TWO-STAGE ANAEROBIC PROCESS COUPLED WITH SINGLE-STAGE AEROBIC PROCESS FOR RAW PALM OIL MILL EFFLUENT TREATMENT

KHAIRUNNISA BINTI ABDUL HALIM

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Dedicated to

My lovely father and mother

Abdul Halim bin Musa

&

Azizah binti Abdul

Thank you for your love, du'a and ever-present encouragement.

Lovely brothers and sisters

Family of 17 (ROTU-NAVY UTM)

Fellow friends

Thank you for your kindness, support and motivation.

The one and only supervisor

Dr. Yong Ee Ling

Sincere appreciation for your patience, time and inspiration.

To all people

Thank you for all of your kindness, encouragement and support.

May Allah bless us and ease everything.

"Work until you no longer have to introduce yourself"

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ABSTRACT

Malaysia is the second large contributor in the palm oil industry after Indonesia. Yearly, approximately 13 million tonnes of crude palm oil are produced. During the crude palm oil extraction process, huge amount of brownish-oily liquid sludge, known as palm oil mill effluent (POME), are generated. The acidic and high organic loadings characteristics of POME can cause severe water pollution if being discharged to the water bodies without proper treatment. In most oil palm production mills, ponding treatment system is adopted. The treatment paradigm, however, has shifted from ponding system to integrated high rate bioreactors by coupling anaerobic and aerobic processes. Despite the outstanding treatment performance exhibited by this bioreactor, diluted POME was used in almost all previous studies instead of fresh raw POME. Thus, treatment performance by the researched bioreactors for fresh raw POME real application may not be as efficient. Therefore, this study aimed to employ the principle of two-stage anaerobic process followed by a single stage aerobic process for the treatment of fresh raw POME. The treatment efficiency of this system was examined by evaluating the removal of several important parameters, namely chemical oxygen demand (COD) and sludge reduction reported in terms of total suspended solids. Throughout the 150 days of operation, approximately 93% and 55% of reduction were observed for COD and TSS, respectively, suggesting this integrated system was competent in treating high strength wastewater. Nonetheless, further research need to be made to ensure the stability consistency and feasibility of this integrated system.

ABSTRAK

Malaysia merupakan penyumbang kedua terbesar dalam industri pengeluaran minyak kelapa sawit selepas Indonesia. Setiap tahun, sekurang-kurangnya 13 juta tan minyak sawit mentah dihasilkan. Melalui proses pengestrakan minyak sawit mentah, sejumlah besar sisa cecair enap-cemar berwarna coklat dan berminyak dikenali sebagai sisa effluen dari kilang kelapa sawit (POME) dihasilkan. POME bersifat asidik dan mempunyai kandungan sisa cemar organik yang tinggi, yang boleh menyebabkan pencemaran air sekiranya ia dilepaskan kepada badan-badan air tanpa rawatan yang betul. Kebanyakkan kilang pemprosesan minyak sawit, sistem rawatan kolam diguna pakai. Corak rawatan ini bagaimanapun bertukar daripada sistem kolam rawatan kepada penggunaan reaktor yang menggabungkan proses biologi; anaerobik dan aerobik bagi merawat POME. Walaupun prestasi yang dipamerkan oleh bioreaktor ini sangat baik berdasarkan kajian sebelum ini, tetapi POME yang terlarut telah digunapakai dan bukannya POME mentah. Sehubungan itu, berkemungkinan prestasi aplikasi bioreaktor tersebut tidak seefektif yang dilaporkan sekiranya digunakan bagi merawat POME mentah. Oleh itu, kajian ini bertujuan untuk menggunakan prinsip dua peringkat proses anaerobik diikuti dengan proses aerobik tunggal bagi merawat POME mentah. Kecekapan rawatan sistem ini telah dikaji dengan menilai penyingkiran beberapa parameter penting iaitu; permintaan oksigen kimia (COD); dan pengurangan enapcemar berdasarkan analisis jumlah pepejal terampai (TSS). Sepanjang 150 hari kajian dijalankan, kira-kira 93% dan 55% pengurangan dapat dicapai, masing-masing bagi COD dan TSS; menunjukkan keupayaan system ini bagi merawat jenis sisa air tercemar berkekuatan tinggi '*high-strength wastewater*'. Namun begitu, kajian lanjut perlu dilakukan bagi memastikan kestabilan yang konsisten; dan kebolehlaksanaan sistem ini dapat dibuktikan.

