REMOVAL OF PHOSPHORUS FROM DOMESTIC WASTEWATER USING DISCONTINUOUS AEROBIC ANOXIC REACTOR

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This thesis is dedicated with lots of love to my parents,
brother and sister

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ABSTRACT

The discharge of excessive amounts of phosphorus (P) from domestic wastewater treatment plant is of interest in this study because the abnormally high levels of P as one of the nutrient elements can lead to eutrophication for the receiving waters. Although many methods have been proposed for the removal of P matter from industrial and municipal wastewater, such as Phoredox, A^2O^{TM} and UCT-type, the use of alternating aerobic-anoxic (AAA) system must be verified. This study proposes the use of Discontinuous Aerobic-Anoxic Reactor (DAAR) to remove P from domestic wastewater at Taman Impian Emas, Skudai, Johor using the nitrification and denitrification type of activated sludge. The objectives of this study are: (1) to evaluate the efficiency of P removal from domestic wastewater by a single reactor under aerobic digestion (AD) condition**,** and (2) to assess the performance of AAA process of using the different cycles of nitrification-denitrification to remove P from domestic wastewater. The average efficiency of AD to remove P from domestic wastewater was 48%. The efficiencies of AAA system to remove P from domestic wastewater, on the other hand, were verified as follows: (1) at 6-h AD and 6-h anoxic time (AT), the efficiency was 0%, indicating that there was no removal of P during the AAA process, (2) at 5-h AD and 5-h AT, the average efficiency was 48%, (3) at 4-h AD and 4-h AT, the average efficiency was 82%, (4) at 3-h AD and 3-h AT, the average efficiency was 91%, and (5) at 2-h AD and 2-h AT, the average efficiency was 88%. Therefore, the AAA system has exhibited a better performance compared to AD. The results of the study also show that the best condition of AAA system had a period of 3-h AD and 3-h AT and reached 91% efficiency with an average treated effluent concentration of less than 1.0 mg P/L. High performance of the AAA process has been proven by using domestic wastewater from Taman Impian Emas, Skudai, Johor, giving new insights into environmental engineering practices.

ABSTRAK

Pelepasan fosforus (P) berlebihan dari loji olahan air sisa domestik adalah tumpuan utama kajian ini kerana tahap yang luar biasa P yang tinggi adalah sebagai salah satu daripada unsur-unsur nutrien boleh menyebabkan eutrofikasi terhadap air sungai. Walaupun banyak kaedah telah dicadangkan untuk penyingkiran P daripada air sisa industri dan perbandaran seperti Phoredox, A^2O^{TM} dan jenis-UCT, penggunaan reaktor tunggal sistem selang seli aerobik-anoksik (AAA) perlu ditentukan. Kajian ini mencadangkan penggunaan reaktor yang tidak selanjar aerobik-anoksik (DAAR) untuk menyingkirkan P daripada air sisa domestik di Taman Impian Emas, Skudai, Johor dengan menggunakan kaedah nitrifikasi dan denitrifikasi enap cemar teraktif. Objektif kajian ini adalah: (1) untuk menilai kecekapan penyingkiran P menggunakan pencernaan aerobik (AD), dan (2) untuk menilai prestasi proses AAA terhadap penyingkiran P dalam reaktor tunggal. Kecekapan purata AD untuk menyingkirkan P dari air sisa domestik adalah 48%, manakala kecekapan sistem AAA untuk menyingkirkan P daripada air sisa domestik telah ditentukan seperti berikut: (1) pada 6-j AD dan 6-j masa anoksik (AT), kecekapan adalah 0%, ini menunjukkan bahawa tidak ada penyingkiran P semasa proses AAA, (2) pada 5-j AD dan 5-j AT, kecekapan purata adalah 48%, (3) pada 4-j AD dan 4-j AT, kecekapan purata adalah 82%, (4) pada 3-j AD dan 3-j AT, kecekapan purata adalah 91%, dan (5) pada 2-j AD dan 2-j AT, kecekapan purata adalah 88%. Oleh itu, sistem AAA telah menunjukkan prestasi yang lebih baik berbanding dengan AD. Hasil kajian juga menunjukkan bahawa keadaan yang terbaik sistem AAA mempunyai tempoh 3-j AD dan 3-j AT dan mencapai kecekapan 91% dengan purata kepekatan efluen dirawat adalah kurang daripada 1.0 mg P/L. Prestasi tinggi proses AAA telah terbukti dengan menggunakan air sisa domestik dari Taman Impian Emas, Skudai, Johor serta memberikan pandangan baru bagi amalan kejuruteraan alam sekitar.

