of suspended organic N removed | Slight | Slight | 20-40 |
| 4. Reverse osmosis | | 60-90% removed | 60-90% removed | 80-90 |
| **Land application** | | | | |
| 1. Irrigation | $\rightarrow NH_3{}^-NH_4^+$ | $\rightarrow NO_3^-$, plant N | $\rightarrow N_2$, plant N | 60-90 |
| 2. Rapid infiltration | $\rightarrow NH_3{}^-NH_4^+$ | $\rightarrow NO_3^-$ | $\rightarrow N_2$ | 30-80 |
| 3. Overland flow | $\rightarrow NH_3{}^-NH_4^+$ | $\rightarrow NO_3^-$, plant N | $\rightarrow N_2$, plant N | 70-90 |

### 2.2.1 NitrificationProcess

Nitrification alone will remove ammonia-nitrogen, but the resulting nitrite- and nitrate-nitrogen normally will not be removed and can serve as nutrients for undesirable algal growths in streams and lakes. However, nitrification can help to eliminate the problems of ammonia toxicity to fish and will minimize excessive oxygen demand exerted by ammonia nitrogen in streams.

Nitrification is the biological formation of nitrite-N ($NO_2^-$N) or $NO_3^-$N from $NH_4^+$ (Alexander, 1977). This process naturally occurs in the environment, where it is carried out by specialized bacteria. Furthermore, this process requires oxygen, hence it will use up the oxygen needed by other organism.

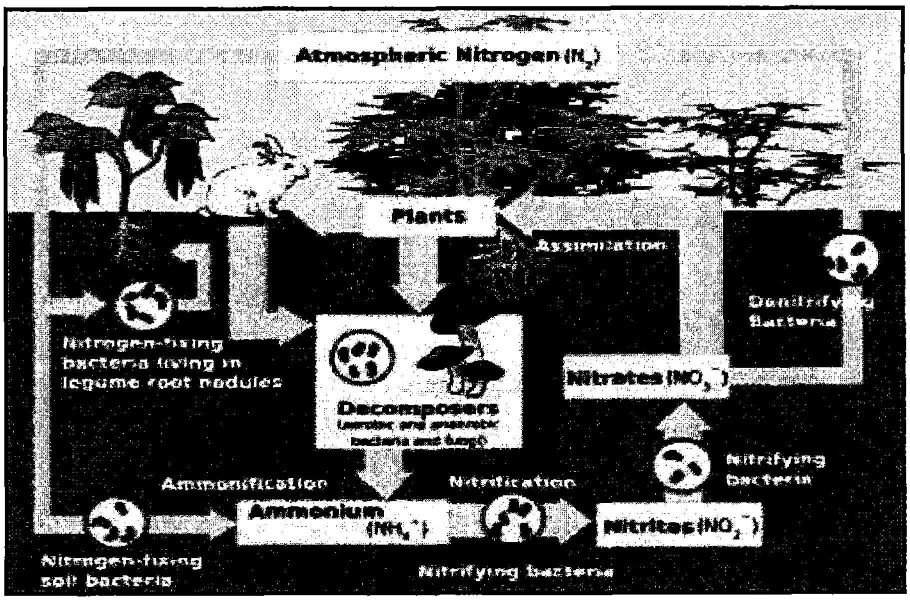
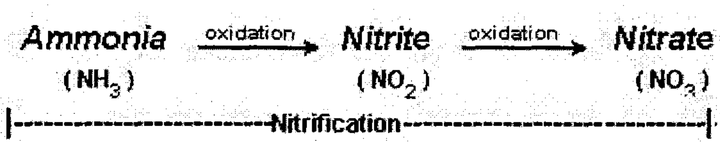



Figure 2.1: Nitrogen Cycle

Figure 2.1 above shows a nitrogen cycle (Sawyer and McCarty, 1978). Biological nitrification is the conversion or oxidation of ammonium ions to nitrite ions and then to nitrate ions. During the oxidation of ammonium ions and nitrite ions, oxygen is added to the ions by a unique group of organisms, the nitrifying bacteria.