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LIST OF ABBREVIATIONS

AD	-	Anaerobic digester
BNR	-	Biological nitrogen removal
BOD	-	Biological Oxygen Demand
CER	-	Certified Emission Reduction
COD	-	Chemical Oxygen Demand
CPO	-	Crude Palm Oil
CSTR	-	Continuous Stirred Tank Reactor
DO	-	Dissolved Oxygen
EFB	-	Empty Fruit Bunches
FFB	-	Fresh Fruit Bunches
HRT	-	Hydraulic Retention Time
IAAB	-	Integrated Anaerobic-Aerobic Bioreactor
MPB	-	Methane Producing Bacteria
N	-	Nitrogen
NH_3-N	-	Ammonia-Nitrogen
NO_2^-	-	Nitrite
NO_3^-	-	Nitrate
OLR	-	Organic Loading Rate
OSA	-	Oxic-settling-anaerobic
POME	-	Palm Oil Mill Effluent
POMS	-	Palm Oil Mill Sludge
S^{2-}	-	Sulfide
SO_4^{2-}	-	Sulfate
SRB	-	Sulfate Reducing Bacteria
SRT	-	Solid Retention Time

SS	-	Suspended Solid
TN	-	Total Ntrogen
TSS	-	Total Suspended Solid
UASB	-	Up-Flow Anaerobic Sludge Blanket
UASFF	-	Up-Flow Anaerobic Sludge Fixed-Film
VSS	-	Volatile Suspended Solid

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Palm oil industry is the one of the largest agricultural industries in Malaysia that produces approximately 13 million tonnes of crude palm oil (CPO) every year (MPOB, 2015). While the generation of CPO has significantly boost the country's economy, it has also resulted in the production of approximately 70.5 million m^3 of thick-sluggish brown liquid waste known as palm oil mill effluent (POME) (Najafpour *et al.*, 2006). POME is hot and acidic where its temperature and pH can range between 75 to 85°C and 4 to 5, respectively (Bala *et al.*, 2014). It contains a mixture of lignocellulosic wastes, carbohydrates and oil with an unpleasant smell (Bala *et al.* 2014). This mixture possesses high amount of organic concentrations (chemical oxygen demand (COD) > 50,000 mg/L; biochemical oxygen demand (BOD) > 25,000 mg/L) making POME the main source for inland water pollution problems when discharged into surface waters without prior treatment (Borja *et al.*, 1996c, Singh *et al.*, 1999, Ma, 2000).

For more than 20 years, majority of the palm oil miller in Malaysia has been practicing biological treatment processes for POME (Chooi, 1984, Ma, 1999, Abdurahman *et al.*, 2013). The processes involves include anaerobic, aerobic and facultative. However, anaerobic process was the most favorable as it showed best treatment performance in handling high organic loading wastes (Tay, 1991), Perez *et al.* (2001). Approximately 85% palm oil millers are still using ponding system (Ma *et al.*, 1993) while others, where land area limited, adopted open digested tank system (Yacob *et al.*, 2005). These conventional treatments, however, demand large treatment area and require long retention time in order to satisfy the discharge limit outline by the Department of Environment (Poh and Chong, 2009). Nonetheless, the increasing demand of palm oil worldwide has made the limits hard to be complied owing to the rising concentration of organic loading (Bhatia *et al.*, 2007, Chan *et al.*, 2013).

