STUDY OF RECYCLED CONCRETE AGGREGATE AS FILTER MEDIA FOR PHOSPHORUS REMOVAL IN SYNTHETIC WASTEWATER

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ABSTRACT

Phosphorus is one of the key nutrients that lead to eutrophication in surface water. However, existing conventional wastewater treatment systems for removing phosphorus are expensive and complex. Recycled concrete aggregate (RCA) may be an alternative solution for phosphorus removal. It can reduce pollution and landfill disposal by converting construction waste into valuable products. This study aims to investigate the physical and chemical characteristics of RCA that influence the removal of phosphorus, as well as the percentage of phosphorus removal using RCAs of two different sizes namely, 5 mm to 10 mm and 25 mm to 30 mm. A total of five vertical laboratory-scale RCA filters were designed and five different concentrations of synthetic wastewater between 10 – 50 mg/L were prepared. The samples taken from the influent and effluent filters were tested and analysed in terms of pH, the uptake capacity of phosphorus (q) and the percentage of phosphorus removal (%). RCA was analysed using Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDX) to determine its chemical composition. The results show that RCA has a high content of aluminium, calcium and magnesium that enhances phosphorus adsorption. RCA measuring between 5 mm to 10 mm in 10 mg/L of synthetic wastewater achieved the highest phosphorus removal percentage of 99.54% at a pH 10. The highest percentage of phosphorus removal achieved was 99.54% in the initial concentration of 10 mg/L by RCA measuring between 5 mm to 10 mm while the lowest percentage of phosphorus removal was 66.25% in the initial concentration of 50 mg/L for RCAs measuring between 25 mm to 30 mm. Furthermore, RCA achieved the highest uptake capacity (q) of 3.45 mg/L in the initial wastewater concentration of 50 mg/L. In conclusion, RCA has the potential to remove phosphorus, particularly in low concentrations of synthetic wastewater and high pH conditions.

ABSTRAK

Fosforus (P) adalah salah satu nutrien utama yang membawa kepada masalah eutrofikasi dalam permukaan air. Walaubagaimanapun, sistem rawatan air sisa konvensional yang sedia ada untuk mengeluarkan fosforus adalah mahal dan memerlukan proses yang kompleks. Konkrit yang dikitar semula menjadi RCA telah dipilih sebagai sistem penapis muncul sebagai teknologi alternatif untuk penyingkiran fosforus. Hal ini dapat mengatasi masalah sisa tapak pembinaan dan menukar sisa ini ke dalam sesuatu produk yang bernilai. Oleh itu, kajian ini bertujuan untuk mengkaji ciri-ciri fizikal dan kimia RCA yang mempengaruhi peratus penyingkiran fosforus dengan menggunakan dua saiz RCA yang berbeza iaitu (5 mm hingga 10 mm) dan (25 mm hingga 30 mm). Sebanyak lima penapis agregat konkrit menegak bersaiz makmal direka bentuk lima kepekatan kumbahan sintetik yang berbeza iaitu 10 - 50 mg/L disediakan. Sampel diambil dari penapis influen dan effluen seminggu sekali, dan dianalisis untuk menentukan pH, kapasiti pengambilan fosforus (q) dan peratus penyingkiran fosforus (%). RCA dianalisis dengan menggunakan Mikroskopi Pengimbasan Elektron (SEM) dan spektroskopi sinar-X-dispersif tenaga untuk menentukan komposisi kimia. Keputusan menunjukkan bahawa RCA sangat tinggi kandungan aluminium, kalsium dan magnesium yang meningkatkan penyingkiran fosforus. RCA yang bersaiz 5 mm hingga 10 mm dan kepekatan air kumbahan sintetik 10 mg/L berpotensi tinggi dalam menyingkirkan fosforus iaitu 99.54% pada pH 9.77. Selain itu, sebanyak 99.94% penyingkiran fosforus berlaku pada RCA saiz 5 mm hingga 10 mm pada kepekatan 10 mg/L manakala 66.25 % pada kepekatan 50 mg/L. Tambahan lagi, kapasiti pengambilan tertinggi (q) sebanyak 3.45 mg/L pada kepekatan 50 mg/L dan RCA yang bersaiz 5 mm hingga 10 mm. Kesimpulannya. RCA mempunyai potensi untuk mengeluarkan fosphorus dari kepekatan air sisa sintetik yang rendah dan pH yang tinggi.

