PRODUCTION OF METHANE GAS BY ULTRASONIC MEMBRANE SYSTEM (UMAS) USING PALM OIL MILL EFFLUENT (POME) AS A SUBSTRATE

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SUPERVISOR'S DECLARATION

"I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering (Gas Technology)."

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STUDENT'S DECLARATION

"I declare that this thesis entitled "Production of Methane Gas by Ultrasonic Membrane Anaerobic System (UMAS) Using Palm Oil Mill Effluent (POME) as A Substrate" is the result of my own research except as cited in references. The thesis has not concurrently submitted in candidature of any other degree."

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Dedicated to my beloved parents

Awang Long bin Awang Puteh & Rosnani binti Ani

And my brothers.

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PRODUCTION OF METHANE GAS BY ULTRASONIC MEMBRANE SYSTEM (UMAS) USING PALM OIL MILL EFFLUENT (POME) AS A SUBSTRATE

ABSTRACT

This study is mainly focusing on methane production from palm oil mill effluent (POME) by using Ultrasonic Membrane Anaerobic System (UMAS). Design of anaerobic reactor was applied in order to design experimental work which is 100 mL volume digester of Ultrasonicated Membrane Anaerobic System (UMAS). The six kinetic parameters of UMAS such as COD, BOD, pH and TSS were studied. Reactor was operated under ambient temperature within the range ~30 to 35 ˚C. POME will be continuous up-flow feeding from the side flow into the anaerobic reactor and effluent samples will be taken from the reactor after 5 hours for analysis of the parameters at each batch of HRT. The start-up of the UMAS reactor was involved step increasing in influent organic volumetric loading rates from higher retention time to lower retention time of 392.16, 128.21, 119.05, 111.11, and 98.04 days. The acclimatization was done within 4 to 9 days to allow all the microorganisms present in the mixed liquor perfectly acclimatized to the new environmental. Mixture of methane and carbon dioxide gases produced was collected by using syringe. NaoH or KOH was filled in the syringe in order to adsorb the carbon dioxide from the methane gas. It is expected that the developed UMAS can be the effective process that has more excellent performance in methane production by encountering the membrane fouling hence decreased the retention time. Meanwhile, the five kinetic parameters listed such as COD content can be reduced up to 86% reduction from the original by complete treatment.

PENGHASILAN GAS METANA OLEH SISTEM MEMBRAN ANAEROBIK BERULTRASONIK MENGGUNAKAN BAHAN BUANGAN MINYAK SAWIT (POME) SEBAGAI SUBSTRAT

ABSTRAK

Penyelidikan ini dijalankan untuk mengkaji penghasilan gas metana daripada bahan buangan miyak sawit (POME) dengan menggunakan Sistem Membran Anaerobik Berultrasonik (UMAS). Rekaan reaktor anaerobik digunakan dalam menghasilkan eksperimen iaitu pencerna UMAS berisipadu 100 mL. Lima parameter kinetik UMAS seperti COD, BOD, pH, dan TSS turut dikaji. Reaktor dioperasikan dengan bersuhukan suhu persekitaran di antara ~30 ke 35 °C. POME dimasukkan secara berterusan ke sisi reaktor anaerobik dan sampel efluen di ambil daripada reaktor selepas 5 jam untuk menganalisa parameter-parameter pada setiap masa tahanan hidraulik (HRT). Untuk permulaan, reaktor UMAS melibatkan peningkatan dalam kadar influen muatan isipadu organik daripada masa tahanan tinggi ke masa tahanan rendah iaitu 392.16, 128.21, 119.05, 111.11, dan 98.04 hari. Fasa penyesuaian dilakukan di antara 4 hingga ke 9 hari untuk membolehkan semua mikroorganisma yang hadir dalam campuran cecair menyesuaikan diri dengan sempurna dengan persekitaran yang baru. Campuran gas metana dan karbon dioksida yang terhasil dikumpul dengan menggunakan picagari. NaOH atau KOH dimasukkan ke dalam picagari untuk menyerap karbon dioksida daripada gas metana. Ia dijangkakan bahawa dengan adanya UMAS boleh menjadi proses efektif yang lebih bagus dalam menghasilkan gas metana dengan mengambil kira pencemaran membran dan mengurangkan masa tahanan. Sementara itu, lima parameter yang disenaraikan seperti kandungan COD boleh dikurangkan sehingga 86 % daripada rawatan lengkap yang sebenar.

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LIST OF SYMBOLS/ABBREVIATIONS

BOD	Biochemical Oxygen Demand (mg/L)
CH_4	Methane
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand (mg/L)
cm	centi meter
HRT	Hydraulic Retention Time (day)
h	hour
MAS	Membrane Anaerobic System
MF	Microfiltration
NH_3	Ammonia
OLR	Organic Loading Rate
POME	Palm Oil Mill Effluent
TSS	Total Suspended Solid (mg/L)
UF	Ultrafiltration
UMAS	Ultrasonic Membrane Anaerobic System

CHAPTER 1

INTRODUCTION

This chapter will give the ideas about the significant of the research formulation. The first chapter will cover up the subtopic of background of study or information, problem statement, research objectives, scope of proposed research, expected outcomes and significance of the proposed research.

1.1 Background of Study

POME wastewater generated from palm oil milling activities and it is conventionally anaerobically using ponding systems or with open digesting tanks (Ma *et al.,* 2003). Raw POME can be defined as a thick brownish colloidal suspension with pH 4-5, non toxic but has unpleasant odor and comprise 95-96% water, 0.6-0.7% oil and 4-5% total suspended solids including 2-4% suspended solids, mainly consisted of debris from palm fruit mesocarp originated from the three main sources which is sterilizer condensate (36%), separator sludge or clarification (60%) and hydrocylone or cyclone waste unit (4%). Approximately 0.65 tonnes of

raw POME is produced for every ton of fresh bunches (FFB) processed. In 2003, a total of 2,106,956 tonnes of FFB were processed, resulting in 1,369,521 tonnes of POME being produced. Generally, POME treatment plants are operated on two-phase anaerobic digestion process and followed by extended aeration process. According to theory, POME can be used as a substrate for anaerobic digestion to produce methane gas because of high contents of organic substances with negligible inhibitory substances (Najafpour *et al.,* 2006; Borja and Banks, 1994, 1995; Faisal and Unno, 2011; Choorit and Wisarnwan, 2007). Lam and Lee (2011) performed a study about the strategies to reduce the environmental problems initiated by POME coupled with renewable energies generation such as biomethane and biohydrogen besides to further strengthen the concepts of the palm oil sustainability announced by Malaysian Palm Oil Board (MPOB) and Malaysian Palm Oil Council (MPOC).