To overcome the incompetency of the conventional anaerobic digestion system in treating POME, lab scale of high rate anaerobic bioreactor was invented (Chan *et al.*, 2012, Choi *et al.*, 2013, Jeong *et al.*, 2014, Khemkhao *et al.*, 2015). The anaerobic bioreactors studied were anaerobic contact digester (Ibrahim *et al.*, 1984); up-flow anaerobic sludge blanket (UASB) (Borja and Banks, 1994a, Ahmad *et al.*, 2011, Fang *et al.*, 2011, Ahmad *et al.*, 2012, Singh *et al.*, 2013a, Singh *et al.*, 2013b); up-flow anaerobic filtration (Borja and Banks, 1994b, Borja and Banks, 1995, Mustapha *et al.*, 2003, Vijayaraghavan and Ahmad, 2006, Chaisri *et al.*, 2007); fluidized bed reactors (Borja and Banks, 1995, Ahmed and Idris, 2006, Al-Mamun and Idris, 2010); up-flow anaerobic sludge fixed-film (UASFF) (Borja *et al.*, 1996b, Najafpour *et al.*, 2006, Zinatizadeh *et al.*, 2006a, Zinatizadeh *et al.*, 2006b, Zinatizadeh *et al.*, 2007); and continuous stirred tank reactors (CSTR) (Poh and Chong, 2010, Mohd Zulkhairi *et al.*, 2010, Wong *et al.*, 2014, Seengenyoung *et al.*, 2014, Khemkhao *et al.*, 2015).

Apart from anaerobic process, aerobic treatment systems including trickling filters (Nik Norulaini *et al.*, 2001), rotating biological contactor (Najafpour *et al.*, 2005) and activated sludge processes (Vijayaraghavan *et al.*, 2007) were employed for the treatment of POME. Other physical treatments comprise of evaporation method (Ma *et al.*, 1997) and membrane technology (Fakhru'l-Razi and Noor, 1999, Ahmad *et al.*, 2003, Ahmad *et al.*, 2006, Ahmad *et al.*, 2007, Idris *et al.*, 2010, Abdurahman *et al.*, 2011) were also studied. Based on those studies, neither anaerobic nor aerobic process alone was sufficient to treat POME to the required regulated standard (Perez *et al.*, 2001, Aggelis *et al.*, 2001, Chan *et al.*, 2009). The physical treatment systems on the other hand, were not economical for the palm oil millers although their treatment performance is very promising. For this purpose, a combination of anaerobic and aerobic system to enhance the overall performance in the treatment of POME was proposed (Vera *et al.,* 1999). The combined system was able to achieve high organic removal organic while reducing the operational cost, amount of sludge as well as evade the correction pH (Vera *et al.*, 1999).

In recent years, the excellent performance of high-rate integrated anaerobic-aerobic treatment system has received utmost attention (Chan *et al.*, 2009, Wang *et al.*, 2009, Chan *et al.*, 2012, Chan *et al.*, 2013, Tabassum *et al.*, 2015). It has been proven that by combining the anaerobic and aerobic processes in the same reactor, this entire system can improve the removal of organic loadings of POME by more than 95% at high loading rate of 10.5 g COD/L/day(Chan *et al.*, 2012). Moreover, this integrated system is smaller in size, cheaper and more effective compare to the previously mentioned anaerobic-aerobic system (Yang and Zhou, 2008, Wang *et al.*, 2009, Chan *et al.*, 2012, Chan *et al.*, 2013). It was also proven that the integrated bioreactor produced useful byproducts revenue generated from the anaerobic process, i.e. methane gas (Zinatizadeh *et al.*, 2006b).

The studies, however, could not represent the real application of the integrated anaerobic-aerobic bioreactor for the treatment of POME. Most of the researchers tend to use at least 10 times diluted POME for their studies (Chan *et al.*, 2012, Baranitharan *et al.*, 2013, Taha and Ibrahim, 2014, Soleimaninanadegani and Manshad, 2014). While dilution can prevent the clogging of pumps, it is important to note that the concentrations of organic loadings and cellulosic compounds were apparently reduced. Thus, the removal of organic loadings achieving more than 90% within shorter hydraulic retention time (HRT) may not be applicable with the current experimental setup. In addition, raw POME contains high ratio of lignin to cellulose compounds that is difficult to degrade causing a huge interference in achieving the targeted performance of the integrated system.