Nitrification occurs in nature and in activated sludge processes and also occurs in aerobic regions of the water column, soil-water interface, and root zone (Reddy and D`Angelo, 1997). Dissolved oxygen levels < 1-2 mg/L in water substantially reduces nitrification (Hammer and Knight, 1994). Nitrification in soil is especially important in nature, because nitrogen in absorbed by plants as a nutrient in the form of nitrate ions. Meanwhile, nitrification in water is of concern in wastewater treatment, because nitrification may be required for regulatory purposes or may contribute to operational problems. Domestic wastewater contains large amounts of organic wastes, so the wastewater will have a high ammonia concentration. Generally, there are two bacterial species involved in nitrification process. During the nitrification process, ammonia concentrations are reduced as a result of the conversion of ammonia to nitrite and nitrate.




In nitrification process, ammonia nitrogen is converted to nitrate utilizing two purely aerobic autotrophs, they are Nitrosomonas and Nitrobacter bacteria. Both bacteria are instrumental in completing nitrification. The nitrification reaction in a two-step process as follows:

Step 1:

Nitrosomonas bacteria, which are purely aerobic autotrophs, convert ammonia nitrogen to nitrite. During the conversion process these bacteria consume large quantities of Dissolved Oxygen (DO) and reduce alkalinity.

$$NH_4^+ + 1.5O_2 \xrightarrow{Nitrosomonas} 2H^+ + H_2O + NO_2^- \qquad (2.1)$$

Step 2:

Nitrobacter bacteria, which are also purely aerobic autotrophs, convert the nitrite to nitrate. Once again, the vital element needed for this conversion to occur is DO and the conversion process further reduces alkalinity. Nitrobacter have a faster growth rate than Nitrosomonos, therefore, the conversion to nitrate occurs rapidly.

$$NO_2^- + 0.5O_2 \xrightarrow{Nitrobacter} NO_3^- \qquad (2.2)$$

The overall oxidation of ammonium is obtained by adding equations (2.1) and (2.2), thereby giving Equation (2.3):

$$NH_4^+ + 2O_2 \longrightarrow NO_3^- + 2H^+ + H_2O \quad (2.3)$$

The nitrification process produces acid [H+], as shown in Equation 2.3. This acid formation lowers the pH of the biological population in the treatment system, and can cause reduction of the growth rate of nitrifying bacteria. Moreover, the nitrification reaction consumes 7.2 mg/L of bicarbonate alkalinity as $CaCO_3$ for each mg/L of ammonia nitrogen oxidized. Thus, wastewaters with low alkalinity require the addition of alkalinity to support uninhibited nitrification. In addition to pH, nitrification is very sensitive to temperature, the DO concentration, and toxic materials.

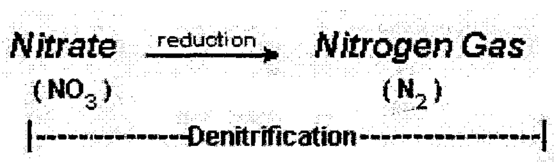
Table 2.3: Basic Physiological and Structural Features of *Nitrosomonas* and *Nitrobacter*

| **Features** | **Nitrosomonas** | **Nitrobacter** |
|---|---|---|
| Carbon sources | Inorganic ($CO_2$) | Inorganic ($CO_2$) |
| Cell shape | Coccus (spherical) | Bacillus (rod-shaped) |
| Cell size, µm | 0.5 to 1.5 | 0.5 x 1.0 |
| Habitat | Soil and water | Soil and water |
| Motility | Yes | No |
| Oxygen requirement | Strict aerobe | Strict aerobe |
| pH growth range | 5.8 to 8.5 | 6.5 to 8.5 |
| Reproduction mode | Binary fission | Budding |
| Generation time | 8 to 36 hours | 12 to 60 hours |
| Temperature growth range | 5 to 30°C | 5° to 40°C |
| Sludge yield | 0.04 to 0.13 pound d of cells per # of $NH_4^+$ oxidized | 0.02 to 0.07 pound of cells per # of $NO_2^-$ oxidized |
| Cytomembranes | Present | Present |

### 2.2.2 Denitrification Process

Biological denitrification is an anaerobic process by facultative heterotrophic bacteria wherein the nitrite ion is the hydrogen ion acceptor in the electron transport system. Facultative anaerobes make up approximately 80% of the bacteria within an activated sludge process. The nitrate ion permits the microbial cell to maintain aerobic metabolism in the absence of free oxygen. In the process, nitrates are reduced to nitrogen gas and carbon compounds are oxidized.