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LIST OF SYMBOL AND ABBREVIATION

ASTM	-	America Standard for Testing and Material
BS	-	British Standard
BS EN	-	British Standard European Norm
BFS	-	Blast furnace slag
C&D	-	Construction and demolition
cm	-	Centimeter
DO	-	Dissolved oxygen
EBPR	-	Enhanced Biological Phosphorus Removal
EDX	-	Energy-dispersive X-ray spectroscopy
mg/L	-	Miligram per Liter
mm	-	Milimeter
N	-	Nitrogen
P	-	Phosphorus
PAO	-	Phosphate accumulating organisms
PHA	-	Polyhydroxyalkanoates
RCA	-	Recycled Concrete Aggregate
rpm	-	Revolution per minute
SEM	-	Scanning electron microscopy
UTHM	-	Universiti Tun Hussein Onn Malaysia
Mm	-	Micrometer
VFA	-	Volatile fatty acids
RF	-	Rock filter
HLR	-	Hydraulic loading rate

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CHAPTER 1

INTRODUCTION

1.1 Background of study

Phosphorus (P) is a main nutrient element for plant growth in the natural water system. However, excessive phosphorus loads in water bodies from industrial, agricultural and household wastes may cause the overgrowth of aquatic plants or algae which accelerates the depletion of dissolved oxygen (DO) in water, thereby leading to serious eutrophication problems. In developing countries, approximately 75% of domestic wastewater is released into the environment without treatment (Rozari *et al*. 2016). Ayaz *et al*. (2012) reported that eutrophication in receiving water bodies may occur when the concentration of phosphorus is 6 mg/L. The Urban Wastewater Treatment Directive (UWWTD) Regulation 1994, by the Environmental Protection Agency Act sets phosphorus discharge consent standards of 2 mg/L of total Phosphorus between 10000 and 100000 pe. Therefore, proper treatment for removing phosphorus from domestic wastewater to achieve the admissible level for natural systems is needed.

The removal of phosphorus from wastewater is a common procedure. Improving water quality is the aim of wastewater treatment. There are many types of conventional methods that have been used for the removal of phosphorus. Phosphorus reaction with chemicals can be removed immediately from water. However, the use of chemicals often increases the cost of wastewater treatment (Zuo *et al*. 2015). Therefore, this study was conducted to investigate the appropriate method for eliminating phosphorus in a filter system using recycled concrete aggregates as it is cost-effective and environmentally friendly. According to Nasir (2016), an important factor that needs to be considered in designing a filter includes the selection of the filter material itself. The utilisation of easily available and low-cost materials has been widely demonstrated by previous studies for the removal of phosphorus including limestone, fly ash, iron oxide, steel slag and blast furnace slag (Johansson, 2013). Therefore, a detailed study of filter media capabilities for the removal of phosphorus is essential.

The removal performance of phosphorus is influenced by temperature, pH, and concentration of metallic salt. pH value has a significant effect on the removal of phosphorus. Generally, adsorption will occur at a low pH while calcium will precipitate during the removal of phosphorus at a high pH (Ahmad *et al*., 2017).

