Faculty of Resource Science and Technology

Optimisation of the Aerobic Digestion Process in Palm Oil Mill Effluent (POME) Ponds

Lynnettee Joinin

(52394)

Bachelor of Science with Honours
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Optimisation of Aerobic Digestion Process in Palm Oil Mill Effluent (POME) Ponds

Lynnettee Joinin
(52394)

A project report submitted in partial fulfilment of the
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Faculty of Resource Science and Technology

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Optimisation of Aerobic Digestion Process in Palm Oil Mill Effluent (POME) Ponds

Lynnettee Joinin

Resource Biotechnology Programme
Faculty of Resource Science and Technology
Universiti Malaysia Sarawak

ABSTRACT

The palm oil industry in Malaysia is one of the industries that generates a high income. However, the increasing production of palm oil products also means increasing generation of palm oil waste which includes palm oil mill effluent (POME) that is very polluting to the environment due to the high biological oxygen demand (BOD) and chemical oxygen demand (COD) content. The present study focuses on the lab-scale ponding treatment of POME which is one of the most popular treatment methods in palm oil mills. The variable factors include oxygen concentration, pond depth and treatment duration. The experiment was designed using the Design-Expert software version 6.0.8 (Stat-Ease, Inc., Minneapolis, USA) using the response surface method (RSM) based on previous studies done on the variable factors chosen. The optimum conditions were found to be 0.5 vvm oxygen concentration, 10 cm pond depth and 5 days treatment duration for BOD removal (47.1%) and COD removal (42.9%). As for colour removal (13.5%), the optimum conditions were found to be 0.5 vvm oxygen concentration, 5 cm pond depth and 5 days treatment.

Keywords: Palm oil mill effluent (POME), ponding treatment, biological oxygen demand (BOD), chemical oxygen demand (COD), response surface method (RSM)

ABSTRAK

Industri minyak sawit di Malaysia merupakan salah satu industri yang menjana pendapatan yang tinggi. Namun begitu, peningkatan penghasilan produk-produk minyak sawit membawa kepada peningkatan penghasilan efluen ladang sawit (POME) yang mencemar alam sekitar disebabkan kandungan oksigen biologi (BOD) serta oksigen kimia (COD) yang tinggi. Fokus kajian ini adalah kolam rawatan POME dalam skala kecil yang merupakan salah satu kaedah rawatan yang popular di lading sawit. Faktor-faktor pembolehubah termasuk kepekatan oksigen, kedalaman kolam dan tempoh rawatan. Eksperimen ini direka menggunakan perisian Design-Expert versi 6.0.8 (Stat-Ease, Inc., Minneapolis, USA) melalui response surface method (RSM) berdasarkan kajian lepas yang telah dilakukan atas faktor-faktor pembolehubah yang telah dipilih. Keadaan optimum merupakan 0.5 vvm kepekatan oksigen, 10 cm kedalaman kolam dan 5 hari tempoh rawatan bagi penyingkiran BOD (47.1%) dan penyingkiran COD (42.9%). Bagi penyingkiran warna, keadaan optimum merupakan 0.5 vvm kepekatan oksigen, 5 cm kedalaman kolam dan 5 hari tempoh rawatan.

***Kata kunci**: Efluen lading sawit (POME), rawatan kolam, oksigen biologi (BOD), oksigen kimia (COD), response surface method (RSM)*

Table of Contents

List of Tables

List of Figures

aerobic digestion of POME. Dependence of Y_1 on the oxygen concentration (X_1) and pond depth (X_2) (Treatment duration, X_3 = 4.56 days); (c) Colour removal (Y_3) for aerobic digestion of POME. Dependence of Y_1 on the oxygen concentration (X_1) and pond depth (X_2) (Treatment duration, X_3 = 4.56 days)

List of Abbreviations

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CPO	Crude Palm Oil
DO	Dissolved Oxygen
DOE	Department of Environment
EFB	Empty Fruit Bunches
FCCCD	Face Centred Central Composite Design
FFB	Fresh Fruit Bunches
HRT	Hydraulic Retention Time
MPOB	Malaysian Palm Oil Board
OLR	Organic Loading Rate
POME	Palm Oil Mill Effluent
RSM	Response Surface Method
TSS	Total Suspended Solids

