MEMBRANE BIOREACTOR FOR THE TERTIARY TREATMENT OF PALM OIL MILL EFFLUENT

MOHD HAFIZUDDIN RAZAK

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Special dedication for my lovely and caring wife, Mrs. Siti Rosimah, and my son, Muhammad Rifqi Hazim, my family and my friends…

“Thanks a lot for invaluable support”

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ABSTRACT

A ponding system comprising of anaerobic and aerobic ponds is currently used to treat palm oil mill effluent (POME). However, the effluents are still coloured and do not comply with the limits set by the Department of Environment (DOE), Malaysia. This study investigates the feasibility of using a Membrane Bioreactor (MBR) as the tertiary treatment. The study was conducted by using wastewater from the Facultative Pond 1 (FP1) and the Facultative Pond 3 (FP3) of PPNJ Palm Oil Mill in Kahang. Initially, the effluents from the ponding system were characterized and an in-depth Chemical Oxygen Demand (COD) fractionation study was conducted on the effluents of FP1 and FP3. The effluents were then treated using a lab-scale MBR system and the effect of powder activated carbon (PAC) on the system performance was evaluated. The characterization of the effluent showed the reduction of the pollutants concentration as the wastewater passed through the ponds arranged in series. From COD fractionation analysis, the biodegradable:non-biodegradable fractions (in %) of FP1 and FP3 were 29:71 and 26:74, respectively. The readily biodegradable fraction in the FP1 was much higher than the FP3, which was 17% and 3.2%, respectively. The average COD removal during the MBR treatment was 87% and 68% for the FP1 and the FP3, respectively. However, the observation on the transmembrane pressure (TMP) behaviour showed that membrane fouling tend to occur quickly during MBR treatment of the FP1 as compared to the FP3 POME. The addition of PAC as the biofouling reducer (BFR) into the MBR improved its performance. The removal of organics with the addition of PAC was 92% and 86% for FP1 and FP3, respectively. The colour residual in the permeate for the FP1 and the FP3 were significantly reduced after the addition of PAC and the time for a membrane before it started to foul was also increased. The study showed the possibility of using an MBR as the tertiary treatment of POME for a better effluent quality.

ABSTRAK

Sistem kolam yang terdiri daripada kolam anaerobik dan kolam aerobik digunakan untuk merawat sisa air kilang kelapa sawit (POME). Walau bagaimanapun, sisa air yang terawat masih berwarna dan tidak menepati had yang telah ditetapkan oleh Jabatan Alam Sekitar (DOE) Malaysia. Kajian ini bertujuan untuk mengkaji keberkesanan Bioreaktor Membran (MBR) sebagai rawatan peringkat tinggi. Kajian dilakukan dengan menggunakan sisa air dari kolam fakultatif 1 (FP1) dan kolam fakultatif 3 (FP3) di Kilang Kelapa Sawit PPNJ Kahang. Pada permulaannya, pencirian sifat sisa air dilakukan termasuklah pecahan Keperluan Oksigen Kimia (COD) yang terkandung dalam sisa air dari FP1 dan FP3. Sisa air POME kemudiannya dirawat menggunakan sistem MBR berskala makmal dan kesan serbuk karbon teraktif (PAC) terhadap prestasi rawatan turut dikaji. Berdasarkan dari perincian sifat sisa air, tahap kepekatan bahan tercemar berkurangan mengikut susunan kolam secara bersiri. Dari analisis pemecahan COD menunjukkan pecahan yang boleh terurai:pecahan yang tidak boleh terurai (dalam %) yang terdapat dalam sisa air FP1 dan FP3 ialah masing – masing 29:71 dan 26:74, mengikut susunan. Pecahan mudah diurai dalam FP1 adalah jauh lebih tinggi iaitu 17 % berbanding FP3 dengan hanya 3.2 % daripada jumlah COD. Purata penyingkiran COD semasa rawatan MBR adalah 87 % bagi FP1 dan 68 % bagi FP3. Walau bagaimanapun, pemerhatian pada tekanan transmembran (TMP) menunjukkan bahawa kesumbatan membran cenderung untuk berlaku dengan lebih cepat semasa rawatan MBR menggunakan FP1 berbanding FP3. Penambahan PAC sebagai pengurang bio-enap (BFR) ke dalam MBR meningkatkan prestasi MBR. Penyingkiran organik dengan penambahan PAC mencatatkan 92 % dan 86 % masing- masing untuk FP1 dan FP3. Kepekatan warna selepas rawatan FP1 dan FP3 berjaya dikurangkan dengan ketara selepas penambahan PAC dan masa yang diambil sebelum membran mula tersumbat juga meningkat. Kajian ini menunjukkan keberhasilan penggunaan MBR sebagai rawatan POME yang tinggi untuk menghasilkan kualiti efluen yang lebih baik.