Unaerated systems and aerated systems vary in the admission of oxygen into the systems throughout the aeration process. Under aerated conditions, calcium and aluminium adsorb on the surface of adsorbents to become the adsorption site for the removal of phosphorus. However, phosphate is precipitated together with Ferum ions. Besides that, highly dissolved oxygen in aerated conditions cause much more carbon dioxide to be exposed to the atmosphere, thereby producing carbonic acid. This results in the increase of pH levels in the system (Hamdan & Mara, 2013). In this study, the unaerated system was chosen due to its better performance compared to the aerated system. The unaerated system is able to remove 76-98% of phosphorus while the aerated system can remove 66-95% of phosphorus. It is evident that the unaerated system has a better performance in terms of phosphorus removal (Ahmad *et al*., 2017). Besides that, the size of recycled concrete aggregates (RCA) also influences the removal of phosphorus. Yassin *et al*., (2016) stated that smaller-sized RCA acts as the best filter medium. 66-99% of phosphorus can be removed by RCA measuring between 5-35 mm. The initial concentration of synthetic wastewater was between 10-50 mg/L. Although the total volume of aggregates used as a filter medium was relatively small, filters nevertheless play important and diverse roles in many projects. However, filter materials for water and effluent treatment are often used in relatively small quantities as high quality aggregates are not readily provided by commercial production processing which may be designed to yield a satisfactory general purpose aggregate at the lowest cost. RCA was choose to be filter media in this study due to it easily available at construction site. There is abundance of waste that has been thrown away at construction site. Thus, this RCA can be made as alternative filter materials and may be made to be something valuable.

1.2 Problem Statement

Excessive nutrients such as phosphorus can lead to serious problems such as eutrophication. Besides, this issue could cause water poisoning and the degradation of recreational opportunities. Therefore, wastewater treatment processes should be optimised to alleviate water pollution.

The removal of phosphorus requires a secondary wastewater treatment process. Enhanced biological phosphorus removal (EBPR) and chemical precipitation are commonly practiced nowadays due to its great consistency in achieving the removal standards (Ramasahayam *et al.*, 2014). Yet, these conventional technologies require advanced cost, constant maintenance by experts and high energy consumption. By itself, chemical precipitation desires an abundance of chemicals and EBPR consumes a lot of energy to maintain its tank performance.

A crush concrete aggregate is one of the alternative treatments for the removal of phosphorus. It is a low-cost, alternative technology for removing nutrients from wastewater. Some of the advantages of crush concrete are its cost efficiency, high availability and relatively easy installation compared to conventional methods. According to previous studies, one of the alternative filter media for the removal of phosphorus is recycled concrete aggregate (RCA). RCA has a high capability for removing phosphorus. It is also easily available and incurs a low cost. Besides, it is a sustainable method since RCA is a recycled product from the construction site. Furthermore, Yassin *et al.*, (2016) reported that steel slag columns can remove nearly 100% of phosphorus due to specific phosphorus adsorption onto metal hydroxides and the precipitation of hydroxyapatite. Thus, the use of RCA is a very economical and promising solution for phosphorus removal from wastewater.

Consequently, RCA was used as an alternative filter media for the removal of phosphorus in this study. This was done to reduce the uncontrolled disposal of waste at construction sites. If the situation is not controlled, it will cause problems to the environment as there will be a decrease in space in urban areas due to waste demolition. On the other hand, RCA can help to save the environment as no excavation of natural resources is needed. Less transportation as well as less land is required. Moreover, the use of RCA can also save time as it is readily available. Besides, RCA has a higher calcium content which translates to a higher ability for removing phosphorus (Yassin *et al*., 2016). Thus, RCA possesses high potential to be used as a filter medium for removing phosphorus. In Malaysia thus making the RCA as a medium for water treatment to reduce the waste and save the environment. Therefore, this study was carried out to investigate the removal efficiency of phosphorus using recycled concrete aggregates in different concentrations of synthetic wastewater in an unaerated filter.

1.3 Objectives

The objective in this study are as the following:

(i) To investigate the effects absorption phosphorus of different initial concentrations synthetic wastewater ranging from 10 mg/L to 50 mg/L onto the RCA under different working PH.