1.0 Introduction

The palm oil industry in Malaysia is undoubtedly a successful one. From 2015 to 2016 alone, the collective palm oil plantation area in Malaysia increased 1.7% from 56430 million m^2 to 57380 million m^2 (Malaysian Palm Oil Board (MPOB), 2017). Subsequently, the production of palm oil mill effluent (POME) through the processing of palm oil fresh fruit bunches (FFB) has also increased throughout the years. Raw POME will cause pollution when discharged into water bodies, therefore, efficient and affordable treatment systems for POME are essential to the environment and the society. The performance efficiency of treatment systems is determined through the analysis of percentage removal of biological oxygen demand (BOD), chemical oxygen demand (COD) and colour.

Ponding system is a low-cost treatment method for POME in Malaysia (Wong, 1980). It consists of a series of anaerobic, facultative and aerobic ponds. Previous researches on the digestion of POME in Malaysia has been focusing mostly on anaerobic digestion. This study specifically focuses on aerobic digestion in a ponding system setting which requires oxygen for decomposition of organic matters to occur. Aerobic digestion has been widely used to treat wastewater due to its high degree of efficiency and high quality of effluent. However, aerobic digestion requires a large area due to the high number of ponds and extra expenses for aeration as well as sludge disposal. There are limited studies done particularly on the design of aerobic ponds for POME treatment and other parameters that affect the aerobic digestion of POME significantly.

Therefore, the objectives of this study were to determine the factors that affect the optimisation of aerobic digestion process of POME, to determine the optimum condition for selected factors in the aerobic digestion process of POME and to determine the percentage reduction in BOD, COD and colour of POME after treatment at the optimised conditions in the aerobic ponds. POME samples were collected from Felcra Jaya Kota Samarahan, Sarawak and were immediately brought to the Reaction Engineering Laboratory, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS) for immediate use. Therefore, the experiment for the whole treatment duration was performed in ambient conditions of atmospheric pressure and room temperature of 25 °C. The analytical method for determination of BOD, COD and colour removal were according to American Public Health Association (APHA) method (American Public Health Association (APHA), 2005). A statistical tool known as face centred central composite design (FCCCD) has been run through response surface method (RSM) in the Design-Expert software version 6.0.8 (Stat-Ease, Inc., Minneapolis, USA) to model and optimise the aerobic digestion process of POME in the lab-scale ponds.

2.0 Literature Review

2.1 Palm Oil Industry in Malaysia

The first commercial oil palm plantation was pioneered by Fauconnier in Tennamaran Estate, Selangor (Tate, 1996). As of 2009, Malaysia and Indonesia collectively contribute up to 90% of global palm oil whereby Malaysia contribute 39% of world's palm oil production and 44% of world's export (Sarmidi, 2009). As of late 2016, the total area of palm oil plantation in Malaysia is 57380 million m^2 (Malaysian Palm Oil Board (MPOB), 2017). Boasting a total revenue of RM 64.59 billion, the palm oil industry is growing each year to produce enough supplies of oils and fats in accordance to the increasing demands from all over the world in a sustainable manner (Malaysian Palm Oil Corporation (MPOC), 2012).