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LIST OF ABBREVIATIONS

ADMI	-	American Dye Manufacturing Institutes
APHA	-	American Public Health Association
BOD	-	Biochemical Oxygen Demand
BOD_5	-	5 day Biochemical Oxygen Demand
COD	-	Chemical Oxygen Demand
CPO	-	Crude Palm Oil
DO	-	Dissolved Oxygen
DOE	-	Department of Environment
FFB	-	Fresh Fruit Bunch
HR	-	High Range
HRT	-	Hydraulic Retention Time
MAS	-	Membrane Anaerobic System
MBR	-	Membrane Bioreactor
MF	-	Microfiltration
MLSS	-	Mixed Liquor Suspended Solid
MLVSS	-	Mixed Liquor Volatile Suspended Solid
MPOB	-	Malaysian Palm Oil Board
NF	-	Nanofiltration
OUR	-	Oxygen Utilization Rate
O&G	-	Oil & Grease
POME	-	Palm Oil Mill Effluent
PPNJ	-	Pertubuhan Peladang Negeri Johor
rbCOD	-	Readily Biodegradable Chemical Oxygen Demand
RO	-	Reverse Osmosis
RSM	-	Response Surface Methodology
sCOD	-	Soluble Chemical Oxygen Demand

SRT	-	Sludge Retention Time
SS	-	Suspended Solid
TCOD	-	Total Chemical Oxygen Demand
TMP	-	Transmembrane Pressure
TN	-	Total Nitrogen
TP	-	Total Phosphorus
UASB	-	Upflow Anaerobic Sludge Blanket
UASFF	-	Upflow Anaerobic Sludge Fixed-Film
UF	-	Ultrafiltration
VLR	-	Volumetric Loading Rate

LIST OF SYMBOLS

et al	-	and friend
m^2	-	unit of area
d	-	day
°C	-	Degree Celcius
h	-	hour
kg	-	Kilogram
mg/L	-	milligram per liter
mL	-	milliliter
N	-	Normality
X_S	-	Particulate Biodegradable COD
X_I	-	Particulate non-biodegradable (inert) COD
%	-	Percent
rpm	-	rotation per minute
S_S	-	Soluble Biodegradable COD
S_I	-	Soluble non-biodegradable (inert) COD
m^3	-	volumetric unit

CHAPTER 1

INTRODUCTION

1.1 Research Background

Production of palm oil in Malaysia has grown rapidly since 1975 and has become one of the main contributors to the Malaysian economy. In 2009, Malaysia had produced 17.56 million tonnes of palm oil where our country contributed 40% of the world palm oil production and became the world's second largest producer of palm oil (MPOB, 2010). Large production of palm oil will consume a large amount of water, whereas more than 50% of the water consumed will end up as liquid wastes generated from palm oil milling processing (Wu *et al*., 2007). The liquid waste is known as palm oil mill effluent (POME).

POME is considered as one of the most polluted wastewater generated from the palm oil industry, which consists of highly colloidal suspension of 95 - 96% water, 0.6 - 0.7% oil and grease and 4 - 5% total solids including 2 - 4% suspended solids (Idris *et al.,* 2010; Lam *et al*., 2011). Raw POME is originally a mixture of sterilizer condensate, oil clarification and hydrocyclone separation, emitted an unpleasant smell and much polluted wastewater (Wu *et al.,* 2007). Untreated POME would certainly caused an environmental problem especially to the water stream such as river due to its high concentration of chemical oxygen demand (COD), biological oxygen demand (BOD), oil and grease, total solids as well as suspended solids. Characterization of POME is necessary before the treatment in order to determine the content of POME in term of biodegradability and also non-biodegradability of organic wastes.

