Faculty of Engineering

Optimization of Factors affecting Chemical Oxygen Demand Reduction from Palm Oil Mill Effluent using Anaerobic Digestion

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Optimization of Factors affecting Chemical Oxygen Demand Reduction from Palm Oil Mill Effluent using Anaerobic Digestion

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DECLARATION

I hereby declare that this thesis is original write-up from my research. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. The thesis has not been accepted for any degree, and not concurrently submitted in candidature of any other degree.

……

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ABSTRACT

This thesis was the outcome of a research conducted on chemical oxygen demand (COD) of palm oil mill effluent (POME) which focused on improving the performance of an anaerobic reactor. This study has addressed COD in POME as the problem to be solved and accordingly, this research was designed to reduce COD level in POME before POME it was discharged to the environment. The study aimed to optimize the factors that affect COD reduction from POME, and it was divided into three specific objectives: (1) determine the significant factors affecting COD reduction from POME, (2) determine the impact of manipulating variables on COD reduction from POME and (3) determine the optimum value of factors that contribute to COD reduction from POME. The novelty of this research was using C/N enriched inoculum from banana peel in a two-stage anaerobic reactor to determine its effects on COD reduction performance of POME A two-stage fermentation process and 350 L lab-scale reactors were used to treat POME. Five input factors were used which include pH, C/N, organic loading rate (OLR), hydraulic retention time (HRT), and sludge retention time (SRT). The Design Expert software was used for data analysis. The research findings found that the significant factors were pH, C/N, and OLR with p-values of 0.0001, 0.0227, and 0.0001 respectively. HRT and SRT also contributed to COD reduction although their contributions were not significant ($p>0.05$). The impact of these five factors was able to contribute up to 80% COD reduction and the lowest value of COD reduction contributed by these five factors is 57%. The findings in surface response diagrams revealed the optimum value of factors that affect COD reduction; 6.5 for pH, 26 for C/N, 8.5 kg/d.m^3 for OLR, 7 days for HRT, 13 days for SRT, and 77% for COD reduction. The developed model was validated, and the results gave an average error within 6.72% and standard deviation error of 3.79%. In this study, banana peel which would normally be discarded upon consumption

was used as inoculum to adjust the C/N to prepare substrate with POME. The findings demonstrated that the addition of banana peel achieved COD reduction up to 77%. Thus, this study justified that further research on POME should be done using different types of substrate and other contributing factors to achieve higher COD reduction from POME.

Keywords: Optimization, chemical oxygen demand reduction, palm oil mill effluent, anaerobic reactor, anaerobic digestion

Pengoptimuman Faktor yang mempengaruhi Pengurangan Permintaan Oksigen Kimia dari Efluen Kilang Kelapa Sawit menggunakan Pencernaan Anaerobik

ABSTRAK

Tesis ini adalah hasil kajian yang dilakukan terhadap permintaan oksigen kimia (COD) efluen kilang kelapa sawit (POME) yang memfokuskan pada peningkatan prestasi reaktor anaerobik. Kajian ini telah menangani COD di POME sebagai masalah yang harus diselesaikan dan dengan demikian, penyelidikan ini dirancang untuk mengurangkan tahap COD di POME sebelum POME dilepaskan oleh kilang. Kajian ini bertujuan untuk mengoptimumkan faktor-faktor yang mempengaruhi pengurangan COD dari POME dan ia dibahagikan kepada tiga objektif khusus: (1) menentukan faktor-faktor penting yang mempengaruhi pengurangan COD dari POME, (2) menentukan kesan manipulasi pemboleh ubah terhadap pengurangan COD dari POME dan (3) tentukan nilai optimum faktor yang menyumbang kepada pengurangan COD dari POME. Keberkesanan dalam penyelidikan ini adalah menggunakan inokulum diperkaya C/N dari kulit pisang dalam reaktor anaerob dua peringkat untuk menentukan kesannya terhadap prestasi penurunan COD POME Proses penapaian dua peringkat dan reaktor skala makmal 350 L digunakan untuk merawat POME. Lima faktor input digunakan termasuk pH, C/N, laju pemuatan organik (OLR), waktu pengekalan hidraulik (HRT), dan waktu penahan lumpur (SRT). Reka bentuk perisian eksperimen (DOE) digunakan untuk analisis data. Hasil kajian mendapati bahawa faktor yang signifikan adalah pH, C/N, dan OLR dengan nilai p masing-masing 0.0001, 0.0227, dan 0.0001. HRT dan SRT juga menyumbang kepada pengurangan COD walaupun sumbangannya tidak signifikan ($p>0.05$). Kesan daripada lima faktor ini dapat menyumbang kepada pengurangan COD sehingga 80% dan nilai pengurangan COD terendah yang disumbangkan oleh lima faktor ini adalah 57%. Penemuan dalam