Denitrification occurs when oxygen levels are depleted and nitrate becomes the primary oxygen source for microorganisms. So, the process is performed under anoxic conditions, which are when the dissolved oxygen concentration is less than 0.5 mg/L, ideally less than 0.2. When bacteria break apart nitrate ($NO_3^-$) to gain the oxygen ($O_2$), the nitrate is reduced to nitrous oxide ($N_2O$), and in turn, nitrogen gas ($N_2$). Since nitrogen gas has low water solubility, it escapes into the atmosphere as gas bubbles. Denitrification must follow the nitrification process in order to achieve total nitrogen removal.




In denitrification process, nitrate, the form of nitrogen that results from the completion of the nitrification process, is converted to nitrogen gas, utilizing facultative heterotrophic bacteria. The process of denitrification occurs under anoxic conditions as follows:

(Nitrate) $NO_3$-N + $\longrightarrow$ Nitrogen Gas ($N_2$) + Oxygen ($O_2$) + Alkalinity ($HCO_3^-$)

## 2.3 Aeration System

Aeration is the process by which the area of contact between water and air is increased, either by natural or by mechanical devices. Aeration is the most important operation in the treatment process to provide oxygenation and mixing. Aeration systems are among the most energy intensive operations in wastewater treatment systems, consuming between 50 – 90% of the total energy costs of typical municipal installations (Wesner *et al., 1977*).

Wastewater treatment plants utilizing biological treatment need to aerate the wastewater and aeration serves two primary purposes consist of:

i. Oxygen is added to the wastewater which is critical to the microorganisms in the biological treatment system and

ii. Mixing of the wastewater, which is contains the food or organic load, and the microorganisms or the mixed liquor suspended solids (MLSS), also improves both the dispersion of the organic load in the system and facilitates contact between the microorganisms and the food.

The others purposes of aeration is to improve their physical and chemical characteristics, to remove or reduction of objectionable taste and odor and to precipitate inorganic contaminants such as iron and manganese while the functions of aeration is oxygenation of the mixed liquor, flocculation of the colloids in sewage influent and suspension of activated sludge floc.

In wastewater treatment, the purpose of aeration is to ensure continued aerobic conditions for the microorganism to degrade the organic matters. The efficiency of aeration systems can be measured in different ways. Different aeration systems have different efficiency (Metcalf and Eddy, 2004). The following Table 2.4 shows the efficiency of various aeration systems adapted to give values in kilowatt-hour per kilogram of oxygen.

Table 2.4: Efficiency of Various Aeration Systems in kWH/kg

| Aeration System | kWH/kg |
|---|---|
| **Mechanical aeration systems** | |
| Brush aerators surface aeration | 0.47-0.66 |
| Slow speed surface | 0.47-0.55 |
| High speed splash surface aeration | 0.51-0.66 |
| Induced surface aeration | 1.10-1.64 |
| **Combination systems** | |
| Submerged turbine | 0.66-1.10 |
| Jets (pumps with compressors) | 0.47-0.82 |
| **Diffused Aeration, Coarse Bubble** | |
| Static tubes | 0.47-0.82 |
| Wide band grid | 0.47-0.66 |
| Misc. coarse bubble | 0.47-0.82 |
| **Diffused Aeration, Fine Pore** | |
| Ceramic disc or ceramic dome grid | 0.23-0.33 |
| Flexible membrane disc | 0.23-0.41 |
| Advanced technology membrane | 0.14 |

### 2.3.1 Diffused Air Aeration

In diffused air systems, air is introduced to the mixed liquor through 'diffusers' located at some distance below the liquor surface. Diffused air systems are classified as coarse or fine bubble systems, depending on the size of bubble generated. Although the boundary between these two categories is not very sharply defined, fine bubble diffusers typically produce bubbles in the 2-5mm size range in clean water, while coarse bubble diffusers produce bubbles in the size range 6-10mm.

Coarse bubble diffuser is designed to introduce oxygen and provide mixing in wastewater and sludge. For tougher applications such as sludge or industrial wastewaters, coarse bubble is often the best solution. It is typically consist of drilled holes or slots in a submerged air distribution system. The bubbles produced may be smaller than the orifice size, through being sheared off by the water pressure. In addition, the oxygen transfer efficiency (OTE) of coarse bubble systems is generally much lower than fine bubble systems. OTE is defined as the percent of oxygen transferred, at zero dissolved oxygen concentration.