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LIST OF ABBREVIATIONS

A/O^{TM}	-	Anaerobic/Aerobic only
A^2O^{TM}	-	Anaerobic/Anoxic/aerobic
AAA	-	Alternating aerobic-anoxic
AD	-	Aerobic Digestion
APHA	-	American Public Health Association
AT	-	Anoxic Time
BOD	-	Biochemical Oxygen Demand
BPR	-	Biological Phosphorus Removal
COD	-	Chemical Oxygen Demand
DAAR	-	Discontinuous Aerobic Anoxic Reactor
DO	-	Dissolved Oxygen
EBPR	-	Enhanced Biological Phosphorus Removal
EUD	-	European Union Directive
INP	-	Inorganic Nitrogen Pollution
MLSS	-	Mixed Liquor Suspended Solid
N	-	Nitrogen
NH_4^+-N	-	Ammonia Nitrogen
NO_2^-	-	Nitrite
NO_3^-	-	Nitrate
P	-	Phosphorous

PAOs	-	Phosphorus Accumulating Organisms
PHB	-	Poly-hydroxybutyrate
poly-P	-	Polyphosphate
RAS	-	Return Activated Sludge
SRTs	-	Solids Retention Time
SVI	-	Sludge Volume Index
TP	-	Total Phosphorous
TSS	-	Total Suspended Solid
UCT	-	University of Capetown
WWTP	-	Wastewater Treatment Plant

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CHAPTER 1

INTRODUCTION

1.1 Background

Since early 1970, the presence of phosphorus in domestic wastewater has received attention due to the realization of its negative impacts on receiving water. In wastewater treatment processing, phosphorus is a vital nutrient for bacteria needed to degrade and biologically stabilize the organic wastes (Hussain *et al*., 2001). Phosphorus (P) is a key nutrient that stimulates the growth of algae and other biological organisms (Mainstone and Parr, 2002). P appears exclusively as orthophosphate, condensed phosphates (polyphosphates), and organically bound phosphate. Condensed phosphates are used extensively as builders in detergents, and organic phosphates are constituents of body waste and food residue (Howard, 1985). According to Tjandraatmadja *et al.* (2010), the household products can be a significant contributor to the P load in domestic wastewater. The discharge of excessive amount of P from domestic wastewater treatment plant (WWTP) is of concern as it is one of the key nutrients that have the potential to contribute to eutrophication in surface water, which can result in an excessive growth of algae (Daniel *et al.*, 1994). The release of P to surface water has led to legislation such as European Union (EU) Urban Wastewater Directive (Commission of the European Communities,1991). The limit values of total phosphorous (TP) for effluent discharge in wastewater treatment plants are in a range of 1.0-2.0 mg P/L. However, some regions such as in United States followed a more strict measure of around 0.5-0.8 mg P/L to control eutrophication (Caravelli *et al.,* 2010).

The removal of P from domestic wastewater can be treated using either the biological or chemical process. Chemical removal is achieved through the use of common products such as alum, ferric iron salts, ferrous iron salts, or lime. After chemical addition and mixing, P compounds are removed by either sedimentation or flocculation (Duenas *et al.*, 2002).