Technology of membrane is expected to provide good and excellent performance in industrial gas application such as oil refinery industries, gas industries and also petrochemicals industries ("Membrane gas separation," n.d.). This technology also has become one of the advanced technologies which undergo a fast growth during a past few decades. Foo (2010) stated that Abbe Nollet is a chemist that firstly studied about membrane technologies in 1748 and proceed with invention by Sourirajan in 1960 membrane technology is said to be achieved the golden age. Membrane has also been proven can be used widely in the chemical industrial especially in gas separation process. In treating POME, usually anaerobic stabilization ponds are widely used because of their low capital and operating cost. However, foul smell generated from anaerobic ponds is disturbed the surrounding community. Another efficient treatment system is the closed anaerobic digester tank

that becomes more popular at present. Furthermore, biogas from the closed treatment system can be further utilized as fuel which is methane gas (Puetpaiboon and Chotwattanasak, n.d.)

1.2 Problem Statement

Methane gas is listed as good alternative to gasoline combustion because it breaks down to CO_2 and water when burned in combustible engines. Methane burns clean and can be generated form organic wastes which is plentiful in households across the modern world. By using methane digesters, thousands of tons of landfill waste that produce methane can be eliminate because these landfill wastes may caused global warming and the reduction of fossil fuels use for the purpose of transportation. Treating POME using anaerobic digestion plants will generate methane, which can be converted to electricity.

Palm oil mills generate an effluent highly contaminated with organic matter (COD around 50,000 mg/L). The conventional system employed for effluent treatment consists in a set of open anaerobic lagoons as it is the most extensive cost-efficient system as long as land is cheap. In order to reach removal efficiencies of 99% of the initial organic load, these systems must be well designed, operated and maintained. this is because there are some primary problem that have been registered with the actual traditional systems in operation such as uneasy oil recovery, groundwater contamination, lagoon clogging due to sludge accumulation as well as frequent acidification. Treating POME in a series of open lagoons at high

temperatures, results in the uncontrolled production of methane and carbon dioxide, which are both green houses gases.

As the technologies keep changes, this treatment system has been replaced with the membrane technologies that widely used nowadays for the creation of process water from groundwater, surface water or wastewater. Membrane Anaerobic Treatment (MAS) have been introduced in order to provide good treatment in treating POME but this technology has been limited due to the membrane fouling problem. The main force of membrane technology is the fact that it works without the addition of chemicals and with a relatively low energy used. Hence, to clean fouling a new approach will be experimentally investigated in the POME membrane base treatment process.

An ultrasound is applied to the MAS to create high intensity wave in order to produce cavitations form membrane cleaning. A large area of membrane can be swept away for cleaning process. In particular, sonication approach also will be applied to reduce fouling because chemicals and chemicals handlings are not necessary besides can be used for both large and small-scale systems. This technique also could be applied during normal condition; hence there is no recorded time for cleaning process.

1.3 Research Objectives

i. To analyze the application of UMAS in wastewater.

ii. To examine the efficiency of UMAS in production of methane by treating POME.

iii. Production of Methane gas (CH_4) by investigating the kinetic parameters of UMAS.

1.4 Scope of Research Proposed

i. To design a 100 mL volume digester of Ultrasonicated Membrane Anaerobic System (UMAS).

ii. To experimentally access the influence of retention time at organic loading rates on performance of UMAS.

iii. To investigate the kinetic parameters of UMAS such as COD, BOD, pH and TSS.

1.5 Expected Outcomes

Even though ultrasound applications are not widely explored in water and wastewater treatment, employing UMAS instead of MAS and incorporated with substrate of POME will obtain effective processes that have more excellent performance in production of CH_4.

1.6 Significance of the Proposed Research

This research utilized POME as substrate in order to produced methane gas by using UMAS. MAS process was performed in the previous studies and identified that this process retained and due to long solids retention times liquefied and decomposed all particular matter. Hence, this study is important to make improvements towards MAS by adding ultrasound using the ultrasonic retention aims to encounter the membrane fouling. Biogas methane from POME treatment is identified as a clean renewable gaseous fuel which can be used commercialized for steam, power and generation ("Palm mill wasted," 2011). Besides turning dirty gas into clean energy, capturing methane from POME can reduce air pollution. According to Ching (2010) nowadays palm oil millers have two choices in running biogas plants which is: (a) methane produced can be converted into electricity and fed into power gird, owned by Tenaga Nasional Bhd (TNB) and (b) methane produced can be injected into the pipeline, owned by Gas Malaysia Sdn Bhd.

1.7 Conclusion

This chapter discussed seven parts of the introduction. The background of study was discussed in the first part. The background of study was discussed in the first part. The next part the problem statement is discussed and followed by research objectives, research questions, scopes of proposed research, and also expected outcomes. Lastly, the significance of the proposed research is explained.

CHAPTER 2

LITERATURE REVIEW

2.1 Chapter Overview

There are four sections in this literature review. First, the introduction of methane as the main composition biogas is discussed. Second, a summary review of the anaerobic digestion is elaborated. POME characterizations are analyzed in the third sections and finally in the final sections, principles of ultrasound are being explained.