(ii) To evaluate the relationship between RCA of different particle sizes and its uptake capacity of phosphorus.

1.4 Scope of Study

This study is focused on developing a filter using recycled concrete aggregates as a medium to filter wastewater. The scope of this study covers the following aspects:

(i) The synthetic wastewater was prepared in five different concentrations between 10 - 50 mg/L.

(ii) The sizes of RCA used were between 5 mm to 10 mm and 25 mm to 30 mm.

(iii) This study focused on the removal of phosphorus content in synthetic wastewater.

(iv) The recycled concrete aggregates were obtained from the Heavy Structure Laboratory, Universiti Tun Hussein Onn Malaysia (UTHM) in the form of concrete waste cubes which were crushed using a machine.

(v) The physical characteristics tests conducted on RCA included the bulk density test, water absorption test and aggregate impact value test (AIV).

(vi) The chemical characteristics tests conducted on RCA included point zero charge test, pH test, scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) analysis.

1.5 Significance of the Study

The purpose of wastewater treatment is generally to enable domestic and industrial effluents to be disposed of without harmful effects to human health or the environment. There are many advantages of using RCA for wastewater treatment. Firstly, it will provide alternative filter material for phosphorus removal for water and wastewater treatment industry.

RCA can **preserve the natural environment by** reducing waste generation resulting in water pollution. Polluted water discharged into the sea or rivers may cause various risks and even eutrophication. By treating wastewater using RCA, water pollution and eutrophication can be reduced.

Conventionally, treating phosphorus requires a complex treatment process with the usage of additional chemicals. By using RCA however, chemical usage in secondary treatment can be reduced. RCA reduces the need for landfill space which further helps to reduce pollution and the need for gravel mining.

Besides, this system will benefit small industries communities in an economical and effective way. This system is also simple to construct as it requires minimal cost, maintenance and land space. On the other hand, RCA is also known as a sustainable medium which can be easily maintained by using only backwash water.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter clarifies the fundamental concepts of wastewater treatment technology which ultimately highlights the use of recycled concrete aggregate (RCA) as filter media. Widespread reviews together with previous research focusing on different types of filter media for the removal of phosphorus and the use of RCA as a filter medium are discussed. Besides that, the properties of RCA as a filter medium and phosphorus removal mechanisms are reviewed.

2.2 Wastewater Sources

There are a few sources that produce wastewater with specific characteristics. It is categorized in terms of its physical, chemical and biological composition (Barca *et al*., 2013).

Wastewater is usually characterized by a grey colour and musty odor (Henze and Ledin, 2011). At the moment, 70% of wastewater is organic while 30% of wastewater is inorganic. Carbohydrates, proteins and fats are the organic components while heavy metals such as nitrogen, phosphorus, pH, sulphur, chlorides, alkalinity and toxic compounds are inorganic components of wastewater. Hydrogen sulphide, methane, ammonia, oxygen, carbon dioxide and nitrogen are regular gases dissolved in wastewater. Wastewater includes various microorganisms that can be categorized as protista, plants, and animals (Henze and Ledin, 2011).

Table 2.1 shows the composition of domestic wastewater while Table 2.2 illustrates sewage release under standards A and B (Environmental Quality (Sewage) Regulations 2009). From the data in Table 2.1, the contaminant with the highest concentration is total solids which is 1200 mg/L followed by chemical oxygen demand (COD) while the contaminant in the lowest concentration is phosphorus which is 25 mg/L.