Enhanced biological phosphorus removal (EBPR) promotes the removal of P from wastewater without the need for chemical precipitants. EBPR can be achieved through activated sludge process by recirculating sludge through anaerobic and aerobic conditions (Barnard, 1975). Biological P removal is achieved by intracellular accumulation of P in the form of polyphosphate (poly-P) granules in excess of the levels normally required to meet the metabolic demands for growth. The P removal of using a biological process can occur through sludge purging when the P containing bacterial cells are removed as organic waste from a treatment system. The poly-P released in an anaerobic environment and P uptakes in the aerobic/anoxic conditions are conducted by bacterial phylotypes and termed as polyphosphate-accumulating organisms (PAOs) (Cao,2011). In general, EBPR process is a relatively inexpensive and environmentally sustainable options compared to chemical P removal. EBPR can be much more economical because of the reduction in cost of chemicals, sludge treatment and disposal. EBPR is the environmentally-friendly technique for wastewater treatment because there is no downstream ecological effect due to the absence of chemical precipitants such as aluminum and iron in the treated effluent (Cao, 2011).

The biological P removal from domestic wastewater of high efficiency can be achieved using two different systems of anaerobic-anoxic sequencing batch reactor and anaerobic-aerobic sequencing batch reactor (Merzouki *et al.*, 2005). These sequences have been attained in continuous flow processes as a spatial sequence of different reactors or compartments connected by different recirculation lines. It needs to be conducted much more complex operating system and hence all of them demanding quite high investments and operating costs (García-Encina *et al.*,2004). On the other hand, in a discontinuous aerobic-anoxic process, the sequence is defined as temporary changes in operating conditions of using the only one reactor.

Therefore, this research focuses on the development of a simple operation of the treatment system to remove P from domestic wastewater using the "Discontinuous Aerobic Anoxic Reactor (DAAR)", a new concept where both the aerobic digestion (AD) and alternating aerobic-anoxic (AAA) condition occur in a single reactor.

1.2 Problem statement

The researches conducted in the late two decades have contributed to the development of biological P removal processes. According to Lopez, (2009), activated sludge of nitrification-denitrification type, at certain conditions, can take up in considerable excess P of organic compounds to provide the requirement for normal biomass growth; the phenomenon known as "luxury uptake". Based on this phenomenon, a number of applications and processes have been developed and the technology has the advantage of avoiding the use of chemicals and excess physicochemical sludge production. However, it requires more complex configurations and operating regimes.

In addition, as treatment processes develop in complexity, land needed for treatment plant set-up would increase too. But in reality, not many countries could afford such a situation. Therefore, wastewater treatment systems presently in used worldwide, needed some diversification in set-up or better if new technologies are invented. Even if land factor is not a constraint, a complicated plant may need high capital investment. Treatment plant with many reactors and clarifiers and other equipment would normally increase cost in maintenance for the operational equipment. In addition, advanced technologies treatment plant would also need highly skilled operators. This would also definitely increase operation costs.

As years gone by, rules and regulation of wastewater treatment plant discharge has become more stringent. Such a development in regulation would continue in future. Therefore, more efficient and advanced treatments have to be developed in order to achieve the required standards. Another issue on hand is the

eutrophication of lakes, rivers and other water resources, which is receiving worldwide attention. Nutrients like nitrogen and phosphorus are the primary causes of eutrophication. It is therefore not unusual to realize that standard for both nutrients have been increasingly stringent over the past two decades. Though existing biological and chemical processes can remove these nutrients, nonetheless it has not come in a simple way and it does increase the cost of treatment. Therefore, researchers are now working round the clock to search for better, simpler and cost effective solutions.

To date, many biological phosphorous removal processes related to activated sludge have been commonly adopt in WWTPs, such as pre-denitrification (A/O) and anaerobic/anoxic/oxic (A/A/O) processes (Shijian *et al*., 2010). Groups of researchers have studied the sequencing batch reactor techniques for phosphorous removal process (Ehab *et al*., 2013). Though existing BPR processes can remove the P nutrient from domestic wastewater, still, this research is conducted to modify the process to enhance P removal performance by using DAAR.

One of the alternative treatments that surface, DAAR stands out for a few particular reason. The strong point about DAAR is that it does not need a train of reactors. All it does need is a single reactor in order to achieve a removal of phosphorus from domestic wastewater. In short, DAAR provides a simple process to remove P from wastewaters. Therefore, the performance of this system to remove P needs to be determined.