gambarajah tindak balas permukaan menunjukkan nilai optimum faktor yang mempengaruhi pengurangan COD; 6.5 untuk pH, 26 untuk C / N, 8.5 kg / d.m3 untuk OLR, 7 hari untuk HRT, 13 hari untuk SRT, dan 77% untuk pengurangan COD. Model yang dibangunkan disahkan dan hasilnya memberikan ralat rata-rata dalam 6.72% dan ralat sisihan piawai 3.79%. Dalam kajian ini, kulit pisang yang biasanya akan dibuang apabila dimakan digunakan sebagai inokulum untuk melaraskan C/N untuk menyediakan substrat dengan POME. Penemuan menunjukkan bahawa penambahan kulit pisang mencapai pengurangan COD sehingga 77%. Oleh itu, kajian ini membenarkan bahawa penyelidikan lebih lanjut mengenai POME harus dilakukan dengan menggunakan pelbagai jenis substrat dan faktor penyumbang lain untuk mencapai pengurangan COD yang lebih tinggi dari POME.

Kata kunci: *Pengoptimuman, pengurangan permintaan oksigen kimia, efluen kilang minyak sawit, reactor anaerob, pencernaan anaerobik*

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LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
C/N	Carbon-to-Nitrogen Ratio
CCD	Central Composite Design
CPO	Crude Palm Oil
COD	Chemical Oxygen Demand
CV	Coefficient of Variation
DOE	Design of Experiment
GHG	Greenhouse Gas
HRT	Hydraulic Retention Time
MLSS	Mixed Liquor Suspended Solid
MLVSS	Mixed Liquor Volatile Suspended Solid
OLR	Organic Loading Rate
pH	Potential of Hydrogen
POME	Palm Oil Mill Effluent
RSM	Response Surface Methodology
SRT	Sludge Retention Time
TS	Total Solid
TSS	Total Suspended Solid
VFA	Volatile Fatty Acid
VIF	Variance Inflating Factor
VS	Volatile Solid
VSS	Volatile Suspended Solid
WTE	Waste-to-Energy

LIST OF NOMENCLATURE

Variable	Description	Unit
t	Time	Day or hour or second
V	Volume	m^3 or L
Q	Flow rate	m^3/hr
X_i	Mixed liquor suspended solids	mg/L
Q_x	Excess biosolids removal rate	m^3/d
X_x	MLSS in the excess biosolids flow	mg/L
W	Volatile solid weight	kg
C	Organic carbon content	g/kg VS
N	Nitrogen content	g/kg VS
COD	Chemical oxygen demand	kg COD/m^3

CHAPTER 1

INTRODUCTION

1.1 Study Background

This thesis is an outcome of a research conducted to reduce chemical oxygen demand (COD) of palm oil mill effluent (POME). This work is experimental research which was conducted at operations research laboratory of Universiti Malaysia Sarawak (UNIMAS) by collecting raw POME from Bau palm oil mill. Two state anaerobic digester was operated with banana peel inoculum to decompose COD of POME. Optimization model was used for conducting research in reducing COD from POME.