Table 2.1: Composition of domestic wastewater (Suhara Sidek, 2010)

	Concentration (mg/L)		
Contaminants	Weak	Medium	Strong
Total Solids (TS)	350	720	1200
Suspended Solid (SS)	100	220	350
Biological Oxygen Demand (BOD)	110	220	400
Chemical Oxygen Demand (COD)	250	500	1000
Nitrogen (total as N)	20	40	85
Phosphorus (total as P)	4	8	25
Alkalinity (as $CaCO_3$)	50	100	200
Grease	50	100	150

Table 2.2: Sewage release of standards A and B (Environmental Quality (Sewage) Regulations 2009)

Parameter	**Unit**	**Standard**	
		A	**B**
Temperature	ºC	40	40
pH Value	-	6.0-9.0	5.5-9.0
BOD_5 at 20°C	mg/L	20	50
COD	mg/L	120	200
Suspended Solids	mg/L	50	100
Ammoniacal Nitrogen (enclosed water body)	mg/L	5.0	5.0
Ammoniacal Nitrogen (river)	mg/L	10.0	20.0
Nitrate - Nitrogen (river)	mg/L	20.0	50.0
Nitrate - Nitrogen (enclosed water body)	mg/L	10.0	10.0
Phosphorus (enclosed water body)	mg/L	5.0	10.0

Note: Standard A is applicable to discharge 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.

2.3 Effect of Phosphorus to the Environment and Human Health

Phosphorus is one of the major nutrient elements for plant growth. However, excessive amounts of phosphorus in the water body will lead to a severe problem of water pollution which is eutrophication (Barca *et al*., 2013). Excessive nutrients will cause excessive plant growth which eventually results in an explosion of algae population (algae bloom). Therefore, controlling the amount of phosphorus which enters the water or wastewater is very essential in order to sustain the good quality of water.

2.4 Phosphorus

Phosphorus is an important nutrient constituent for aquatic plant growth in the natural water system. However, excessive phosphorus loads in water bodies due to industrial, agricultural and household wastes might cause the overgrowth of aquatic plants or algae. This will accelerate the depletion of dissolved oxygen (DO) in water and lead to eutrophication. Hence, strict effluent quality standards for wastewater treatment plants (WWTPs) are implemented by governments all over the world. (Keeley *et al*., 2016).

Municipal wastewaters comprehend from 5 to 20 mg/L of total phosphorus, of which 1-5 mg/l are organic and the rest are inorganic. Phosphorus is one of the main constituents of synthetic detergents. The individual phosphorus impact varies between 0.65 and 4.80 g/inhabitant per day with an average of about 2.18 g. Generally, secondary treatment can only remove 1-2 mg/L of phosphorus, so excess phosphorus is often discharged in the final effluent and causes eutrophication in surface water (Han *et al*., 2016).

Bowman *et al*., (2011) found that the addition of phosphorus in the range of even 0.1-5.6 μ/L over a long period might activate algal blooms in part of a natural lake. Therefore, phosphorus removal from wastewater is important. To remove phosphorus, it must either be rehabilitated into a particulate form or removed as a particulate by sedimentation or filtration using membrane treatment.

The most regularly used method for phosphorus removal from wastewater is chemical precipitation and this method is able to reduce the concentration of phosphorus to values below 1 mg/L in sewage treatment plants. Nevertheless, chemical precipitation is expensive in many parts of the world and it might produce new pollutants such as chloride and sulphate (Altundogan and Tumen, 2012). In addition, it also requires the disposal for the precipitate formed and neutralisation of the treated effluent. Figure 2.1 demonstrates the cycle of phosphorus.

