TERTIARY TREATMENT OF PALM OIL MILL EFFLUENT USING SEQUENTIAL BATCH REACTOR

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.....Specially dedicated to my supportive lecturers:

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Dr. Muzaffar bin Zainal Abideen - *"Fear God, not human" &*

Dr. M. Ponraj - *"As a student, it is ok to make a mistake"****.....***

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ABSTRACT

Palm oil mill effluent (POME) is a liquid by-product of palm oil processing. Today, most palm oil mills in Malaysia have adopted ponding treatment system as a primary and secondary treatment of POME. However, this system alone is not sufficient in producing treated effluent that can fulfil the effluent discharge standards. This study was therefore conducted to investigate the feasibility of sequencing batch reactor (SBR) as a tertiary treatment for POME. The study started with examining the effectiveness of ponding treatment system at Pertubuhan Peladang Negeri Johor (PPNJ) Kahang Palm Oil Mill in treating POME and the effect of average rainfall, quantity and quality of the processed fresh fruit bunch (FFB) on raw POME characteristics and ponding treatment system performance. This was followed by the assessment of SBR performance at both laboratory and pilot-scale. The SBR operations were evaluated during its acclimatisation stage as well as the effects of organic loading rate (OLR) and food over microorganism ratio (F/M) on the SBR treatment performance. It was found that PPNJ ponding treatment system, which comprised of five ponds are efficient for POME treatment. The average removal in terms of Total Chemical Oxygen Demand (TCOD), Soluble Chemical Oxygen Demand (SCOD), Total Nitrogen (TN), Total Phosphorus (TP) and Total Suspended Solids (TSS) was 96%, 96%, 86%, 96% and 95%, respectively. However, even though the removal percentage was high, only pH and TN fulfilled the Department of Environment (DOE) effluent discharge standards, whereas the concentration of TSS and TCOD in the treated effluent exceeded the allowable limit. The ponding treatment system was also incapable to decolourise POME and it increased the concentration of Ammonia-Nitrogen (NH_3-N) in the treated effluent. Both quantity and quality of processed FFB affected the colour intensity in POME. The average rainfall has minor effect on TP removal, while the quantity of FFB processed influenced SCOD, TCOD and colour removal by the ponding treatment system. Rainfall variation and quantity of processed FFB were found not to significantly affect the removal of TN, TSS and NH_3-N by the ponding treatment system. When the partially digested POME was further treated using laboratory-scale SBR, the removal of SCOD ranged from 5 to about 49% with an average of 27%. The best OLR and F/M ratio for the laboratory-scale SBR were 0.58 kg COD/m^3 day and 0.26 g COD/g MLVSS day, respectively. For the pilot-scale SBR, the removal of SCOD ranged from about 3% to 65% with an average of 32%. The best OLR and F/M ratio for the pilot-plant SBR were 0.72 kg COD/m^3 day and 0.17 g COD/g MLVSS day, respectively. Comparatively, SCOD removal by the pilot-scale SBR was slightly better than the laboratory-scale SBR at the best OLR and F/M ratio. In conclusion, ponding systems had demonstrated to be effective for POME treatment except for NH_3-N and colour removal. Further treatment of partially treated POME by SBR yields further organic removal.