2.2 Methane as the Main Composition in Biogas

The most inert hydrocarbon, methane (CH_4) is one of the major components of biogas besides carbon dioxides (CO_2) (Ferreira-Aparicio, 2002). It is widely used in the UK, Europe and USA and holds the characteristics of colourless, odourless, flammable gas and the main constituent, 85 % to 90 %. Processing methane by

anaerobic digestion is quite similar to natural gas that is extracted from the wellhead and piped to our homes ("Methane production guide," n.d.). Natural gas will always have a higher calorific value than the pure methane since it varies in hydrocarbons other than methane itself which it ethane, propane and butane. Generally, content of methane for biogas is between 55 - 80 % depending on the process of digestion and the remaining composition is dominantly carbon dioxide, with trace quantities (0-15,000 ppm) of corrosive hydrogen sulphide and water. Methane is identified more effective 20 times in trapping heat in the atmosphere compared to the carbon dioxide CO_2 over a 100-yaer period (Environmental Protection Agency, 2010). Thus, utilizing renewable energy such as methane can prevent its release to the atmosphere and can be employed to obtain Certified Emission Reduction (CFR) credit by Clean Development Mechanism (CDM) under Kyoto protocol (Poh and Chong, 2009).

2.2.1 Methane Production by Anaerobic Digestion

One of the most common chemical processes in nature is that anaerobic digestion. Anaerobic can be defined as the decay or breakdown in the absence of air or more specifically oxygen and this process is identified similar to fermentation. In 17th century, Jan Bapita Van Helmont was the first person who's determined the flammable gases could evolve from decaying organic matter. Then, in 1776 Count Alessandro Volta make a conclusion and pointed out that there was a direct correlation between the amount of decaying matter and the amount of flammable gas produced. While Sir Humphry Davy determined that the methane was present in the gases produced during the anaerobic digestion of cattle manure. Digestion via anaerobic has been successfully demonstrated for its ability to recycle biological

wastes hence produce biogas (Abraham *et al.,* 2007; Mshandete, 2009). Sewage and agricultural waste especially consists many nutrients for the anaerobes and generally composition of substrates plays a dominant role in determining methane yield and rates of production (Saleh *et al.,* 2011). There are six typical composition of biogas from digestion via anaerobic is methane (CH_4) 60 %, carbon dioxide (CO_2) 35 %, hydrogen sulphide (H_2S) 3 %, hydrogen (H_2) 1 % and ammonia (NH_3) or other gases 5 % (Monnet, 2003; Khanal, 2008; Wooster, 2009). The residual is called digestate which rich in nutrients and can be a good source for soil amendments or liquid fertilizers. In 1859, the first digestion plant was built at a leper colony in Bombay India and it was reported that anaerobic digestion reached England in 1895 when biogas was recovered from a sewage treatment facility and the fuel used to the street lamps in Exeter. The microbiology development led Buswell and others to research more in order to identify anaerobic bacteria and the conditions that promote to the production of methane. Term swamp gas is always used as methane gas produced by anaerobic digestion and gas made with a digester is called biogas.

Generally conventional systems of anaerobic digestion are operated under conditions of continuous darkness. However, methane production was lower than that in continuous darkness whereby phototropic bacteria that grew up in the LUASB reactor will use electron donors and compete with methanogens, thus leading to a decreased methane yield (Tada and Sawayama, 2004). Mountfort and Asher (1987) purport that in an anaerobic digester, methane manufactured by acetate usually accounts for 60 – 80 % of the total. Since there are some studies about methane production by anaerobic digestion (biogas plants) under illumination especially regarding optimum light condition (Yang *et al.,* 2004), hence Yang *et al*. (2009)

performed a paper reports on an effective and appropriate illumination time for activating methanogens for the photoenhancement of methane production by using thermophilic (55 ˚C) anaerobic digestion and acetate as the sole carbon substrate. By providing the system under optimum operating conditions, the anaerobic digestion process is highly stable, economical, and requires relatively small space. Besides it consists of low and stabilized sludge with high dewaterability and high tolerance toward xenobiotics, and 10 - 20 % of COD is removed (Lettinga, 1995; Droste, 1997; Eddy, 2003). Saleh *et al.* (2011) experimentally identify and optimize factors such as temperature, sludge volume as inocolum, POME volume, and co-substrate addition including oil palm EFB, kernel and shell, for an anaerobic digestion process to produce biomethane. Wu *et al.* (2006) in their study used pre-filtered POME as a production medium for protease production by a local wild-type *Aspergillus terreus* in order to examine the possible utilization of the recovered and concentrated protein. Sulaiman *et al.,* (2009) experimentally investigated the digester performance in terms of COD removal efficiency and biogas productivity primarily methane when the digester is subjected to natural mixing (NM), minimal horizontal mixing (MHM), minimal horizontal and vertical mixing (MHVM) and vigorous mixing (VM) regimes. Apart from numerous studies done a lot of researches in order to improve the methane gas production, the number of anaerobic digesters in the EU has increased dramatically (Sulaiman *et al.,* 2009; Xie *et al.,* 2011). Anaerobic digestion involves the degradation of complex organic matter by a consortium of microorganisms or microbes which can be classified along with a series of metabolic pathways and leading to an energy-rich biogas which can be used as renewable energy such as methane in order to replace fossil energy sources (Pavlostathis and Giraldogomez, 1991; Raposo, 2011). According to Takiguchi *et al.* (2000) the

volume of waste sludge can be reduced by anaerobic digestion and produce methane gas that can be utilized in supplying the thermal energy requirement in wastewater treatment facilities.