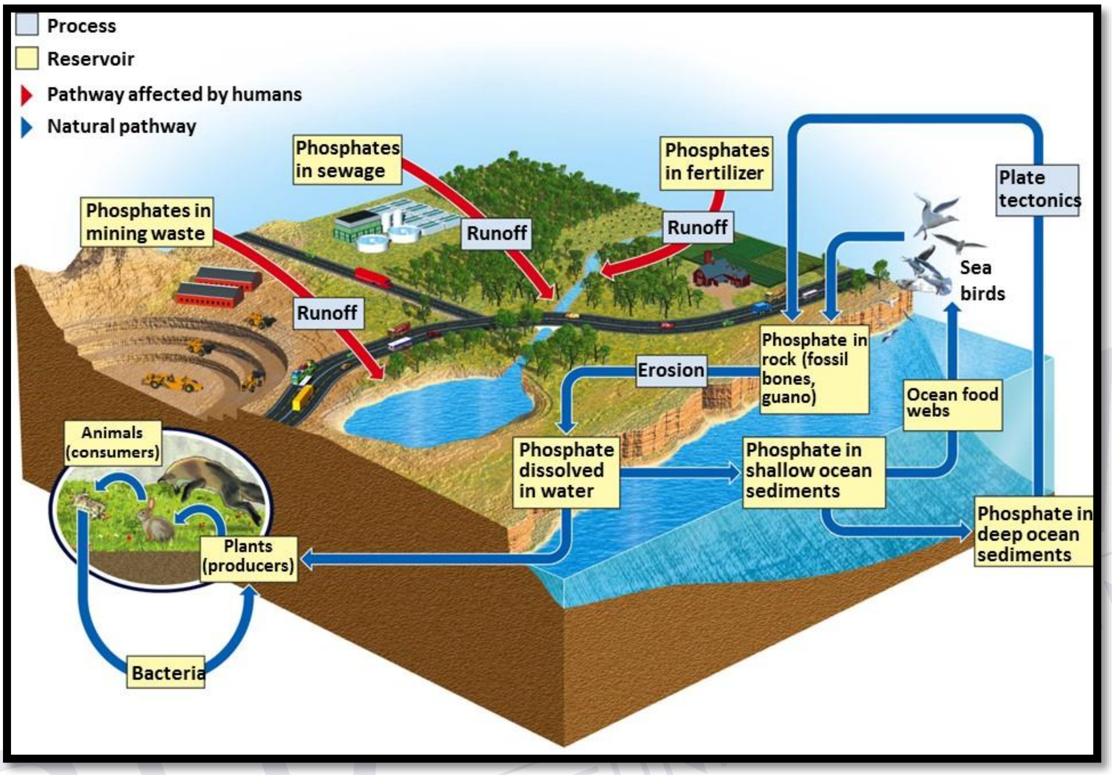

Figure 2.1: The cycle of phosphorus (Miller & Spoolman, 2012)

2.4.1 Phosphorus sources

Based on studies conducted in Malaysia, industrial food waste is a major source of phosphorus which contributes to water pollution. Figure 2.2 shows the average comparison of phosphorus production in Malaysia. Industrial food waste makes up 20% of phosphorus production followed by 15% of raw phosphorus production. Community activities and the increasing human population also contribute to relatively high phosphorus emissions.

The population growth in the country has led to a high demand in food production. Consequently, the use of fertilisers in the agricultural sector also increases dramatically according to customer demand. Farmers use fertilisers in abundance to accelerate the growth of crops but the overuse of fertilisers can lead to surface runoff and the contamination of underground water and rivers.