2.2 Palm Oil Processing

Palm oil mills in Malaysia process fresh fruit bunches (FFB) to produce crude palm oil (CPO) and palm kernel (Thani et al., 1999). Basically, fresh fruit bunches (FFB) are sterilized to deactivate hydrolytic enzyme and loosen the fruit from bunches. Next, the fruits are stripped and separated from the bunch in a rotary drum stripper. Then, in a digester, the fruits are mashed up to break the mesocarp oil-bearing cells. Twin screw presses are used to press out the oil from the digested mash of fruits under high pressure. Hot water is added to enhance the flow of the oils. The crude oil slurry is fed to a clarification system for oil separation and purification before being sent to storage tanks. The fibre and nut (press cake) are conveyed to a depericarper for separation. The crude palm oil (CPO) contains a mixture of palm oil, water and fibrous materials (Thani et al., 1999). Large quantities of water are used during the extraction of crude palm oil. About 50% of the water results in palm oil mill effluent (POME), the other 50% being lost as steam, mainly through sterilizer exhaust, piping leakages, as well as wash waters (Thani et al., 1999). An average of 900–1500 kg of POME is generated for each one kg of crude palm oil produced (Wu et al., 2010). Meanwhile, the nuts from the press cake are cracked and the kernels are separated from the shells. Finally, the palm kernels are dried with warm air.

2.3 Palm Oil Mill Effluent

POME is mainly made up of sterilizer condensate (36%), clarification wastewater (60%) and hydro-cyclone wastewater (4%) generated during the production of palm oil (Rupani et al., 2010). According to Ng, Goh and Tay (1987), POME may vary depending on batches, days, processing techniques, age and type of fruit. Other factors may also include the discharge limit of the factory, climate and condition of the palm oil processing (Ahmad, Sumathi & Hameed, 2006). Consisting of water soluble components of palm fruits as well as suspended cellulosic materials like palm fibre, and oil residues (Agamuthu, 1995), raw POME is considered the most harmful waste compared to other wastes generated from processing of oil palm fruits (Rupani et al., 2010) due to the high biological oxygen demand (BOD), as shown in Table 1, which leads to anaerobic condition and release of harmful gases, particularly hydrogen sulphide (Ahmad, Ismail & Bhatia, 2003). Thus, POME discharge standards, as shown in Table 2, are strictly emphasized through the enactment of the Environmental Quality Act in 1978. In addition, POME contains coloured compounds composed of organic compounds such as anthocyanin and carotene pigment that were extracted from fresh fruit bunches in the sterilization process as well as polyphenol compounds, tannin, polyalcohol, and melanoidin (Mohammed, Ketabachi & McKay, 2014). These coloured compounds cause reduction in photosynthetic activities, produce carcinogenic by-products in drinking water, chelate with metal ions, and are toxic to aquatic biota. Thus, failure of conventional treatment methods to decolourise POME has become an important problem to be addressed as colour has emerged as a critical water quality parameter for many including Malaysia (Neoh et al., 2012).

Table 1. Characteristics of Palm Oil Mill Effluent (POME) and its respective standard discharge limit set by Malaysian Department of Environment (DOE) (Tabassum et al., 2015).

Parameter	**Average Value**	**Standard Discharge Limit**
Temperature (°C)	85	-
pH	4.7	5.0–9.0
BOD (mg/L)	25000	100
COD (mg/L)	50000	50
Total Solids (mg/L)	40500	-
Suspended Solids (mg/L)	18000	400
Total Volatile Solids (mg/L)	34000	-
Ammonia Nitrogen (mg/L)	35	-
Total Nitrogen (mg/L)	750	150
Phosphorus (mg/L)	180	-
Magnesium (mg/L)	615	-
Boron (mg/L)	7.6	-
Manganese (mg/L)	439	-
Calcium (mg/L)	2.0	10
Zinc (mg/L)	2.3	10
Copper (mg/L)	0.9	10
Iron (mg/L)	46.5	50
Potassium (mg/L)	2270	-
Chromium (mg/L)	10.2	-

2.4 POME Treatment

The various POME treatment options in Malaysia include open tank digester and extended aeration system, closed anaerobic digester and land application system as well as pond treatment system (Ma, 1999). The choice of treatment systems depends largely on the company's preference, location of the mill and availability of useable land. The pond treatment system is utilised by more than 85% of the palm oil mills in Malaysia (Ma, 1999).

