UNIVERSITI PUTRA MALAYSIA

SCALED-DOWN BIOGAS PRODUCTION FROM ANAEROBIC TREATMENT OF PALM OIL MILL EFFLUENT

MOHAMAD FIRWANCE BIN BASRI

SCALED-DOWN BIOGAS PRODUCTION FROM ANAEROBIC TREATMENT OF PALM OIL MILL EFFLUENT

By

MOHAMAD FIRWANCE BIN BASRI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Master of Science

March 2007

Dedicated to:

My Loving and Caring Wife

Ernaleza Mahsum

My Cute, Funny and Sweet Children

Muhammad Furqan and Muhammad Farhan

My Loving and Supporting Parents and Parent-in Laws

My father and father-in law who nurtured and gave me strong spirit

Basri Mir and Mahsum Mohd Nooh

and

My mother and mother-in law who cares and understands

Salmiah Mohd Zain and Dayang Norimah Datu Shamsuddin

My Beloved Sister and Brothers

Haslinda, Ahmad Qadri and Mohd Syukri

My Sporting Sisters and Brother-in Laws:

Ernie, Erma, Ermie, Erda, Pija and Pijul

And to ALL

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Master of Science

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March 2007

Chairman: Professor Mohd. Ali Hassan, PhD

Faculty: Engineering

This study is an extension of a 500 m^3 methane recovery test plant study located at Serting Hilir Palm Oil Mill, Negeri Sembilan conducted by our research group on anaerobic treatment of palm oil mill effluent (POME). Biomass washout has become one of the problems faced by our research group because of the continuous mixing of effluent during anaerobic treatment of POME. Therefore, in this study, anaerobic POME treatment using a scaled down 50 L bioreactor which mimics the 500 m^3 bioreactor was carried out to improve biogas production with and without biomass sedimentation.

Three series of experiments were conducted under different conditions in terms of biomass sedimentation applied to the system. The first experiment was operated under semi-continuous mode whereas the second and third experiments were operated based on mix and settle mode system. As expected, by retaining biomass in the bioreactor, there was an improvement on the anaerobic process as the system from the second and third experiments were be able to operate at organic loading rate

(OLR) of 3.5 and 6.0 kg COD/m^3/d, respectively while the first experiment only achieved OLR of 3.0 kg COD/m^3/d. At these OLR value, the hydraulic retention time (HRT) obtained was 10 days in the third experiment and followed by the first and second experiments with 15 days of HRT. The highest biogas production was achieved from the third experiment which was 2.42 m^3/m^3 of reactor/d. This was followed by second and first experiments which were 1.55 and 1.20 m^3/m^3 of reactor/d respectively. The highest methane production rate was also obtained in the third experiment with 0.992 m^3/m^3 of reactor/d as compared to the second and first experiments which were 0.655 and 0.553 m^3/m^3 of reactor/d, respectively. For COD removal, more than 90% of COD was removed for all of the experiments.

The experimental data for the first experiment was applied to the two-stage mathematical model of acidogenesis and methanogenesis which were developed by previous researchers. The first experimental data was used because it represented the actual scenario on how the methane recovery test plant was operated in which biomass washout was taken into consideration. In modelling the behavior of the anaerobic digestion process, the mathematical model was used to simulate the methane production from the anaerobic treatment of POME. From the simulation result, the model was shown to be satisfactory for simulating methane production from the anaerobic treatment of POME.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENURUNAN SKALA PENGHASILAN BIOGAS DARI RAWATAN ANAEROBIK EFLUEN KILANG MINYAK SAWIT