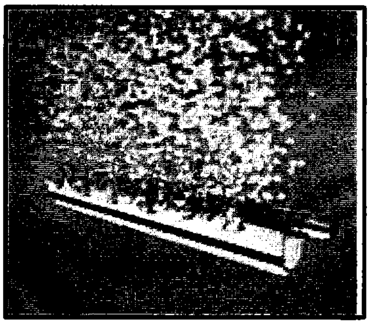


Figure 2.2: Coarse Bubble Diffuser

Fine bubble diffusers is defined as a diffuser system that air bubbles introduce into the wastewater with submerge diffuser. Fine bubble diffusers are constructed from a range of materials including ceramics, porous plastics and perforated membranes. Ceramics and porous plastics have interconnected pore structures through which the air flows to be discharged at the diffuser surface as a bubble stream. Size of the bubble range is 0.5mm to 5mm, but the common used of fine bubble in wastewater treatment is 2mm. Besides that, fine bubble diffuser is one of the method where the oxygen can be transfer into the aeration tank. The fine bubble diffuser will produce the air from the bottom and rise up to the surface of aeration tank, therefore the efficient of oxygen transfer will occur.

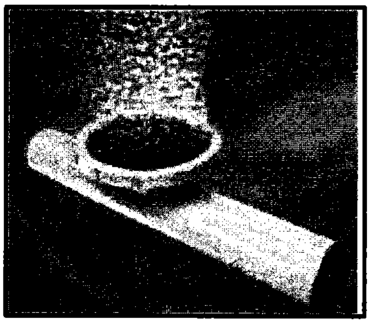


Figure 2.3: Fine Bubble Diffuser

Table 2.5 and 2.6 below shows the advantages and disadvantages of coarse bubble and fine bubble diffusers.

Table 2.5: Advantages and Disadvantages of Coarse Bubble Diffuser

| Advantages | Disadvantages |
|---|---|
| 1. Useful in secondary treatment. In the processing tanks, floc, sediment and carbonate build up tend to plug or clog the fine or small air release opening.<br>2. Useful for a digester with high solid concentration.<br>3. It has ability to shear through more viscous wastewater. | 1. Only supply 10% and would required almost 2 to 3 times more energy to produce the same result as the fine bubble diffusers.<br>2. Fine bubbles system should yield 50% energy cost savings. |

Table 2.6: Advantages and Disadvantages of Fine Bubble Diffuser

| Advantages | Disadvantages |
|---|---|
| 1. Delivers high oxygen transfer efficiencies.<br>2. Delivers high aeration efficiencies (mass oxygen transferred per unit power per unit time).<br>3. Suitable for **high** oxygen demands.<br>4. Easily adaptable to existing setups or for plant upgrades.<br>5. Flexibility of application to various tank geometries.<br>6. Result in lower volatile organic compound emissions than coarse bubble diffusers or mechanical aeration devices. | 1. Fine pore diffusers are susceptible to chemical or biological fouling that may impair transfer efficiency and generate high headloss.<br>2. It may be susceptible to chemical attack, especially perforated membranes. So, it must be exercised in the proper selection of materials for a given wastewater.<br>3. It produces high efficiencies at low airflow rates but, airflow distribution is critical to their performance and selection of proper airflow control orifices is important. |

| | |
|---|---|
| | 4. It required airflow in an aeration basin. Normally at the effluent end, and maybe dictated by mixing or not oxygen transfer.<br>5. Aeration basin design must incorporate a means to easily dewater the tank for cleaning. |

#### 2.3.1.1 Diffuser Performance

The efficiency of oxygen transfer depends on many factors, including the type, size, and shape of the diffuser; the air flow rate; the depth of submersion; tank geometry including the header and diffuser location; and wastewater characteristics. Aeration devices are conventionally evaluated in clean water and the results adjusted to process operating conditions through widely used conversion factors.

Typically, oxygen transfer rates and oxygen transfer efficiencies are commonly given in manufacturer information and in design manuals for a depth of 4.6 m (15 ft), such as is commonly found in larger aeration tanks (Tchobanoglous and Burton 1991; U.S. 1989). But it is anticipated that oxygen transfer rates and efficiencies vary significantly for smaller, much shallower systems.

Oxygen transfer efficiency of an aeration system is the ration of the amount of oxygen that actually dissolves into the water to the total amount of oxygen pumped into the water. In wastewater, the factor called alpha is used to adjust the clean water transfer efficiency to take into account the effects of wastewater characteristics on transfer efficiency.