To overcome the shortcomings of the currently studied integrated system for the treatment of fresh raw POME, this study implements a two-stage anaerobic process coupling with a single-stage aerobic bioreactor was employed. In this study, the feasibility and treatment performance of the proposed system in treating fresh raw POME was evaluated based on the chemical oxygen demand and sludge reduction capacity.

1.2 Problem Statement

Integrated anaerobic-aerobic bioreactor has shown to be a promising technology for the treatment of POME. This integrated bioreactor, nonetheless, still lacks on its application for the treatment of fresh raw POME. In general, fresh raw POME was diluted 10 times in order to prevent the clogging of pumps caused by the lignocellulosic compounds. It is important to note that the organic loading and strength of other chemical parameters were also reduced by 10 times. Therefore, the removal efficiencies based on 10 times diluted POME may not be accurate when fresh raw POME is employed on currently researched integrated system. In addition, raw POME contains high ratio of lignin to cellulose compounds that is difficult to degrade causing a huge interference in achieving the targeted performance of the integrated system. Thus, a two-stage anaerobic process coupling with a single-stage aerobic bioreactor was proposed with the intention to breakdown the lignocellulosic compounds in the first stage anaerobic process.

1.3 Objectives of Study

Generally, the purpose of the study is to:

1. apply the principle of two-stage anaerobic followed by single stage aerobic process for the treatment of palm oil mill effluent; and
2. evaluate the treatment performance of the integrated system in terms of chemical oxygen demand (COD) and sludge reduction.

1.4 Scopes of Study

The purpose of this study is to evaluate the performance of the integrated two-stage anaerobic process coupled with single-stage aerobic process for raw POME treatment; in terms of COD and TSS removal. In order to achieve this objective the following tasks were conducted:

- Development of the lab scale of two-stage anaerobic coupled with single stage aerobic reactor.
  The lab scale of the integrated system was developed and fabricated, with volume of 3.2L and 2.2L for anaerobic digester (AD) 1; and AD2 and aerobic reactor, respectively.
- Sample collection characterization
  The sample was collected from Felda Bukit Besar Palm Oil Mill, and characterized by the following parameters: pH, COD, BOD_5, TSS, sulfate, sulfide, nitrate, nitrite and ammoniacal nitrogen.
- Acclimatization of the bacteria.
  The two-stage anaerobic reactor and single-stage aerobic reactor was inoculated with fresh raw POME. All reactors were inoculated separately for 90 days.

- Integration of the reactors
  Reactors were integrated when the biological stability (in terms of COD and TSS) was achieved.
- Monitoring performance
  The treatment performance of this system was observed and analyzed, which was focusing on the COD and TSS removal. COD and TSS were used to assess treatment efficiency and sludge reduction capacity, respectively. the study was carried out until day 150.

1.5 Significance of the Study

Integrated anaerobic-aerobic bioreactor has been extensively researched in recent years to overcome the incompetency of the conventional method. However, most if not all studies used diluted POME to examine the treatment efficiencies of the integrated system instead of fresh raw POME owing to the high content of lignocellulosic compounds that affects the operation of the bioreactor. With dilution, all components in fresh raw POME were diluted causing the real application of this integrated system questionable. Therefore, this study proposed an integrated two-stage anaerobic coupled with a single stage aerobic system for the treatment of fresh raw POME. According to theoretical principles, lignocellulosic components can be broken down into simpler organic compounds in the first stage anaerobic bioreactor followed by their reduction in the second stage anaerobic and single stage aerobic bioreactors. This solved the potential mechanical problems, which interfered with the operation of the currently available integrated system. In addition, this study was the first to directly treat fresh raw POME using combined biological treatment processes.

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