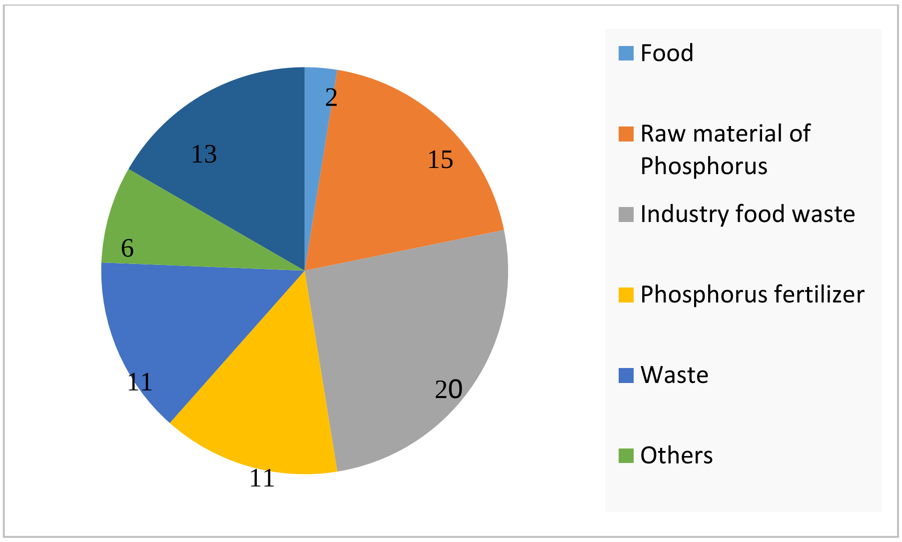

Figure 2.2: Sources of phosphorus production in Malaysia (Ozudin, 2015)

2.4.2 Phosphorus and Eutrophication

Eutrophication refers to an increase in the biological productivity of a body of water as a result of nutrient enhancement. Nitrogen and phosphorus are such nutrients that might create favourable circumstances for the development of toxin-producing cyanobacteria which could cause harm to humans (Eynard *et al.*, 2000). Similarly, it may cause health hazards among humans and livestock, as well as unwanted changes in aquatic populations (Akpor & Muchie, 2011).

There are about 300-400 mg/L more dissolved inorganic materials in municipal water supply, yet the growth of algae may occur at phosphorus levels as low as 0.05 mg/L (Manahan, 2009). Since phosphorus is known to be a growth-limiting plant nutrient in natural water, the release of wastewater high in soluble phosphate will activate fertilisation.

2.5 Wastewater Treatment System

One or two stages of wastewater treatment are normally involved in the treatment of wastewater (Miller & Spoolman, 2012). Figure 2.3 illustrates a wastewater treatment system. The basic treatment system typically consists of primary and secondary treatments. The physical-chemical process for sedimentation usually occurs during primary treatment while biological units such as filtering and activated sludge are included during the secondary treatment (Tansel, 2018).

Primary treatment comprises of the removal of insoluble matter such as grit, grease and scum. The treatment process consists of screening, grit removal and the sedimentation or settling tank (Manahan, 2009). Screening eliminates or decreases the size of trash and large solids in wastewater followed by grit removal which prevents grit accumulation by allowing grit to settle in a tank before it is grinded automatically. This is done to diminish the possibility of clogged pipes and protect moving parts from abrasion and wear (Hammer & Hammer, 2012). Also, it prevents floating material from accumulating on the surface of WSP and heavy solids from entering the pond sludge layer (Mara, 2003). Then, primary sedimentation is applied to eliminate both settleable and floatable solids. Primary treatment removes almost 60% of suspended solids and 30-40% of oxygen demanding organic wastes. However, no removal of pathogens, phosphates, nitrates, and salts occur (Miller & Spoolman, 2012).