Alpha is the ratio of oxygen transfer in generic wastewater to oxygen transfer in clean water and it is especially important because alpha factor varies with the physical features of the diffuser system, the geometry of the reactor, and the characteristics of the wastewater. However, wastewater-constituents may affect porous diffuser oxygen transfer efficiencies to a greater extent than other aeration devices, resulting in lower alpha factors. The presence of constituents such as detergents, dissolved solids, and suspended solids can affect the bubble shape and size and result in diminished oxygen transfer capability.

Values of alpha varying from 0.4 to 0.9 have been reported for fine-bubble diffuser systems (Hwang and Stenstrom, 1985). Therefore, considerable care must be implemented in the selection of the appropriate alpha factors.

## 2.4 Oxygen Dispersion Efficiency and Mixing

In the treatment of wastewater, an aeration system is ineffective in providing a complete and uniform transfer of oxygen throughout the entire basin. Although many systems are designed to aerate wastewater, they vary in their effectiveness in providing uniform oxygen dispersion.

Other than that, diffused air, surface splashes, and rotor have limited areas of influence, causing short-circuiting, dead zones, and only partial aeration are the typical aeration systems. Because the mixer technology produces a horizontal and circular flow pattern and the equipment provides for whole basin circulation.

The conventional splashing type make the system pump water upward and throws it into the air, so it create a high aerosol environment. To overcoming gravity also consumes large amounts of energy. The short-circuiting and dead spots may be occurring due to inadequate basin mixing. Sludge deposits typically accumulate at corners and between units in the basin. It is also create and even greater oxygen demand.

Besides that, blower or diffuser systems introduce compressed air through diffusers into the water from the bottom of the basin. More horsepower on higher energy consumption is required to overcome the water head resistance and the mixing pattern is a limited vertical column as air raises from the diffuser heads to the surface of water. From time to time, the system of diffuser heads clog as solids and biofilm accumulation and this can reduces oxygen transfer efficiency.

## 2.5 Dissolved Oxygen

According to Gerardi (2002), dissolved oxygen (DO) is the free or chemically uncombined oxygen in wastewater. Since wastewater or the bacterial degradation of wastes has avidity for oxygen, oxygen dissipated quickly in wastewater. DO is the most important indicator of the health of a water body and its capacity to support a balanced aquatic ecosystem of plants and animals.

The nitrification contributes to the rapid loss of oxygen within wastewater. In other word, quantity of dissolved oxygen in the sewage will experience reductions and it will be used by microorganisms during the decomposition process of organic substances found in sewage that may lead to the death of marine organism.

The dynamic nature of dissolved oxygen results from interaction of three factors (Hargreaves, 2006):

1) Oxygen is not very soluble in water so water has only a limited capacity to trap the oxygen.
2) The rate of oxygen use by living creatures in the pond mud can be high.
3) Oxygen diffuses very slowly from the atmosphere into undisturbed water.

Hence, combination of these three factors induced limited solubility, rapid use and slow replenishment. However, an optimal DO concentration to achieve nitrification is relatively low from 2 to 3 mg/l and unfortunately, many activated sludge processes are over aerated to achieve nitrification.

Table 2.7 below shows the DO concentration and nitrification achieved. Factors responsible for this limited amount of nitrification are the lack of oxygen diffusion through the floc particle and competition for oxygen by other organisms. Nitrification accelerates when DO concentration is increased.

Table 2.7: DO Concentration and Nitrification Achieved

| DO Concentration | Nitrification Achieved |
|---|---|
| <0.5 mg/l | Little, if any, nitrification occurs |
| 0.5 to 1.9 mg/l | Nitrification occurs but inefficiently |
| 2.0 to 2.9 mg/l | Significant nitrification occurs |
| 3.0 mg/l | Maximum nitrification |

## 2.6 Wastewater and Composition

Every community produces both liquid, solid wastes and air emissions. The liquid waste and wastewater is essentially the water supply of the community after it has been used in variety of applications. From the standpoint of sources of generation, wastewater maybe defined as a combination of liquid or water-carried wastes removed from residential, offices, institutions, commercial and industrial establishments together with such groundwater, surface water and storm water as may be present.

Wastewater is 99.97 percent water by mass. The remaining 0.03 percent is organic and inorganic compounds of anthropogenic and natural origin that is either dissolved or suspended in the water as shown in Table 2.8 below. The naturally occurring constituents in wastewater were present in the source water that was supplied to the user. Besides that, the concentration of these materials is very small and is measured in milligrams per litre or parts per million of water (mg/l). After passed the treatment, the effluent is returned to the environment in a way that is safe for our health and for the environment.