The oil palm industry is a major agro-industry in Malaysia and is developing as one of the country's important industries. Malaysia is behind Indonesia in terms of the largest producer of this vegetable-based oil. Table 1.1 shows the production of crude palm oil (CPO) in the year 2018 and 2019 (MPOB, 2018, 2019).

Table 1.1: CPO Production in Malaysia for 2018 and 2019 (MPOB, 2018, 2019)

Months	2018 ('000 tonnes)	2019 ('000 tonnes)
January	1,586	1,737
February	1,342	1,544
March	1,574	1,672
April	1,558	1,649
May	1,525	1,671
June	1,332	1,510
July	1,503	1,740
August	1,620	1,821
September	1,853	1,842
October	1,964	1,795
November	1,845	1,538
December	1,808	1,333

It is reported that the plantation of oil palm amounted to 5.90 million hectares of land in 2019, a rise of 0.9% from 5.85 million hectares reported in 2018 (MPOB, 2018, 2019). 26.9% of the total Malaysian oil palm planted area is in Sarawak, while Sabah and Peninsular Malaysia accounted for 26.2% and 46.9% respectively.

In the extraction of CPO and other products, a hazardous effluent is produced known to be POME. The properties of POME are listed in Table 1.2.

Table 1.2: Properties of POME (Zainal et al., 2017)

Parameter	Average value concentration
Chemical oxygen demand (mg/L)	51000
Biochemical oxygen demand (mg/L)	25000
pH	4.2
Total suspended solids (mg/L)	18000
Total volatile solids (mg/L)	34000
Oil and grease (mg/L)	4000–6000
Ammoniacal nitrogen (mg/L)	35
Total nitrogen (mg/L)	750

Untreated POME is acidic in nature and contains an oily residue. The presence of oxygen is required to breakdown the oily mixture which is known as biochemical oxygen demand (BOD). Occasionally, the BOD of untreated POME is hundredfold of that of municipal wastewater (Madaki & Seng, 2013). Raw POME is made up of 95–96% water, less than 5% of total solids, and oil and grease. The production of 1 tonne of CPO produces about 1.0–2.5 m^3 of POME (Ahmad et al., 2015; Jefferson et al., 2016). The temperature of POME when it enters the cooling pond is about 80–90°C. Although POME is a non-toxic effluent, it has an unpleasant odour which can cause nuisance to the neighbourhood of the mills (Chan & Chong, 2019).

Various anaerobic technologies are being used by palm oil mills to treat POME. The common types of anaerobic bioreactors used in treating POME include anaerobic fluidized bed-reactor (AFBR), anaerobic sequencing batch reactor (ASBR), continuous stirred tank reactor (CSTR), expanded granular sludge bed (EGSB), up-flow anaerobic filtration (ABF), up-flow anaerobic sludge blanket (UASB), and up-flow anaerobic sludge fixed film (UASFF) reactors (Poh & Chong, 2009; Ahmad et al., 2015). Due to the advancement in bioprocess engineering, various strategies had been undertaken to improve yields and efficiencies of bioreactors. This has led to the development of new types of reactors such as advanced anaerobic expanded granular sludge bed (AnaEG), anaerobic membrane reactor (AnMBR) and up-flow anaerobic sludge blanket-hollow centred packed beds (UASB-HCPB) (Choong et al., 2018; Aziz et al., 2019). According to Aziz et al. (2019), AnaEG, AnMBR and UASB-HCPB are still in the early stages and further research is required on their operational conditions and effectiveness in treating POME.

Information published on POME related to COD indicates that it is one of the top listed pollutants responsible to damaging water resources and greenhouse gas emission. It was also reported that the performance of anaerobic reactor with higher concentration of carbon-to-nitrogen (C/N) would be significantly higher compared to the traditional COD reduction process (Nurliyana et al., 2015; Raman et al., 2019). On this background, the COD of POME get priority to be reduced before it discharges to water bodies and environment. However, the fundamental theme of this study was to increase the performance of COD reduction from POME by the aid of a two-stage CSTR and C/N enriched inoculum.