The most common treatment of POME applied by most palm oil mill in Malaysia is based on the conventional biological method, which consists of anaerobic and facultative pond system. This method requires a large area and a long retention time for an efficient treatment of POME. To date, many studies have been carried out for the treatment of POME at lab-scale and also at pilot-scale. Most of the past studies either proposed a new method of the treatment or a new technology for POME treatment. Recent studies exploited POME which contains high concentrations of protein, carbohydrate, nitrogenous compounds, lipids and minerals for bioresources recovery (Wu *et al*., 2007; Lam *et al*., 2011). Other than that, some studies improvised the existing technology and evaluated the performance of the technology used in the treatment of POME.

Membrane technology has been introduced in the treatment of wastewater with the invention of membrane bioreactor (MBR). MBR comprises of a conventional activated sludge process coupled with membrane separation to retain biomass in the reactor. Many studies have been carried out using an MBR to treat POME at a lab-scale and pilot scale. However, until now there is no report of utilizing an MBR at an industrial scale. The types of membrane used depend on the stage of the treatment of POME, as well as the material of the membrane. The types and materials of the membrane will affect the treatment as each type of membranes and material has different characteristics. The performance of MBR is greatly affected by important parameters such as the hydraulic retention time (HRT), sludge retention time (SRT) and mixed liquor suspended solids (MLSS) (Lim *et al*., 2004).

The performance of MBR may be restricted by the tendency of membrane fouling due to high organic loading of MBR; the surface of membrane developed resistance thus decreasing the flux of membrane. This phenomenon is called biofouling, which causes a reduction in permeability and frequent membrane cleaning is needed (Guglielmi *et al.,* 2007). There are several factors that contribute to membrane fouling such as membrane properties, effluent characteristics and operating condition (Meng *et al*., 2009). Therefore, the type of membrane used in the treatment must be suitable with the characteristics of the effluent. Operating conditions also plays an important role in the performance of MBR; operating MBR at optimum condition, will improve the performance of MBR in the treatment of POME, hence achieving a high quality of permeate which complies with the standard determined by the Department of Environment (DOE).

1.2 Problem Statement

Palm oil milling processes does not only produce crude palm oil (CPO), kernel oil and shell, but also produces by-products such as liquid effluent, solid wastes and gaseous emission. The by-products generated by the palm oil mill such as liquid effluent usually have a significant impact to the environment if the wastes generated were not dealt properly. Liquid effluents from the palm oil mill, commonly known as POME, contains very high suspended solids, high Biological Oxygen Demand (BOD), high Chemical Oxygen Demand (COD) and very high colour intensity. Although POME has very high BOD, COD and suspended solids, POME is a non-toxic wastewater since they were no addition of chemicals during the palm oil milling processes (Zinatizadeh *et al*., 2005). Despite its non-toxic characteristic, POME still caused a major problem to the environment.

Most of the treatment of POME in Malaysia is still dependent on the conventional method which is based on the biological treatment of aerobic and anaerobic ponding systems. The conventional method requires a large area for aerobic-anaerobic ponding system, and also needs proper maintenance and monitoring as the treatments solely depend on the microorganisms to degrade the pollutants. This method greatly decreased the concentration of organic wastes, but still does not achieve the standard set by DOE. The disadvantages of this method are that it requires large spaces and also it is a time consuming process. Therefore, the application of membrane technology during the treatment of POME can be applied as the finishing treatment to achieve a high quality of effluent, hence complying with the discharge limits of effluent.

MBR is one of the promising technologies in the wastewater treatment, which combines the membrane filtration technology and activated sludge system. Membrane filtration technology has been recognized as an effective and reliable technology to treat high strength wastewater and shows the potential to be applied in the treatment of POME. Compared to the conventional treatment of POME, the MBR was able to achieve a high sludge retention time (SRT) and able to maintain high mixed liquor suspended solids (MLSS), thus producing better and a high quality of effluent. However, the application of the MBR in the treatment of wastewater including POME raises concerns on the flux productions and membrane fouling behaviour.