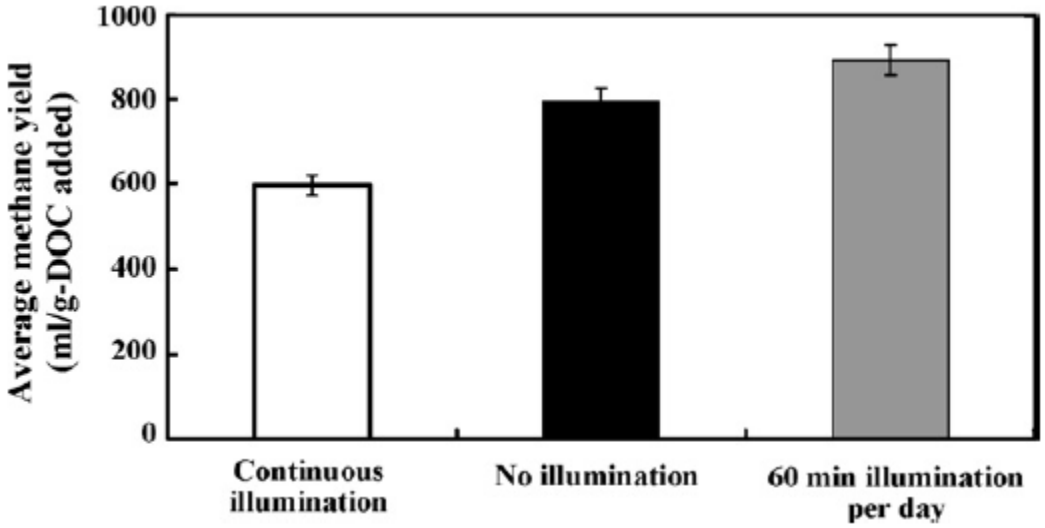

Figure 2.1: Average methane yield under different illumination conditions during semi-continuous operation period (Yang *et al.,* 2009)

2.3 Anaerobic Digestion

Anaerobic digestion can be defined as a biochemical technological process for the treatment of organic substrates such as sewage and industrial effluents, animal manures and solid substrates including energy crops, agricultural residues and food wastes (Raposo *et al.,* 2011). Anaerobic digestion is one of the most widely used processed in the world and aims to stabilize the biosolid waste such as from the agro and municipal waste to industrial waste as well as for the treatment of organic sludge in waste water treatment facilities (Björnsson, 2000; Hartman and Ahring, 2005; Davidsson *et al.,* 2007; Comino *et al.,* 2009; Lin *et al.,* 2011). Chen *et al.,* (2008)

purport that this type of digestion is a method engineered to decompose organic matter by a variety of anaerobic microorganisms under oxygen-free conditions. The final product of anaerobic digester includes biogas which is 60 – 70 % methane and an organic residue rich in nitrogen. Since having the capability in reducing chemical oxygen demand (COD) and biological oxygen demand (BOD), the technology of anaerobic digestion has been successfully implemented in the treatment of agricultural wastes, food wastes, and wastewater sludge. It has already established as a reliable technology in Europe and Asia and used to treat more than 10% in organic waste in several European countries (De Baere, 2000). The major reactions of the anaerobic digestions are shown in Figure 2.2.

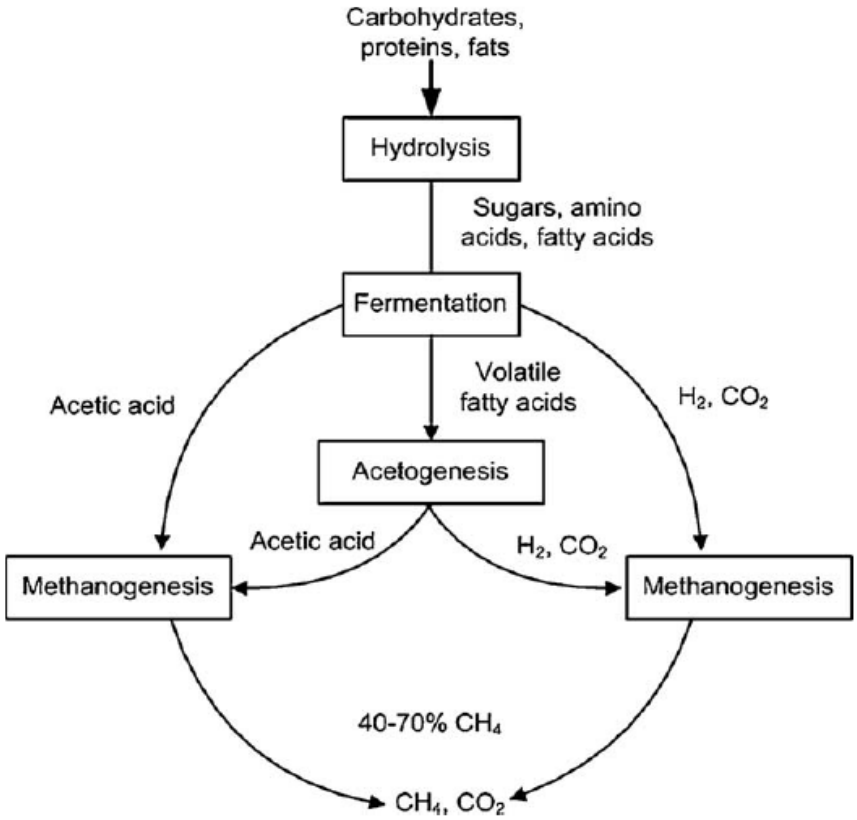

Figure 2.2: Process flow of the Degradation of Organic Material through Anaerobic Digestion (Li *et al.,* 2011)

From Figure 2.2, hydrolysis occurs at the beginning of anaerobic digestion reducing complex organic polymers to simple soluble molecules by extracellular enzymes. Hydrolization of protein, lipids and carbohydrate polymers into amino acids, long-chain fatty acids and sugars occurs respectively. By fermentative bacteria, the reduced compounds are then converted to a mixture of short chain volatile fatty acids (VFAs) and other side products such as CO_2, H_2 and acetic acid. Acetogenic bacteria further convert the organic acids to acetate, CO_2, and/or H_2 which are the direct substrates of production of methane (Gerardi, 2003). A variety of methanogenic bacteria consume acetate, CO_2, and H_2 to produce methane in the final step which known as methanogenesis. Due to its sensitivity to feedback inhibition by acidic intermediates, methanogenesis become the primary focus in many anaerobic digestions (Li *et al.,* 2011).