2.5 The Pond Treatment System

Most of the pond treatment systems for POME treatment in Malaysia are classified as waste stabilisation pond that employs biological treatment in which bacteria are used to break down the organic matters to significantly reduces the BOD and chemical oxygen demand (COD) in raw POME. Generally, this system consists of a series of anaerobic, facultative anaerobic and aerated ponds which are made up of earthen structures with no lining (Ma, 1999). This system requires less energy due to the absence of mechanical mixing, operation control or monitoring. However, this system requires large space of area, long hydraulic retention time (HRT) of 40–60 days and production of corrosive and odorous gas directly to the atmosphere which could have detrimental impacts to the environments (Wu et al., 2010). Moreover, the accumulation of solid as well as the formation of scum from oil and grease in the POME reduces the efficiency of ponds (Yacob et al., 2005). Possible solutions include using submersible pumps or excavators to remove the sludge which can be used as fertilizers due to the nutrient content (Yacob et al., 2005). The clean-up is normally carried out every five years or when the volume of the pond is greatly reduced (Wong, 1980).

2.5.1 Anaerobic Ponds

Anaerobic ponds for POME treatment consist of at least two ponds connected in series to other ponds. The raw POME is channelled into the anaerobic pond from the sludge recovery tank. Anaerobic ponds are usually designed to be deeper compared to aerobic and facultative ponds to establish anaerobic condition whereby the deeper regions contain minimal to no dissolved oxygen (Rupani et al., 2010). The depth of anaerobic ponds for POME treatment in Malaysia are usually in the range of 5–7 m (Ahmed et al., 2015). Three zones can be identified in the pond which are the scum layer, the supernatant layer and the sludge layer. Anaerobic reaction takes place in the sediment. Anaerobic ponds are very effective in treatment of effluents with high strength, biodegradable organic contents (BOD > 500) generated in large quantities by agricultural and food industries therefore these ponds are suitable to be used as preliminary treatment before secondary treatment takes place (Ahmed et al., 2015). The organic loading for POME treatment in anaerobic ponds varies from 0.2–0.35 kg BOD/m^3/day with a minimum HRT of 30 days.

2.5.2 Facultative Ponds

Facultative ponds, as the name implies, consists of an upper aerobic and a lower anaerobic zone (Zupancic & Ros, 2008). Effluent that flows into the facultative pond from the anaerobic pond will form a sludge layer, made up of settleable and flocculated colloidal matter, whereby organic matters are decomposed anaerobically (Rajbhandari & Annachatre, 2004). Meanwhile, the soluble and suspended organic matters are decomposed either aerobically, facultatively or, rarely, anaerobically (Zupancic & Ros, 2008). Facultative ponds are shallower compared to anaerobic ponds, usually with a depth that falls in the range of 1–1.5 m to maintain satisfactory dissolved oxygen contents. The HRT for POME treatment in facultative ponds is between 8–16 days (Rupani et al., 2010).

2.5.3 Aerated Ponds

Aerated ponds provide tertiary treatment process whereby effluent quality is further improved by the removal of suspended solids, ammonia, nitrate, phosphate concentration and enteric microorganisms (Rupani et al., 2010). The two types of aerated ponds are the aerobic pond and the aerobic-anaerobic pond. In the aerobic pond, all the solids are in suspension. Meanwhile, in the aerobic-anaerobic pond, a degree of turbulence is maintained to ensure uniform distribution of oxygen throughout the pond but is usually insufficient to maintain all the solids in suspension thus solids that settle at the bottom would undergo anaerobic decomposition. Periodic de-sludging is required in the aerobic-anaerobic pond. About 70–90 % of BOD removal is achieved in aerobic ponds yet the effluent may contain a relatively high concentration of suspended solids which results in a turbid appearance (Yacob et al., 2005). Therefore, the installation of settling pond for removal of solids is recommended. Aerated ponds have a HRT of around 8 days and some are equipped with mechanical surface aerators for oxygen supply which is energy consuming and costly.