ABSTRAK

Efluen kilang kelapa sawit (POME) adalah sisa cecair yang terhasil daripada aktiviti pemprosesan minyak kelapa sawit. Pada hari ini, kebanyakan kilang di Malaysia menggunakan sistem rawatan kolam sebagai rawatan primer dan sekunder untuk POME. Walau bagaimanapun, penggunaan sistem ini sahaja tidak dapat menghasilkan efluen yang dapat memenuhi piawai pelepasan efluen. Oleh sebab itu, kajian ini telah dijalankan bagi mengkaji keupayaan sistem reaktor berkelompok penjujukan (SBR) sebagai rawatan tertier untuk POME. Kajian ini bermula dengan menilai keberkesanan sistem rawatan kolam di Kilang Kelapa Sawit Pertubuhan Peladang Negeri Johor (PPNJ) Kahang dalam merawat POME serta kesan purata hujan, kuantiti dan kualiti tandan buah segar (FFB) yang diproses terhadap ciri-ciri POME dan prestasi sistem rawatan kolam. Ini diikuti dengan penilaian keberkesanan SBR di peringkat skala makmal dan loji pandu. Operasi SBR telah dinilai pada peringkat penyesuaian serta kesan kadar beban organik (OLR) dan nisbah makanan kepada mikroorganisma (F/M) terhadap prestasi rawatan SBR. Didapati bahawa sistem rawatan kolam yang terdiri daripada lima kolam rawatan adalah berkesan dalam merawat POME. Purata penyingkiran bagi Jumlah Permintaan Oksigen Kimia (TCOD), Permintaan Oksigen Kimia Larut (SCOD), Jumlah Nitrogen (TN), Jumlah Fosforus (TP) dan Jumlah Pepejal Terampai (TSS) adalah sebanyak 96%, 96%, 86%, 96% dan 95%. Walaupun peratus penyingkiran adalah tinggi, hanya pH dan TN memenuhi piawaian pelepasan efluen Jabatan Alam Sekitar (DOE) manakala kandungan TSS dan TCOD dalam efluen terawat melebihi had pelepasan yang telah ditetapkan. Sistem rawatan kolam juga tidak dapat menyahwarnakan POME dan juga telah menyebabkan peningkatan kandungan Ammonia-Nitrogen (NH_3-N) dalam efluen terawat. Kedua-dua kuantiti dan kualiti FFB yang diproses mempengaruhi kepekatan warna dalam POME. Purata hujan menpunyai sedikit kesan terhadap penyingkiran TP manakala jumlah FFB diproses mempengaruhi penyingkiran SCOD, TCOD dan warna dalam sistem rawatan kolam. Variasi hujan yang diterima dan kuantiti FFB yang diproses didapati tidak memberikan kesan yang ketara terhadap penyingkiran TN, TSS dan NH_3-N oleh sistem rawatan kolam. Apabila POME separa terawat diolah menggunakan SBR berskala makmal, penyingkiran SCOD berada dalam julat 5 hingga kira-kira 49% dengan purata 27%. OLR dan nisbah F/M terbaik bagi SBR berskala makmal adalah 0.58 kg COD/m^3 hari dan 0.26 g COD/g MLVSS hari. Untuk SBR loji pandu, penyingkiran SCOD adalah dalam julat kira-kira 3 hingga 65% dengan purata 32%. OLR dan nisbah F/M terbaik bagi SBR loji pandu adalah 0.72 kg COD/m^3 hari dan 0.17 g COD/g MLVSS hari. Secara perbandingan, penyingkiran SCOD oleh SBR loji pandu adalah lebih baik daripada SBR berskala makmal pada OLR dan nisbah F/M terbaik. Sebagai kesimpulan, sistem rawatan kolam didapati berkesan dalam merawat POME kecuali untuk penyingkiran NH_3-N dan warna. Rawatan lanjutan POME separa terawat dengan menggunakan SBR berjaya menghasilkan penyingkiran tambahan kandungan organik.

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LIST OF ABBREVIATIONS

ADMI	-	American Dye Manufacturer Institute
AP1/2	-	Anaerobic Pond 1/2
APHA	-	American Public Health Association
BNR	-	Biological Nutrient Removal
BOD	-	Biochemical Oxygen Demand
BOD_5	-	5-days Biochemical Oxygen Demand
C:N:P	-	Carbon:Nitrogen:Phosphorus ratio
$CaCO_3$	-	Calcium Carbonate
Cd^{2+}	-	Cadmium ion
CH_4	-	Methane
CO_2	-	Carbon Dioxide
COD	-	Chemical Oxygen Demand
CPO	-	Crude Palm Oil
DNA	-	Deoxyribonucleic Acid
DO	-	Dissolved Oxygen
DOE	-	Department of Environment
EFB	-	Empty Fruit Bunch
F/M	-	Food to Microorganisms Ratio
FFB	-	Fresh Fruit Bunch
FP1/2/3		Facultative Pond 1/2/3
HDPE	-	High Density Polyethylene
Hg^{2+}	-	Mercuric Ion
HR	-	High Range
HRT	-	Hydraulic Retention Time
HT1/2	-	Holding Tank 1/2
IPASA	-	Institut Pengurusan Alam Sekitar dan Sumber Air
MLSS	-	Mixed Liquor Suspended Solids