2.4 POME Characterizations

Oil palm wastes are widely studied as the resource of biomass for technology of anaerobic digestion technology (Lorestani, 2006). In palm oil industry, in order to produce 1 ton of crude palm oil, 5 - 7.5 ton of water are required and 50 % of water will generates as palm oil mill effluent (POME) and by average 0.9 – 1.5 and 0.1 m^3 of POME is generate for each ton (Ma and Ong, 1988) of crude palm oil produced. Raw POME can be defined as a thick brownish colloidal suspension with pH 4-5, non toxic but has unpleasant odor and comprise 95 - 96% water, 0.6 - 0.7 % oil and 4 - 5 % total suspended solids including 2 - 4 % suspended solids, mainly consisted of debris from palm fruit mesocarp originated from the three main sources which is

sterilizer condensate (36%), separator sludge or clarification (60%) and hydrocylone or cyclone waste unit (4%) (Khalid and Wan, 1992; Borja and Banks, 1994;; Ahmad *et al.,* 2003; Vijayaraghavan and Ahmad, 2006; Lorestani, 2006; Wu *et al.,* 2007; Vijaya *et al.,* 2008; Poh and Chong, 2009). Generally POME is generated from oil milling activities and conventionally treated anaerobically using ponding systems or with open digesting tanks (Ma *et al.,* 2003). Latex adsorption, coagulation-flocculation, and activated carbon treatment have been introduced (Ahmad *et al.,* 2003, 2005; Prasertsan *et al.,* 1997) as the pre-treatment processes for POME but the problem is the potential bioresources in the POME might be greatly decreased along with chemical and adsorption processes.

2.4.1 POME in Anaerobic Digestion

Anaerobic digestion can be considered as one of the sources of renewable energy since have the ability to digests the high-strength complex wastewater with total COD (can reach up to 94 kg m^{-3}) by consuming lower energy consumption and most valuable things in generating renewable energy in the form of methane (Vijayaraghavan and Ahmad, 2006; Ismail *et al.,* 2010; Alrawi *et al.,* 2011). Culturing microalgae for biodiesel and bioethanol production by using POME combined with wastewater treatment were proposed as a new method to enhance production of renewable energies from palm oil mills (Lee and Lam, 2011). Poh and Chong (2011) mentioned that the application of high rate anaerobic bioreactors to replace conventional treatment methods for POME treatment has rising up due to the fact that these high-rate anaerobic bioreactors had smaller foot prints, better in producing treated effluent quality and greater volume of biogas with higher purity of

methane which can be benefit to human being. Screening and identification of the microbes in the mixed culture is essential in identifying the key methanogens which were responsible for the methane production from POME. There are some distinct advantages in the application of high-rate anaerobic bioreactors on the POME treatment. According to Poh and Chong (2009) by operating the anaerobic treatment of POME under thermophilic conditions was demonstrated to better quality of effluent and generating higher rate in biogas production. By employed anaerobic contact digester under thermophilic conditions, Ibrahim *et al.* (2006) managed more than 90 % of BOD removal obtained from POME treatment while Wong (1983) and Cail and Barford (1985) reduced more than 70 % of COP in POME with batch and semi-continuous digesters respectively under the same conditions. The most conventional method in treating POME is known as ponding system or tank system (Ma and Ong, 1985; Khalid and Mustaffa, 1992; Sulaiman *et al.,* 2009) and other process may also provide the industries of oil palm into the improvement of current POME treatment process (Wu *et al.,* 2009). Newly with the introduction of Clean Development Mechanism (CDM), many of the Malaysian palm oil mills are converting the conventional open tanks treatment system to the modern closed tanks in order to capture the methane gas as a potential source for renewable energy. According to Yaacob *et al.,* (2006) a semicommercial scale 500 m^3 closed anaerobic digester tank was commisionised to study the anaerobic treatment of POME and production of methane for CDM. However Ahmad *et al.,* (2005) pointed out that the treatment with anaerobic and aerobic systems base is quite inefficient in treating POME, which unfortunately can contribute to the source of environmental pollution.

2.4.2 Effect POME to Environmental

Currently, after the announcement by Fifth Fuel Policy under the Eight Malaysia Plan (2001-2005), palm oil is become intensively used as a source to produce biodiesel (Lim and Teong, 2010). But, the non-governmental organizations (NGOs) always questioned about the sustainability of the palm oil production. Besides palm oil mills, the criticism also including to POME because POME is considered as the most dominant pollutant generated by palm oil mills (Poh and Chong, 2009). POME discharging can contributes a serious and hazardous problem of inland water and air (biomethane emission) (Wu *et al.,* 2010) pollution since have high values of COD, (50,000 mg/L), oil and grease (4,000 mg/L), total solids (40,500 mg/L), suspended solids (19,020 mg/L) as well as BOD (25,000mg/L) (Ma, 1995) and the Malaysian Department of Environment (DOE) BOD discharge standard is 100 mg/L. According to Hwang *et al.* (1978) the palm oil mill industry in Malaysia is identified as the one that produces the largest pollution into the rivers throughout the country. It is estimated in 2003, more than 3.79 million hectares of land were under cultivation of palm oil, occupying more than one-third of the total area cultivated area in Malaysia and 11% the total land area (Yusoff and Hansen, 2007). The primary product is the crude palm oil (CPO) and various forms of solid and liquid wastes such as empty fruit branches (EFB), palm press fiber (PPF), palm kernel cake (PKC), palm kernel shell (PKS), sludge cake (SC), as well as palm oil mill effluent (POME) (Prasertsan and Prasertsan, 1996). In year 2009, Malaysian palm Oil Board (2009) pointed out that Malaysian palm oil mills have been generated about 43.8 million m^3 (11,600 million gallon) of POME base on the total crude palm oil production of 17.56 million tonnes and Malaysia currently accounts for 41 % of

world's palm oil production and 47 % of world exports (Mumtaz *et al.,* 2010). Ahmad and Chan (2009) based on statistics reported by Malaysian palm Oil Board in 2009 pointed out that if each people is assumed to produce 14.6 kg annually, this BOD value will be equivalent to the waste generated by 75 million people which nearly equivalent to thrice of the current population in Malaysia.