Oleh

MOHAMAD FIRWANCE BIN BASRI

Mac 2007

Pengerusi: **Profesor Mohd. Ali Hassan, PhD**

Fakulti: **Kejuruteraan**

Kajian ini adalah lanjutan kepada kajian 500 m^3 Loji Ujian Pemulihan Metana yang terletak di Kilang Sawit Serting, Negeri Sembilan yang dijalankan oleh kumpulan penyelidikan kami untuk rawatan anaerobik efluen kilang minyak sawit. Kehilangan biojisim semasa rawatan anaerobik efluen kilang minyak sawit telah menjadi salah satu dari masalah yang dihadapi oleh kumpulan kami disebabkan oleh pencampuran efluen yang selanjar. Oleh yang demikian, di dalam kajian ini, rawatan anaerobik efluen kilang minyak sawit telah dijalankan menggunakan bioreaktor 50 L yang menyerupai bioreaktor 500 m^3 bagi memperbaiki penghasilan biogas pada keadaan pemendakan biojisim dan tanpa pemendakan biojisim.

Sebanyak tiga siri eksperimen telah dijalankan pada keadaan berbeza dari segi pemendakan biojisim yang diaplikasikan kepada sistem tersebut. Eksperimen pertama telah dijalankan di bawah mod separa selanjar manakala eksperimen kedua dan ketiga dijalankan berdasarkan sistem mod campur dan mendak. Seperti yang dijangkakan, dengan mengekalkan biojisim di dalam bioreaktor, ianya dapat

memperbaiki proses anaerobik kerana sistem dari eksperimen kedua dan ketiga dapat dijalankan pada kadar bebanan organik 3.5 dan 6.0 kg COD/m^3/hari masing-masing manakala eksperimen pertama hanya memperolehi kadar bebanan organik 3.0 kg COD/m^3/hari sahaja. Pada nilai kadar bebanan organik ini, masa tahanan hidraulik 10 hari diperolehi bagi eksperimen ketiga dan diikuti oleh eksperimen pertama dan kedua iaitu dengan masa penahanan hidraulik 15 hari. Kadar penghasilan biogas tertinggi diperolehi dari eksperimen ketiga iaitu 2.42 m^3/m^3 reaktor/hari. Ini diikuti oleh eksperimen kedua dan pertama iaitu 1.55 dan 1.20 m^3/m^3 reaktor/hari masing-masing. Kadar penghasilan metana tertinggi juga diperolehi dari eksperimen ketiga iaitu 0.992 m^3/m^3 reaktor/hari berbanding dengan eksperimen kedua dan pertama iaitu 0.655 dan 0.553 m^3/m^3 reaktor/hari masing-masing. Bagi penyingkiran COD, lebih dari 90% COD disingkirkan untuk semua eksperimen.

Data eksperimen pertama telah diaplikasikan kepada model matematik dua peringkat iaitu asidogenesis dan metanogenesis yang mana telah dibangunkan oleh penyelidik-penyelidik sebelum ini. Data eksperimen ini telah digunakan adalah kerana ianya menyerupai senario sebenar bagaimana Loji Ujian Pemulihan Metana telah dikendalikan yang mana mengambil kira kehilangan biojisim. Di dalam permodelan sifat proses pencernaan anaerobik, model matematik telah digunakan untuk mensimulasikan penghasilan metana dari rawatan anaerobik efluen kilang minyak sawit. Dari keputusan simulasi, model tersebut telah menunjukkan keputusan yang memuaskan untuk mensimulasikan penghasilan metana dari rawatan anaerobik efluen kilang minyak sawit.

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I certify that an Examination Committee has met on the 23rd March 2007 to conduct the final examination of Mohamad Firwance bin Basri on his Master of Science thesis entitled "Scaled-Down Biogas Production from Anaerobic Treatment of Palm Oil Mill Effluent (POME)" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the Candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the Degree of Master of Science. The members of the Supervisory Committee are as follows:

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Date: 14 JUNE 2007

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

MOHAMAD FIRWANCE BIN BASRI

Date:

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LIST OF ABBREVIATIONS

μ	Specific growth rate
μ_1	Acidogenic bacteria specific growth rate
μ_2	Methanogenic bacteria specific growth rate
μ_{max1}	Maximum acidogenic bacteria specific growth rate
μ_{max2}	Maximum methanogenic bacteria specific growth rate
A	Total acetic acid concentration
A_o	Influent total acetic acid concentration
AH	Unionized acetic acid concentration
AFBR	Anaerobic fixed bed reactors
AN	Ammoniacal Nitrogen
APB	Acid producing bacteria
BOD	Biological oxygen demand
COD	Chemical oxygen demand
CSTR	Continuous stirred tank reactor
D	Dilution rate
D	Diameter
EFB	Empty fruit bunch
F	Volumetric loading rate
FELDA	Federal Land Development Authority
FF	Fixed film
FFB	Fresh fruit bunch
GHG	Greenhouse gases
GI	Galvanize iron

H	Height
H^+	Hydrogen ion concentration
HRT	Hydraulic retention time
K_e	Dissociation constant for acetic acid at 35^{o}C
K_{d1}	Decay constant for acidogenic bacteria
K_{d2}	Decay constant for methanogenic bacteria
K_{im}	Inhibition constant of acetic acid (expressed as unionized acid) on methane production
K_{ix1}	Inhibition constant of acidogenic bacteria growth (expressed as unionized acetic acid)
K_{ix2}	Inhibition constant of methanogenic bacteria growth (expressed as unionized acetic acid)
K_m	Saturation constant of methane production (expressed as unionized acetic acid)
K_{x1}	Saturation constant in the expression of acidogenic bacteria grwoth
K_{x2}	Saturation constant for the methanogenic bacteria growth (expressed as unionized acetic acid)
O & G	Oil and grease
OLR	Organic loading rate
ppm	Part per million
POME	Palm oil mill effluent
PVC	Polyvinyl chloride
S	Glucose equivalent concentration
S_o	Influent glucose equivalent concentration
SHI	Sumitomo Heavy Industries
SMAHS	Submerged membrane adsorption hybrid system
SS	Suspended solids

STR	Stirred tank reactor
t	Time
TN	Total nitrogen
TS	Total solids
UASB	Up-flow anaerobic sludge blanket
UASFF	Up-flow anaerobic sludge blanket fixed film
v/v	Volume per volume
VFA	Volatile fatty acid
V_m^{max}	Maximal production rate of methane per weight of methanogenic bacteria per day
V_R	Bioreactor working volume
X_1	Acidogenic bacteria concentration
X_2	Methanogenic bacteria concentration
X_{o1}	Influent acidogenic bacteria concentration
X_{o2}	Influent methanogenic bacteria concentration
Y_{as}	Maximum yield of glucose conversion to acid
Y_{so}	Maximum yield of glucose
Y_{x1s}	Maximum growth yield of acidogenic bacteria on glucose
Y_{x2a}	Maximum growth yield of methanogenic bacteria on acetic acid

CHAPTER 1

INTRODUCTION

Palm oil is one of the main commodities in world trade. Malaysia was the largest palm oil producer in the world in 2004 with 12.6 million tonnes of production, which was about 52 per cent of the total world palm oil production (MPOB, 2005a). The total exports of oil palm products produced by Malaysia, constituting palm oil, palm kernel oil, palm kernel cake, oleochemicals and finished products increased marginally by 3.1% or 0.53 million tonnes from 16.82 million tonnes in 2003 to 17.35 million tonnes in 2004 (MPOB, 2005b).

With such a huge production, palm oil industry generate large amount of by-products such as shells, fibers, kernels, empty fruit bunches (EFB) and palm oil mill effluent (POME). Basically, most of these wastes can be used as a renewable energy source and other value-added by-products. POME is the largest palm oil industry by-products, it is high in chemical oxygen demand (COD) and biological oxygen demand (BOD) content and could create environmental problems if it is not properly treated. On the other hand, it is a potential renewable energy source if it is treated anaerobically to produce methane. Methane can be used as fuel to generate electricity.

In Malaysia, various treatments have been used to treat POME in order to meet the department of environmental (DOE) discharge standard. Anaerobic treatment of POME is widely used because of its low operation cost. During anaerobic treatment, large amount of methane (CH_4) and carbon dioxide (CO_2) are produced, which is harmful to the environment but can be used as renewable energy source. The uncontrolled release of CH_4 and CO_2 to the atmosphere can cause greenhouse gases (GHG) effect.