Membrane fouling has significant effects on the performance of MBR in flux production, where the suspended solids deposition on the membrane surface clogged the membrane pores, hence reducing the permeability of the membrane. Many factors contributed to membrane fouling such as wastewater characteristics, aeration, operating conditions, biomass concentration, etc. These factors played an important role in membrane fouling development and consequently will lower the performance of MBR, thus increasing the operating cost of the treatment. Reducing membrane fouling becomes the main concern of the researchers in order to improve the performance of the MBR in the treatment of wastewater.

The concentration of organic wastes in wastewater determines the strength of the wastewater. Wastewater with a low organic concentration is easily treated either by physical and/or chemical and/or biological treatment compared to wastewater with a high organic concentration. Conventional treatment of POME uses a series of treatment in ponds which produces different quality and characteristics of the treated POME. MBR treatment of POME with different characteristics may affect the performance of the treatment and would lead to a different quality of the treated effluent.

The study utilized the lab-scale MBR to treat biologically treated POME from different ponds as the feed, with the aims of investigating the effects of the influent characteristics on the MBR treatment performance in terms of organic removal and membrane fouling behaviour. The COD fractionation of POME could demonstrate the exact dissolved organic pollutants to be removed based on the loading rate calculation. The addition of powder activated carbon (PAC) as the biofouling reducing agent into the MBR could enhance the removal of organic pollutants and reduce the fouling rate of membrane.

1.3 Objectives of the Study

The objectives of the study are:

i) To characterize the total biodegradable organic and non-biodegradable organic contents in biological treated POME from the ponding system
ii) To determine the effects of influent characteristics on the performance of MBR
iii) To investigate the effect of using powder activated carbon (PAC) on the MBR performance during the treatment of POME

1.4 Scope of Study

Most of the study was conducted at the Pollution Control Laboratory, Faculty of Chemical Engineering, UTM Skudai, and all of the weekly sampling and on-site analysis were done near Pertubuhan Peladang Negeri Johor (PPNJ) Palm Oil Mill, Kahang, Kluang, Johor. In the early stage, the POME samples were collected from all of the ponds including anaerobic ponds and facultative ponds for characterizations such as COD, BOD, TS, SS, TN, AN and pH. After characterization, samples from facultative pond 1 (FP1) and facultative pond 3 (FP3) were selected to further characterized its total biodegradable organic and total non-biodegradable organic

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In this study, the lab-scale MBR with working dimension of 0.35m (height) x 0.23m (length) x 0.25m (width), and a total volume capacity up to 20-L was used.

The membrane module used was bought from China, built with polyvinyledene fluoride (PVDF) material, flat sheet membrane type, pore size of 0.1µm and effective area of $0.1 m^2$. The critical flux of the membrane was determined to obtain the suitable flux for POME treatment in MBR. The operating conditions of the MBR were maintained during the treatment except for the influent concentration (organic loading).

The performances of the MBR during the treatment of POME were evaluated in terms of organic removal and TMP behaviour. The evaluations of the MBR performances in treating POME were carried out for 14 days for each test and samples (FP1 and FP3). The results obtained were plotted and compared. After the evaluation of the MBR performances during the treatment of FP1 and FP3, PAC as the biofouling reducer agent was introduced into the MBR. The purpose of adding PAC into the MBR was to investigate its effect on the MBR performance during the treatment of POME.

1.5 Thesis Outline

This thesis consists of five chapters. In the first chapter, general information about the research were discussed including the background of the research, problem statement, objectives and scope of the study. Chapter 2 is an overview of palm oil mill effluent (POME) and its characteristics, types of treatment and technology used for the treatments of POME and membrane bioreactor (MBR) as well as the challenges of using membrane technology in wastewater treatment. Chapter 3 discusses the outline of the research, materials and methods including the chemical used for analysis, equipment and tools, how to do the analysis, and samples preparation for analysis as well as the procedures of the experiments conducted during the study.

Chapter 4 presents the results and the analysis of the study conducted. It also discusses the comparison of the MBR performances in terms of organic removal and membrane fouling behaviour using FP1 and FP3 as the influent. The last chapter of this thesis presents the conclusions of this study and the recommendations for future works.

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