2.5 Principles of Ultrasound

Ultrasound has been widely used in industrial application for chemical processing of filtration, precipitation, and crystallization, atomization and electroplating (Latt and Kobayashi, 2006). The advantages of this process are the low-energy requirement involved in ultrasound and high binding capacity of the polymers (Bemberis and Neely, 1986; Chaufer and Deratani, 1988).

2.5.1 Theory of Acoustic

Ultrasound is a cyclic sound pressure with frequency higher than the range of audible human frequencies (~20 kHz) (Niemczewski, 2007). According to acoustic theory, the sound pressure in liquid is function of time and space and can be obtained according to following equation (Cai *et al.,* 2009):

$$SP = P_A \cos [\omega(t + y/c)] \quad (2.1)$$

Where c is sound velocity in liquid, y is the space coordinate, t is time, ω is angular frequency and equals to 2πf (f is frequency of ultrasonic wave) and P_A is acoustic amplitude. The pressure or acoustic amplitude can be related to the intensity of the ultrasound source by the following relation (Laborde *et al.,* 1998; Servant *et al.,* 2000):

$$P_A = \sqrt{2\ \rho_L\ I_{US}\ c} \tag{2.2}$$

Where I_{US} is the intensity of the ultrasound and ρ is the density if fluid. Acoustic cavitation is one of the primary effects of power ultrasound in a continuum fluid. For frequencies higher than 600 kHz, the behaviour of cavitation is different from that is seen at lower frequencies (20 kHz) (Araz *et al.,* 2004). The absorption of the acoustic energy will be increased with the higher frequency power intensity leading to increased acoustic streaming (de Castro and Capote, 2007). Araz *et al.* (2004) purport that power ultrasound is characterised by an ability to transmit substantial amounts of mechanical power through small mechanical movements. The passing of ultrasonic waves of a suitably high intensity through liquid and gaseous media is accomplished by primary phenomena such as cavitation, acoustic streaming; and secondary phenomena of physiochemical nature such as dispersion and coagulation (Muralidhara *et al.,* 1986, 1987; Kowalska *et al.,* 1988; Tuori, 1998; Ensminger, 1988)

2.5.2 Fouling Effects in Treatment using Membranes

According to Jiang *et al.* (1995) the fouling mechanisms occurred in ultra and microfiltration membranes are due to three factors: (a) the construction of cake layer on the membrane surfaces, (b) blocking of the membrane pores, and (c) adsorption of fouling material on the membrane surface or in the pore walls. Irreversible deposition of retained particles, colloids, macromolecules, salts, at the membrane surface and/or inside the membrane also can cause the membrane fouling (Chai *et al.,* 1999). Cheryan (1986) purport that in water treatment using membranes in the chemical and biological industries, fouling results in a significant decline of the permeate flux in ultrafiltration (UF) and microfiltration (MF). Membrane fouling is characterized by the significant decline of the permeate flux, since the permeate flux decline is due to plugging and adsorption of rejected macro-molecules solute in micro-pores of membrane surface (Li *et al.,* 2002) Therefore, such fouling is very serious problem in filtration process (Noble and Stern, 1995; Mulder, 1996). According to Kyllönen *et al.* (2005) the level of membrane fouling is dependent on the feed suspension properties (particle size, particle concentration, pH, ionic strength), membrane properties (hydrophobicity, charge, pore size), and hydrodynamics (cross-flow velocity, transmembrane pressure.).

2.5.3 Overcome Membrane Fouling by Ultrasound

Before ultrasound approach has been discovered, chemicals such as detergents and acids or alkalis are often used to clean fouled membranes (Howell and Velicangil, 1982; Cheryan, 1986; Kulkarni *et al.,* 1986; Ho and Sirkar, 1992). Since

the chemical solution used for cleaning sometimes damages the membrane materials and caused secondary pollution, Crozes *et al.* (1997) noticed that the chemical cleaning should be minimized or avoided.

The effect of using ultrasound to clean the membrane fouling has been focused and applied by some researches since its control and flux recovery are very important in the membrane filtration process such as for the enhancement of permeate flux in the capsule membrane (Okahata and Naguchi, 1983; Li *et al.,* 1997; Chai *et al.,* 1998, 1999; Kabayash *et al.,* 1999; Li *et al.,* 2002; Kobayashi *et al.,* 2003; Muthukumaran *et al.,* 2005;). Ultrasound has been widely used as a method for cleaning materials because of the cavitation phenomenon and proved to be able to enhance membrane permeability of solvent and permeate through membrane, facilitate improved separation rate and migitate membrane fouling effectively in crossflow filtration of macromolecules (Tarleton and Wakeman, 1990; Price, 1992; Chai *et al.,* 1998; Mikko *et al.,* 2004; Juang and Lin, 2004; Latt and Kobayashi, 2006). In addition, ultrasonic cleaning is impressed to remove fouling condition and highly recover the declined flux in membrane treatment (Kobayashi *et al.,* 2000). Because of that, there have been a numerous studies about the enhancement of the solute permeate flux employing ultrasound treatment (Kost and Langer, n.d.; Okahata and Noguchi, 1983; Julian and Zentner, 1986; Li *et al.,* 1995, 1996; Band *et al.,* 1997). It was shown that low frequency ultrasound such as 28 kHz and 45 kHz, reduced the membrane fouling layer resistance and enhanced the mass transfer through the membrane more effectively than high frequency one, thus effectively control its fouling (Lamminen, 2004; Teng *et al.,* 2006; Latt and Kobayashi, 2006; Sui *et al.,* 2008). This approved by Kobayashi *et al*. (2003) that was found

ultrasonication with 28 kHz frequency enhanced water cleaning of membranes fouled by peptone or milk solution instead of 100 kHz frequency. The membrane flux increased with increasing ultrasonic power intensity for the low frequency ultrasound. Some previous study reported that by combining ultrasound with water flushing could effectively clean polysulfone (PS), polyvinylidene fluoride (PVDF) and poluacrylonitrile (PAN) membranes fouled by peptone solutions (Li *et al.,* 2002; Kobayashi et al., 2003) and nylon membranes fouled by Kraft paper mill effluent (Chai *et al*. 1999). Lim and Bai (2003) experimentally investigated the effect of using ultrasonic to clean membrane fouling in aerobic MBR and found that combination of periodic exerting ultrasound on membranes with water backwashing could remove effectively the cake layer form the membrane surface and achieve best result for cleaning.