Table 2.8: Physical, Chemical, and Biological Characteristics of Wastewater and Their Sources *Wastewater Engineering. Treatment Disposal Reuse,* G. Tchobanoglous and F.L. Burton (Eds.), 1820 pp. New York: McGraw-Hill.

| **Characteristics** | **Sources** |
|---|---|
| Physical properties: | |
| Color | Domestic and industrial wastes, natural decay of organic materials |
| Odor | Decomposing wastewater, industrial wastes |
| Solids | Domestic water supply, domestic and industrial wastes, soil erosion, inflow/infiltration |
| Temperature | Domestic and industrial wastes |
| Chemical constituents: | |
| Organic: | |
| Carbohydrates | Domestic, commercial, and industrial wastes |
| Fats, oils, and grease | Domestic, commercial, and industrial wastes |
| Pesticides | Agricultural wastes |
| Phenols | Industrial wastes |
| Proteins | Domestic, commercial, and industrial wastes |
| Priority pollutants | Domestic, commercial, and industrial wastes |
| Surfactants | Domestic, commercial, and industrial wastes |
| Volatile organic compounds | Domestic, commercial, and industrial wastes |
| Other | Natural decay of organic materials |
| Inorganic: | |
| Alkalinity | Domestic wastes, domestic water supply, groundwater infiltration |
| Chlorides | Domestic wastes, domestic water supply, groundwater infiltration |
| Heavy metals | Industrial wastes |
| Nitrogen | Domestic and agricultural wastes |
| pH | Domestic, commercial, and industrial wastes |

| | |
|---|---|
| Phosphorus | Domestic, commercial, and industrial wastes, natural runoff |
| Priority pollutants | Domestic, commercial, and industrial waste |
| Sulfur | Domestic water supply; domestic, commercial, and industrial wastes |
| Gases: | |
| Hydrogen sulfide | Decomposition of domestic wastes |
| Methane | Decomposition of domestic wastes |
| Oxygen | Domestic water supply, surface-water infiltration |
| Biological constituents: | |
| Animals | Open watercourses and treatment plants |
| Plants | Open watercourses and treatment plants |
| Protists: | |
| Eubacteria | Domestic wastes, surface-water infiltration, treatment plants |
| Archaebacteria | Domestic wastes, surface-water infiltration, treatment plants |
| Viruses | Domestic wastes |

## 2.7 Domestic Wastewater

Domestic wastewater or sewage is the discharge from domestic residences, commercial or industrial premises into the public sewer, originated from all aspects of human sanitary water usage. It is typically composed of human body wastes such as faeces and urine together constitutes a combination of flows from bathroom, toilets, kitchen sinks, floor traps, dishwashers and washing machines. However, apart from domestic wastewater originated from residences, premises such as commercial, institutional and industrial also contribute a domestic wastewater component. In Malaysia, a separate sewerage conveyance system is adopted from the domestic use only. The analysis of human faeces and urine is given in Table 2.9.

Table 2.9: Composition of Human Faeces and Urine

| Quantity of Faeces | Faeces | Urine |
|---|---|---|
| Quantity (wet)/person/day | 135-270 g | 1.0-1.3 kg |
| Quantity (dry solids)/person/day | 35-70 g | 50-70 g |
| Approximate Composition (%) | | |
| Moisture | 66-80 | 93-96 |
| Organic Matter | 88-97 | 65-85 |
| Phosphorus | 30-5.4 | 2.5-5.0 |
| Potassium | 1.0-2.5 | 3.0-4.5 |
| Calcium | 4.5 | 4.5-6.0 |
| Carbon | 44-55 | 11-17 |
| Moisture | 66-80 | 93-96 |
| Nitrogen | 5.0-7.0 | 15-19 |

## 2.8 Characteristic of Domestic Wastewater

Domestic wastewater is a gray colour, turbid liquid or sometimes said to have an odor of kerosene or freshly-turned earth. Wastewater characteristics generally related with the quality of the physical, chemical and biological. For the physical parameters, it is including color, taste and odor, temperature, turbidity and solids content. Solids content can be categorized into suspended solids and dissolved solids in the form of organic or inorganic.