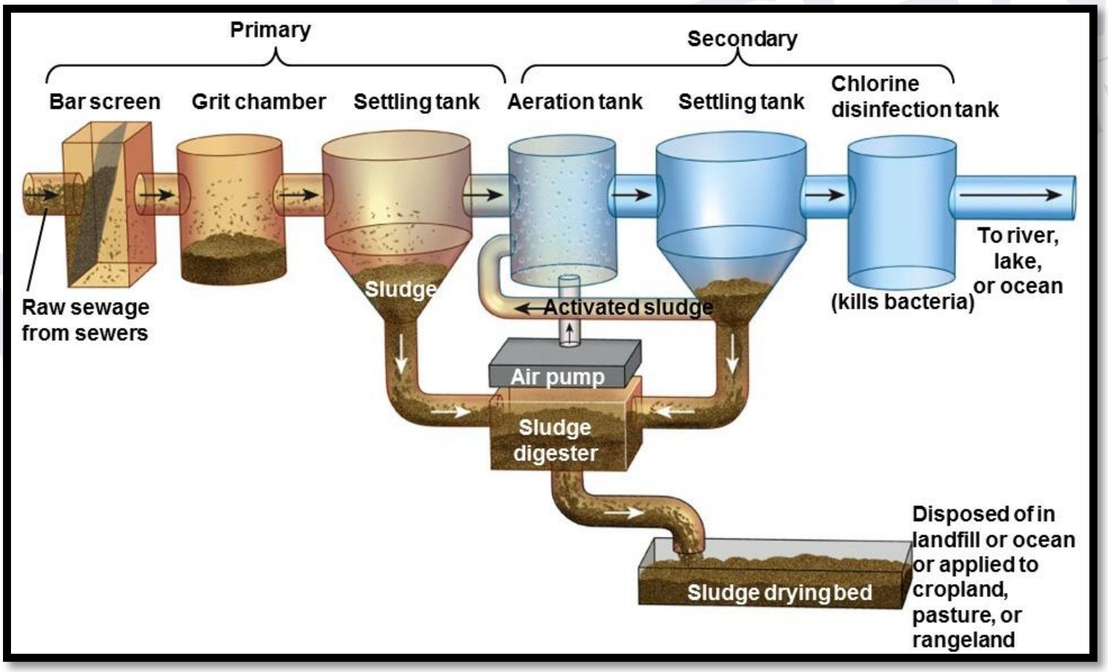

Figure 2.3: Wastewater treatment system (Miller & Spoolman, 2012)

Moving on, secondary wastewater treatment is designed mostly to remove BOD through biological processes. It is done by using microorganisms provided with added oxygen to degrade organic materials in a solution (Manahan, 2009). Polyphosphates would gradually hydrolyse to orthophosphate whereas gradually bound phosphate would release orthophosphate upon bacterial decomposition (Hammer & Hammer, 2012). Phosphorus might otherwise be removed either during secondary treatment or advanced treatment at the end of the process (Valsami-Jones, 2011). After primary and secondary treatment, almost 95-97% of suspended solids and organic wastes are removed. Yet, a very small fraction of persistent organic substances and only 70% of phosphorus and 50% nitrogen are removed during secondary treatment (Miller & Spoolman, 2012). As mentioned by Manahan (2009), phosphorus removal may occur in the sewage treatment process in the primary settler, in the aeration chamber of the activated sludge unit (secondary treatment), or even after secondary waste treatment (tertiary or advanced treatment). Hence, in order to obtain considerable phosphorus removal from wastewater, an advanced treatment system may be needed after the secondary treatment.

Tertiary wastewater treatment, also known as advanced wastewater treatment, is carried out on effluents from secondary treatment. It regularly includes a series of specified chemical and physical processes to remove specific pollutants from the secondary effluents. Generally, the advanced treatment utilises filtration to remove nutrients; phosphates and nitrates from the effluents (Miller & Spoolman, 2012). Besides, other contaminants removed by this treatment are suspended solids and dissolved organic compounds (Manahan, 2009). This comprises the removal of phosphorus from solution, oxidising ammonia to nitrate (nitrification), converting nitrogen to nitrogen gas (denitrification), and inactivating pathogenic bacteria and viruses (disinfection) (Hammer & Hammer, 2012).

2.5.1 Phosphorus Removal Technologies for Wastewater

Wastewater treatment systems consist of conventional, mechanical and natural treatment systems or a combination of the mentioned treatment systems (Hamdan, 2010). A number of phosphorus removal technologies have been established, but they have either been extensively practised or are still under development. Commonly, phosphorus removal can be done by transforming phosphorus to a chemical species by adding a metal salt or lime, combining phosphorus to the biomass, or applying nanoprocesses such as reverse osmosis, electrodialysis reversal or nanofilters to remove specific pollutants (Water Environment Federation, 2011). Strom (2016) stated that existing treatment technologies include physical, chemical and biological technologies. Physical treatments consist of filtration for particulate phosphorus and membrane technologies, chemical treatments involve precipitation and physical-

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