CHAPTER 3

MATERIALS & METHODS

3.1 Chapter Overview

This chapter will discuss about the materials used in this experiment together with the experimental procedure to carry out the experiment. The overview of methodology approached in treating POME by UMAS through this study as followed:

3.2 List of Materials/Chemical Reagent/Material and Equipment

3.2.1 Materials (Feed Substrates)

The feed substrate (raw POME) samples were obtained from Lepar Hilir 1, Pahang and adjusted from a COD concentration ranging 540 to 5472 mg/L to the desired COD concentration (approximately 900 to 3000 mg/L). The wastewater

characteristics vary a great deal in terms of pH, COD and solids concentration. Samples were screened through a strainer to remove coarse particles to avoid pump damage and membrane fouling. Initial characterizations of the raw samples such as COD, BOD_5, TSS, VSS, pH and turbidity will be measured.

Table 3.1 The Characteristics of the Raw POME obtained from Lepar Hilir, Pahang

Parameter	Concentration
COD (mg/L)	900-3000
BOD_5 (mg/L)	500-2000
TSS (mg/L)	30
Ammoniacal Nitrogen (mg/L)	400
Nitrate (mg/L)	15
pH	5-13

*Except pH, all other parameters are in mg/L

3.2.2 Chemical Reagents

Sodium hydroxide to measure methane gas.

a) Biological Oxygen Demand (BOD_5) Test

Phosphate buffer, magnesium sulphate, calcium chloride and ferric chloride solution, sulphuric acid.

b) Chemical Oxygen Demand (COD) Test

Digestion Solution for COD (20–1500 ppm) of high range

c) Ammonia-Nitrogen and Nitrate- Nitrogen Test

Ammonia Cyanurate Reagent Powder Pillows, Ammonia Salicylate Reagent Powder Pillows and NitraVer 5 Nitrate Reagent Powder Pillows.

3.2.3 Material and Equipment

a) Biological Oxygen Demand (BOD_5) Test

Incubation bottles (300 mL), BOD, BOD incubator, volumetric flask (1L), beaker (500 mL), and Dissolved Oxygen (DO) meter.

b) Chemical Oxygen Demand (COD) Test

COD digestion reactor, spectrometer (HACH DR/2800), COD digestion reagent vial HR, dropper and tissue.

c) Total Suspended Solid (TSS) Test

Glass fiber filter disk (47 mm), measuring cylinder (100 mL), pipette (10 mL), analytical balance, oven (preheated to 103°C to 105 °C), desiccator, Buncher flask and funnel, vacuum pump and aluminium weighing dishes.

d) Ammonia-Nitrogen and Nitrate- Nitrogen Test

Rounded sample cell (10 mL) for nitrate test, HACH Spectrophotometer DR/2800, measuring cylinder (25 mL) and beaker (50 mL).

3.2.4 Apparatus and Instrumentations

Laboratory digester is used to treat POME by UMAS.

3.3 Experimental Procedure

3.3.1 Reactor Set-up

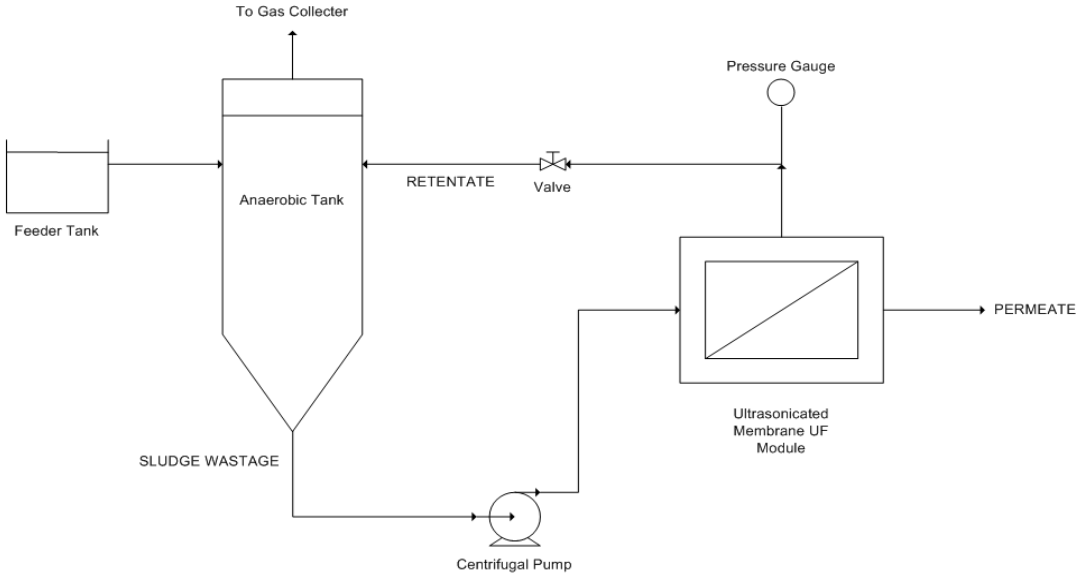

Figure 3.1 Experimental Set-up for UMAS

The schematic diagram of the UMAS reactor is shown in Figure 3.1. The UMAS reactor consists of a cross flow ultra-filtration membrane (CUF) apparatus, a centrifugal pump, and an anaerobic digester. The anaerobic digester reactor design configuration is depicted in Figure 3.1. The reactor was composed of clear PVC with an inner diameter of 15 cm and a total height of 100 cm. The working volume was 40.0 litres and aluminium foils were used to cover up the whole surface of reactor in order to prevent reaction between the POME and the light. The operating pressure for this study was maintained to 5 bars by manipulating the gate valve at the retentate line after the CUF unit.