2.6 Principle of Aerobic Digestion

Aerobic digestion of wastewater sludge is defined as the stabilization process in which the aerobic microorganisms consume the biological degradable organic components of the sludge to produce biologically stable products as well as to reduce both sludge mass and volume (Bernard & Gray, 2000). The condition of the process is endogenous. The removal of organic material by the microorganism is to synthesise new microorganisms which leads to increase in biomass. Some organic materials will also be oxidised to carbon dioxide, water and soluble inert material. These will mainly provide energy for the microorganisms' vital function. Once the source of organic material is depleted, endogenous respiration occurs whereby the cellular material of the microorganism are oxidised to provide the energy required. The total quantity of biomass will be reduced and the remaining material will exist at a low energy state if the condition is maintained over a period of time. The product is considered as biologically stable and suitable to be disposed to the environment (Zupancic & Ros, 2008).

2.7 Parameters Affecting Aerobic Digestion of POME

2.7.1 Effect of Pond Depth

The pond depth is a length measurement from the bottom of the pond until the surface of the pond. A study done by Sukias et al., (2001) concluded that a typical treatment pond may receive enough sunlight for photosynthesis only up to 15 cm from the surface of the effluent. Therefore, the condition at above 20 cm from the surface of the effluent will be anaerobic. This factor has been taken into consideration for the dimension of the aerobic ponds in this study whereby ponds of depth 5 cm, 10 cm and 15 cm were compared to find out which depth is in the optimum range for aerobic digestion.

2.7.2 Effect of Oxygen Concentration

Oxygen concentration or oxygen flow rate in terms of vessel volume per minute (vvm) is the amount of oxygen supplied in a litre of the vessel in exactly one minute. Studies have shown that 0.5 vvm, or 0.5 liters of oxygen per liter of effluent per minute, is adequate to achieve maximum reduction of chemical oxygen demand (COD) in domestic wastewater sludge (Alam & Fakhru'l-Razi, 2002) and in palm oil empty fruit bunches (EFB) (64.82%) (Fadilah, Tey & Suhaimi, 2009). Thus, based on this fact, the lab-scale ponds for this experiment were equipped with oxygen flow rate of 0.0 vvm, 0.5 vvm and 1.0 vvm.

2.7.3 Effect of Hydraulic Retention Time (HRT)

Hydraulic retention time (HRT) is the measure of the average length of time that a compound, such as water, remains in a storage unit, such as a pond. In a study done by Chan, Chong and Law (2011) on the optimisation of aerobic treatment of POME, as hydraulic retention time (HRT) increased so did the corresponding COD removal efficiency. The study concluded that at 36 hours, both COD and BOD removal were higher compared to 18, 24 and 30 hours. In another study of POME biodegradation by filamentous fungi, the COD was monitored every 20 hours for 8 days for both experiments (Jalaludin et al., 2016). Since HRT is alike to the treatment duration in this study, 4, 7 and 10 days were chosen as the optimum treatment durations.

2.7.4 Effect of Organic Loading Rate (OLR)

OLR is useful for the design of aerobic system as it is a combination of the effect of hydraulic loading and organic concentration (Chen, Sun & Chung, 2008). In the aerobic treatment of anaerobically digested POME, it was reported that the increase of OLR from 1.8 g to 3.1 g COD (L/day) had resulted in an enhancement in COD removal from 93 to 97% (Chan, Chong & Law, 2010a). This implies that increase in OLR can indeed stimulate the activity of microorganism and enhance the growth of aerobic culture by providing more organic substance. In general, the percentages of COD, BOD and TSS removed increased with the increase of OLR up to a maximum level, and then it declined with further increase of OLR due to the increase of the non-biodegradable organic load in the influent, causing substrate inhibition to the native biomass growth and its metabolic activities (Chan et al., 2011).

2.7.5 Effect of Temperature

The effects of temperature on aerobic treatment of anaerobically digested POME were investigated by Chan, Chong and Low (2010b). The results show that the performance of sequencing batch reactor was better at mesophilic temperature (28 °C) compared to thermophilic temperature (55°C) whereby the COD, BOD and total suspended solids (TSS) concentration of treated effluent increased with temperature.

2.7.6 Effect of Microbial Content

The microbial content of POME is a good indicator of biodegradability of wastewater. Most of these organisms are spore formers, it helps them to survive the harsh environmental