MPOB	-	Malaysian Palm Oil Board
MRE	-	Mixed Raw Effluent
N_2	-	Nitrogen gas
NH_3-N	-	Ammoniacal-nitrogen
NH_4-N	-	Ammonium-nitrogen
NO_3-N	-	Nitrate-nitrogen
OLR	-	Organic Loading Rate
O_2	-	Oxygen gas
PAOs	-	Polyphosphate-Accumulating Organisms
POME	-	Palm Oil Mill Effluent
POMSE	-	Palm Oil Mill Secondary Effluent
PO_4-P	-	Phosphate-phosphorus
PPNJ	-	Pertubuhan Peladang Negeri Johor
Pt-Co	-	Platinum-Cobalt
PVP	-	Polyvinylpyrrolidone
SBR	-	Sequencing/Sequential Batch Reactor
SCOD	-	Soluble Chemical Oxygen Demand
SRT	-	Sludge Retention Time
SS	-	Suspended Solids
TCOD	-	Total Chemical Oxygen Demand
TKN	-	Total Kjeldahl Nitrogen
TN	-	Total Nitrogen
TOC	-	Total Organic Carbon
TP	-	Total Phosphorus
TS	-	Total Solids
TSS	-	Total Suspended Solids
UTM	-	Universiti Teknologi Malaysia
UASB	-	Up-Flow Anaerobic Sludge Blanket
VSS	-	Volatile Suspended Solids

LIST OF SYMBOLS

%	-	percent
°C	-	degree Celcius
µ	-	micro
d	-	day
et al.	-	and friend
g	-	gram
h	-	hour
kg/m^3day	-	kilogram per cubic meter.day
kPa	-	kilopascal
L	-	liter
liter/h	-	liter per hour
m	-	meter (length unit)
m^3	-	cubic meter (volumetric unit)
m^3/h	-	cubic meter per hour
mg/L	-	milligram per liter
mL	-	mililiter
mt	-	metric tonnes
nm	-	nanometer
rpm	-	rotation per minute
sp.	-	species

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Palm oil is derived from the fleshy mesocarp of oil palm fruit (Rupani *et al.*, 2010) and can be used as raw material for various products ranging from soap to food products. The extraction of palm oil involved a sequence of operations and requires considerable quantity of water. Consequently, huge quantity of heavily polluted wastewater is generated at different stages of palm oil processing and the effluent constitutes a major source of environmental pollution. Since 1982, ponding system is the widely used conventional treatment for POME in Malaysia. This system has recorded significant percentage of pollutants reduction producing good quality treated effluent (Mumtaz *et al.,* 2010). Unfortunately, this system alone is not sufficient in producing high quality wastewater to meet the industrial wastewater discharge standards (Chan *et al.*, 2010a). Thus, finding a tertiary treatment has become important today so that the treated effluent characteristics are well within the guideline values of each parameter.

One of the methods to improve the treated effluent quality is by adopting Sequencing Batch Reactor (SBR) after the ponding treatment system. This treatment is based on the principles of activated sludge process and has been widely used to treat various types of wastewater (Mace and Mata-Alvarez, 2002). Previous studies have shown that the performance of SBR are greatly affected by different factors such as process loading factors, environmental factors as well as operational factors and these parameters can be manipulated to optimise the SBR treatment process. As

different industries produced different characteristics of wastewater, it is crucial to manipulate these parameters to maximise the SBR treatment performance. Therefore, the purpose of this study is to investigate the application of laboratory and pilot-scale SBR for the treatment of partially digested POME and the effect of two variable parameters on SBR treatment performance. This study also focuses on performance comparison between laboratory and pilot-scale SBR in treating partially digested POME.

1.2 Problem Statement

Significant number of studies has been conducted on the subject of POME treatment. Although many new technologies have been discovered with promising effluent quality, ponding system are still the most widely applied treatment system for POME in Malaysia and this system has shown excellent performance in treating POME (Ma and Ong, 1985; Ugoji, 1996; Razak, 2015). The performances of this ponding treatment system are affected by several factors such as operating temperature, mixing, pH and OLR (Abdurahman *et al.*, 2013). Ponding treatment system performance could also be influenced by other factors such as rainfall and quantity and quality of the processed fresh fruit bunch (FFB). However, the effects of these factors are apparently missing in the literature. Hence, there is a need to investigate the effect of these variables on raw POME characteristics and the ponding treatment system performance.