Chemical parameters of wastewater usually viewed from two main categories, it is in form of organic and inorganic. For organic category of chemical parameters including biochemical oxygen demand (BOD), chemical oxygen demand (COD), total oxygen demand (TOD), protein, oils, fats and carbohydrates. While in inorganic form, chemical parameters are including pH (acidity, alkalinity), heavy metals (mercury, lead, chromium and zinc), chlorine, nitrogen, phosphorus and sulfate. Biological parameters of domestic wastewater are including coliforms, fecal coliforms, pathogens and viruses.

Actually, parameters as mentioned above is varies with the concentration of contaminants in the wastewater which generally depending on the type of domestic water use, quality and quantity of industrial waste discharge and infiltration runoff into the collection system. Then, the survey should be given in a fixed time to obtain an adequate control. For this purpose, the concentration of pollutants in the wastewater was divided into three main levels of low, medium and strong (Metcalf and Eddy, 1999) as shown in Table 2.10.

Table 2.10: Typical Composition of Untreated Domestic Wastewater

| **Contaminants** | **Unit** | **Concentration** | | |
|---|---|---|---|---|
| | | **Weak** | **Medium** | **Strong** |
| Solids, total (TS) | mg $L^{-1}$ | 350 | 720 | 1200 |
| Dissolved, total (TDS) | mg $L^{-1}$ | 250 | 500 | 850 |
| Fixed | mg $L^{-1}$ | 145 | 300 | 525 |
| Volatile | mg $L^{-1}$ | 105 | 200 | 325 |
| Suspended solids (SS) | mg $L^{-1}$ | 100 | 220 | 350 |
| Fixed | mg $L^{-1}$ | 20 | 55 | 75 |
| Volatile | mg $L^{-1}$ | 80 | 165 | 275 |
| Settleable solids | mg $L^{-1}$ | 5 | 10 | 20 |
| $BOD_5$ at 20° C | mg $L^{-1}$ | 110 | 220 | 400 |
| Total organic carbon (TOC) | mg $L^{-1}$ | 80 | 160 | 290 |
| Chemical oxygen demand (COD) | mg $L^{-1}$ | 250 | 500 | 1000 |
| Nitrogen (total as N) | mg $L^{-1}$ | 20 | 40 | 85 |
| Organic | mg $L^{-1}$ | 8 | 15 | 35 |
| Free ammonia | mg $L^{-1}$ | 12 | 25 | 50 |
| Nitrites | mg $L^{-1}$ | 0 | 0 | 0 |
| Nitrates | mg $L^{-1}$ | 0 | 0 | 0 |
| Phosphorus (total as P) | mg $L^{-1}$ | 4 | 8 | 15 |
| Organic | mg $L^{-1}$ | 1 | 3 | 5 |
| Inorganic | mg $L^{-1}$ | 3 | 5 | 10 |

| | | | | |
|---|---|---|---|---|
| Chlorides | mg $L^{-1}$ | 30 | 50 | 100 |
| Sulfate | mg $L^{-1}$ | 20 | 30 | 50 |
| Alkalinity (as $CaCO_3$) | mg $L^{-1}$ | 50 | 100 | 200 |
| Grease | mg $L^{-1}$ | 50 | 100 | 150 |
| Total coliform | CFU 100 $mL^{-1}$ | $10^6$-$10^7$ | $10^7$-$10^8$ | $10^8$-$10^9$ |
| Volatile organic compounds (VOCs) | mg $L^{-1}$ | <100 | 100-400 | >400 |

### 2.8.1 Physical Characteristics

Physical characteristics generally related with the measurement of parameters that can be done through the naked eye or touch. The wastewater has physical characteristics such as temperature, solids, turbidity, colour, taste and odor.

i) Temperatute

Temperature is one of the most important parameters. Temperature is determined as a catalyst, a depressant, an activator, a restrictor, a stimulator, a controller and a killer. It affects the self-purification of streams. Rise in temperature enhances toxicity of poisons and intensity of odor besides changing the taste. Also increase in temperature causes growth of undesirable water plants and wastewater fungus. It influences the biological species present and their rates of biological activity. Hence, temperature has an effect on most chemical reactions that occur in natural water systems and also has a pronounced effect on the solubility of gases in water. Aerobic digestion ceases at a temperature greater than 50°C but at less than 15°C anaerobic digestion is affected as methane bacteria become inactive.

The temperature affects the reaction rates and solubility levels of chemicals. Most of chemical reactions involving dissolution of solids

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