Biogas is a mixture of colourless flammable gases obtained by anaerobic digestion of plant based (lignocellulosic) organic waste materials and also from other type of organic waste such as cow dung, pig slurry, effluent from slaughter house and landfill. Biogas from anaerobic decomposition comprising methane, carbon dioxide and a small amount of nitrogen (N_2), hydrogen (H_2) and hydrogen sulfide (H_2S) (Price, 1985).

Currently, our research group has conducted and still pursuing research on anaerobic treatment of POME for biogas production. A 500 m^3 pilot plant for biogas production research was constructed in year 2004 (Yacob, 2005). As for this study, a scaled down 50 L bioreactor was designed and fabricated based on the design of the 500 m^3 pilot plant bioreactor. By having a small scale bioreactor, different operations parameters can be tested and studied in order to achieve optimum operations. Moreover, it is much easier to change and manipulate operational conditions for a small bioreactor as compared with a large scale bioreactor. As reported by Yacob (2005), biomass washout from the 500 m^3 during anaerobic treatment of POME has become one of the problems faced in his study because of the continuous re-circulation of effluent. This has caused fully suspended of solid which then contributed to biomass washout. Yacob (2005) recommended that the mixing should be stopped at least 2-3 hours before loading to encourage the solids to settle down thus reducing the washout of biomass. Therefore, in this study, series of experiments were conducted at different conditions of biomass sedimentation which could improve biogas production by increasing anaerobic POME treatment performance using the 50 L scaled down bioreactor.

Theoretically, anaerobic digestion can be modelled and formulated mathematically using differential equations. Even though anaerobic digestion is a complex process, model simplicity is always taken as an approach to solve the modeling of the process. Currently, numbers of anaerobic models had been published and widely accepted (Havlik *et al.*, 1986; Moletta *et al.*, 1986). These models can be used to simulate methane production rate, pH, alkalinity and so on of anaerobic digestion.

In this study, the objectives are:

1. To optimize anaerobic treatment of POME in the 500 m^3 pilot plant to improve biogas production from anaerobic treatment of POME with and without biomass sedimentation by using a 50 L bioreactor.

2. To simulate biogas (CH_4) production of anaerobic treatment of POME using established mathematical model.

CHAPTER 2

LITERATURE REVIEW

2.1 Palm Oil

Palm oil is extracted from the palm fruits *Elaeis guineensis*. In its virgin form, the oil is bright orange-red due to the high content of carotene. Malaysia is currently the world's largest palm oil exporters in the world. In 2004, it produces 12.6 million tonnes of palm oil, which is about 52 per cent of the total world palm oil production (MPOB, 2005a). Malaysia is so lucky to be the largest producer of this commodity because palm oil is one of the main sources of edible oils in the world besides corn oil, coconut oil, soybean oil and olive oil.

2.2 Palm Oil Mill Effluent (POME)

In the palm oil extraction process, a considerable amount of water is used (Agamuthu, 1995), leading to the generation of large volumes of wastewater, known as palm oil mill effluent (POME). Figure 2.1 shows the normal schematic flow diagram of a palm oil mill. During palm oil extraction, about 1.5 tonnes of palm oil mill effluent is produced per tonne of fresh fruit bunch (FFB) processed (Ahmad *et al.*, 2003). POME is generated from the sterilization and clarification processes and in hydrocylone operation where the broken shells are separated from the kernels (Basiron and Darus, 1995) as can be seen in Figure 2.1.