1.3 Objectives

The objectives of this study are as follows:

i. to evaluate the efficiency of P removal from domestic wastewater by a single reactor under AD condition, and

ii. to assess the performance of AAA process of using the different cycles of nitrification-denitrification to remove P from domestic wastewater.

1.4 Scope of the study

The scope of this study is as follows:

i. to characterize the raw wastewater and determine the level of pollutant loading the reactors of both under AD and AAA processes by analyzing the concentrations of Chemical Oxygen Demand (COD), Total Phosphorus (TP), Ammonia Nitrogen (NH_4^+-N), Nitrite (NO_2^-), Nitrate (NO_3^-) and Total Suspended Solid (TSS)for domestic wastewater of Taman Impian Emas, Skudai, Johor,

ii. to perform the first stage of the experiment by operating the reactor under AD condition with the specific targets to achieve:

- a stable condition of the reactor's performance identified by the level of COD removal to reach at approximately 85% efficiency,
- a concentration of mixed liquor suspended solid (MLSS)in the reactor should be in a range of 5-8 g/L, and
- a level of the sludge volume index (SVI) ranged from 100to 250 mL/g, meaning that microbial products of activated sludge can be settled perfectly, and

iii. to perform the second stage of the experiment by operating the reactor under AAA process for developing the nitrification-denitrificationtype of activated sludge using: (1) the periods of 6 h AD and 6 h anoxic time, (2) the periods of 5 h AD and 5 h anoxic time, (3) the periods of 4 h AD and 4 h anoxic time, (4) the periods of 3 h AD and 3 h anoxic time, and (5) the periods of 2 h AD and 2 h anoxic time.

1.5 Significance of the study

The significances of this study are as follows:

i. to evaluate the efficiency of carbonaceous matter removal from domestic wastewater by a single reactor until achieving a steady state under AD condition,
ii. to evaluate the performance of AAA process of using the different cycles of nitrification-denitrification to remove P from domestic wastewater,
iii. to understand the possibility of operating a single reactor to enhance the biological phosphorous removal efficiency from domestic wastewater, and
iv. to verify the optimum operation of AAA treatment system based on the modification of the periods of AD and AT.

1.6 Thesis organization

After briefly introducing the background in Chapter 1, this study reviews the literatures in Chapter 2 for concern with the different types of biological P removal processes. The materials and methods in Chapter 3 include the configuration of DAAR, characterization of domestic wastewater, methodology of controlling the DAAR and analytical methods. Presentation and discussion of the results can be found in Chapter 4, describing the performance of both treatment systems i.e., the AD and AAA processes, where the AAA process is a new approach in biological systems for domestic wastewater treatment. The last chapter presents the conclusions of this study and the recommendation for future works.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

By comparing the performances of biological treatment process under the AD and different AAA conditions to remove P from domestic wastewater can reach at the following conclusions:

(1) The efficiency of AD treatment process to remove total phosphorous matter from domestic wastewater ranges from 29 to 71% with an average of 48%. It is evident that the performance of the AD process to remove P from a polluted water by continuous aeration is still low.

(2) The study's findings showed that at given condition of the AAA treatment system can reach at 91% efficiency of its efficiency with the period of 3 h AD and 3 h AT. The average TP concentration of less than 1.0 mg P/L can be achieved in effluent of the AAA treatment plant and coped with the stringent standards of effluent discharge regulated by the law. This finding is valid with TP influent concentration of 8.44 mg/L.

5.2 Recommendations

According to the result findings, the following recommendation are suggested for the future works, such that:

i. the identification of bacterial strains is necessary to having a new knowledge on the types of phosphorus-biodegrading bacteria suitable for an AAA treatment process,

ii. the development of empirical models based on the experimental data will be useful for determining the design parameters for the future applications at industrial scale AAA treatment processes,

iii. microbiological study can be done to investigate the different characteristics of microorganism under AD and AAA conditions,

iv. a study can be carried out by using the different HRT as follows: (1) 19 h and (2) 20 h, to compare the efficiency of P removal from domestic wastewater, and

v. a study can be carried out by using the different type of raw wastewater such as industrial wastewater to see whether the system is capable to remove the pollutant elements from the industrial wastewater before they are return to the environment.

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