As mentioned earlier, ponding treatment system alone is not sufficient in producing treated effluent that complies with the standards imposed by the Department of Environment (DOE). Previous works have shown that treated effluent from ponding treatment system or also known as palm oil mill secondary effluent (POMSE) has much lower level of COD, BOD and TSS than raw POME. However, it still has strong odour, relatively high organic content and thick brownish colour, which could potentially pollute the water environment and destroy the ecosystem (Shahrifun *et al.*, 2015). This has prompted the use of tertiary treatment system to enhance the quality of treated effluent. In this study, SBR was adopted as

the tertiary treatment for POME after the ponding treatment system. Although SBR system has been used for years at some actual POME treatment system, reports on the feasibility of SBR in treating POMSE and the effects of organic loading rate (OLR) and food to microorganisms ratio (F/M) on SCOD biodegradation are still scarce. Thus, this study will provide some overview regarding SBR performance in POMSE treatment.

1.3 Objective of Study

The objectives of this study are:

1) To determine the effectiveness of actual POME ponding treatment system and the influence of average rainfall and quality and quantity of the processed FFB on raw POME properties and ponding treatment system performance in treating POME.

2) To compare the treatability of POMSE at both laboratory and pilot-scale SBR as well as the effect of F/M and OLR on SCOD removal.

1.4 Scope of Study

The properties of POME, POMSE together with the effectiveness of ponding treatment system in treating POME were evaluated at PPNJ Kahang palm oil mill. Samples of raw POME and POMSE were collected and characterised to determine the efficiency of ponding treatment system. The parameters were analysed at PPNJ mill and UTM laboratories, which include pH, TCOD, SCOD, TSS, TN, TP, colour and NH_3-N. The effects of rainfall and quality and quantity of processed FFB on raw POME characteristics and ponding system performance were also studied.

This study also covers the application of SBR as a tertiary treatment for POME. An aerobic-anoxic laboratory-scale SBR with a working volume of 10 L was used in the preliminary study while a pilot-scale SBR with a working volume of 70 m^3 was employed at site to treat POMSE. The laboratory-scale study was conducted at Research Laboratory 3, Faculty of Civil Engineering, UTM Skudai, while the pilot-scale study was carried out at UTM Pilot Plant Kahang that is located next to PPNJ Kahang palm oil mill. After the acclimatisation period, the variation of F/M ratio and OLR were applied for both laboratory and pilot-scale SBRs to determine their effects on the SCOD removal. The performances of both laboratory and pilot-scale SBR in terms of SCOD degradation then were compared.

1.5 Significance of Study

The significances of the study are:

1. It provides information on the effect of rainfall and quality as well as quantity of processed FFB on raw POME characteristics and ponding treatment system performance.

2. It demonstrates the practical potential of SBR system as a tertiary treatment for POME. As the standards for the quality of POME discharged into watercourse becomes more stringent these days and to reduce the undesired environmental pollution, an efficient tertiary treatment system is highly desirable at all palm oil mills.

1.6 Thesis Outline

This thesis is divided into five chapters. Chapter 1 is an introductory chapter that presents a general statement of this study. It includes a problem statements that describe the problems being investigated, objectives of the study that emphasize on

the desired outcomes, scope of study and significance of study which discusses the importance and benefits in conducting this study. Chapter 2 provides the background knowledge and ideas related to the study. It gives an overview of POME, which includes its sources, characteristics, hazardous impacts and example of treatments. The use of SBR system for various effluent treatments and the effect of its operating parameters on biological nutrient removal (BNR) are discussed. This chapter also comprises general discussion about microorganisms in POME treatment. Chapter 3 describes the methodology of the study in order to achieve the objectives. Chapter 4 discusses the experimental results as well as the interpretation and explanation of those research findings. Research questions are answered in this part, and the findings are re-evaluated with the existing knowledge that is related to the findings. The purpose of Chapter 5 is to conclude the results obtained for each research objective. This is followed by the recommendations and suggestions for future study in the related field.

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