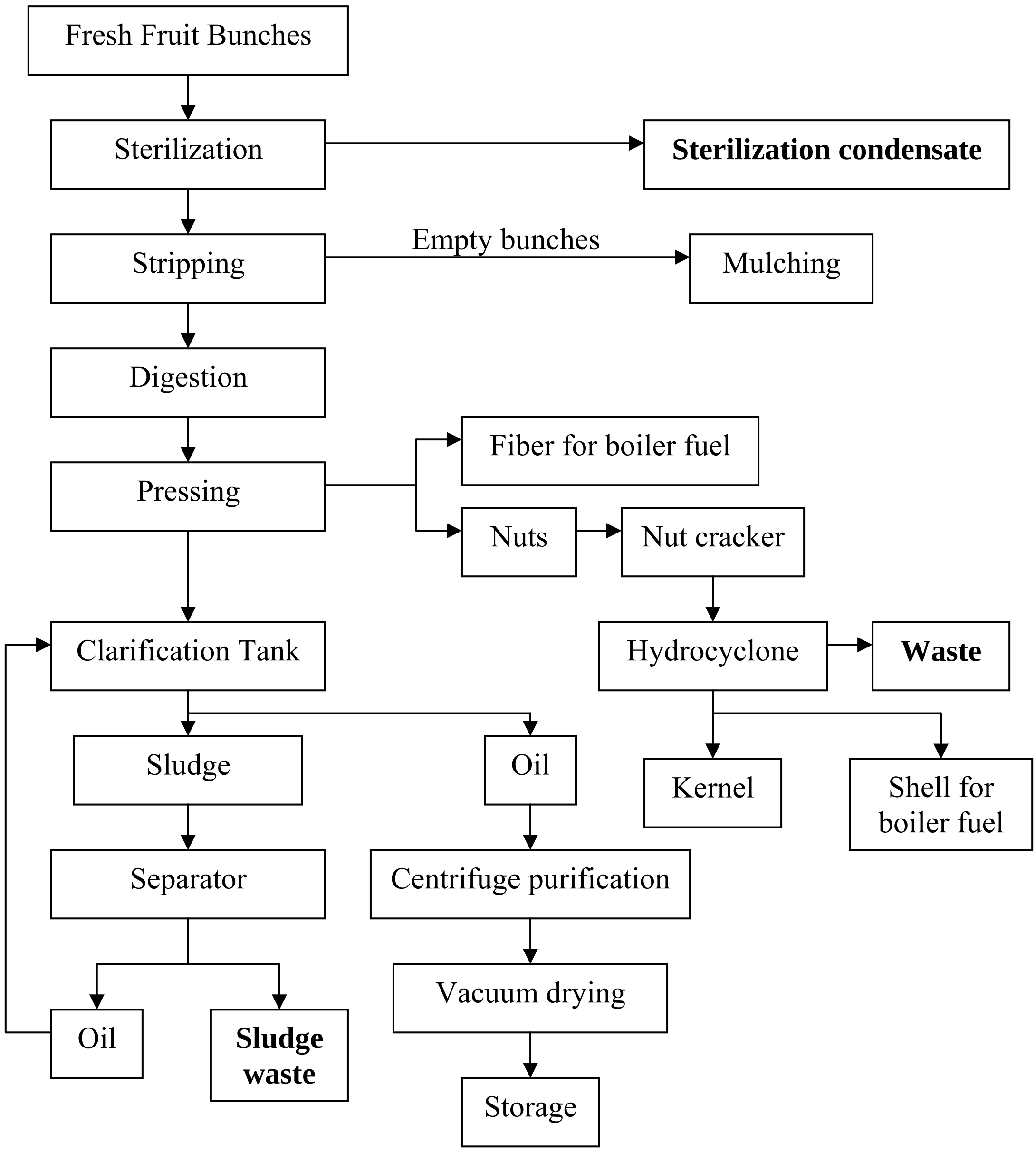

Figure 2.1: Schematic flow diagram of processing normally carried out in a palm oil mill (Basiron and Darus, 1995)

POME is a thick brownish liquid with average chemical oxygen demand (COD) and biochemical oxygen demand (BOD) values of 50 000 and 25 000 mg/l, respectively. It is discharged at a temperature of 80-90^{o}C and has a pH typically between 4 and 5 (Ma and Halim, 1988; Polprasert, 1989; Singh *et al.*, 1999). The characteristics of POME are shown in Table 2.1 (Basiron and Darus, 1995).