3.3.2 Sample Preservation

Before the POME was fed to the reactor, it was preserved at a temperature less than 4˚C but above the freezing point in order to prevent the wastewater from undergoing biodegradation due to microbial action. A portion of sample was analyzed for its characteristics such as pH, COD, BOD, TSS, ammonia nitrogen and nitrate.

Raw POME was treated by UMAS in a laboratory digester with an effective 40 L volume. The dilution of the raw POME is done in order to match the COD with that one of the effluent coming out of the anaerobic digester. In order to vary the influent COD concentration to the UMAS reactor, a suitable aliquot of raw POME was diluted and analyzed for its initial characteristics.

3.3.3 POME Characteristics

The characteristics of the raw POME such as pH, biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solid (TSS), ammoniacal nitrogen (Am-N), and nitrate (NO_3) were determined according to the Standard Methods for the Examination of Water and Wastewater (AHPA, 2000) and DR/4000 Spectrophotometer Procedures Manual.

3.3.4 Reactor Operation and Monitoring

Reactor was operated under ambient temperature (~30-35 ˚C). POME is continuous up-flow feeding from the side flow into the anaerobic reactor. HRT was adjusted volumetrically through controlling the flow rate of the influent feed. Effluent samples were taken from the reactor after 5 hours for analysis at each batch of HRT with the manual pump. The samples were subjected to the analysis of the following parameters such as COD, pH, alkalinity, suspended solids and volatile suspended solids based on the American Public Health and Association (APHA) standard methods for water and wastewater analysis (APHA 2005). The start-up of the UMAS reactor involved step increasing in influent organic volumetric loading rates from higher retention time to lower retention time of to 30, 25, 20, 15, 10, and 5 days The acclimatization phase was used the feed flow-rate of 0.375 L which correspond to the HRT of 4 days for about 9 days to allow all the microorganisms present in the mixed liquor perfectly acclimatized to the new environmental.

3.3.4.1 Acclimatization Phase

Acclimatization process of the UMAS reactor is done with the feed of 40 L which corresponds to HRT of 4 days to allow the anaerobic bacteria which present in the mixed liquor entirely will acclimatize to the new environmental in the reactor. After 4 days of loading period in the anaerobic reactor, parameters of POME is measured and recorded. Parameters for the treated POME (permeate) are measured after 5 hours later.

3.3.5 Determination of Parameters (Analytical Methods)

The organic strength (COD) of the wastewater is determined by a calorimetric method (HACH, 1997). The biodegradability of the wastewater is measured in terms of BOD_5.

3.3.5.1 Determination of Biochemical Oxygen Demand (BOD_5)

Dilution water is prepared by adding 1 mL of each phosphate buffer, magnesium sulphate, calcium chloride, ferric chloride solution into 1 L volumetric flask. Distilled water is added to 1L. For determination BOD_5, 10 mL of POME is diluted to 300 mL in a 500 mL beaker. pH value is adjusted to the range of 6.5 to 7.5 by adding acid or alkali. All prepared samples are controlled in 300 mL incubation bottle respectively. Dissolved oxygen (DO) concentration is measured for each sample by using Dissolved Oxygen Meter and all the data are tabulated in a table. Water is added to the flared mouth of bottle and cover up by aluminium foil. All the bottles is kept in BOD incubator for five days by setting the temperature to 20 ˚C. Final DO value is measured after five days later and BOD_5 is calculated by using the formula below:

$$BOD_5 \text{ (mg/L)} = (D_1 - D_2) / P \qquad (3.1)$$

Where,

D_1 = DO value for initial sample

D_2 = DO value for final sample

P = Decimal volumetric fraction of sample used

Or;

$$BOD_5 \text{ (mg/L)} = (D_1 - D_2) \text{ x Dilution Factor} \quad (3.2)$$

Where,

Dilution Factor = Bottle volume (300 mL) / Sample volume

3.3.5.2 Determination of Suspended Solid (TSS)

A filter disk is dried in the oven at 103 ˚C to 105 ˚C for 1 hour, cooled in desiccators and is weight. Filtering apparatus is assembled to begin suction. The filter is wet with a small volume of distilled water to seat it. 50 mL of water sample (mixed to ensure homogeneity) is pipette onto centre of filter disc in a Buchner flask by using gentle suction (under vacuum). Filter is washed three successive 10 mL volumes of distilled water, allowing complete drainage between washings, and suction process is continued for about 3 min after filtration is complete. Filter is carefully removed from filtration apparatus and is transferred to aluminium weighing dish/crucible dish as a support. The sample is dried at least 1 hour at 103 ˚C to 105 ˚C in an oven, then is allowed to cool in desiccator to balance temperature and weigh.

The cycle of drying, cooling, desiccating, weighing are repeated until a constant weight is obtained.

3.3.5.3 Determination of Chemical Oxygen Demand (COD)

100 mL of wastewater sample is homogenized for 30 seconds in a blender. Notice here that homogenization time need to be increased if the samples containing large amounts of solids. The homogenized sample is poured into a 250 mL beaker and is stirred gently with a magnetic stir plate. This step is done for the 200 – 15 000 mg/L sample or to improve accuracy and reproducibility of the other ranges. Both of these steps are omitted if the sample does not contain suspended solid.

COD reactor is preheated to 150 ˚C and the safety shield is placed in front of the reactor. The caps are removed from two COD Digestion Reagent Vials (20-1500 ppm). The first vial is hold at a 45˚ angle. A clean volumetric pipette is used to add 2.00 mL of sample to the vial. This is **the prepared sample**. The same procedure is repeated for the second vial but 2.00 mL of de-ionized water is pipette to the vial instead of the wastewater. This is the **blank**. The vials are cap tightly, rinsed with de-ionized water and are wiped with a clean paper towel. The vials are hold by the cap over a sink and gently invert for several times to mix. The vials are placed and preheated in the preheated COD Reactor. After heated the vials for two hours, the vials are allowed to cool to 120 ˚C for about 20 minutes. Each vial are inverted for several times while still warm, then are allowed to cool down at room temperature. For setting up the COD Reactor, program for 435 COD HR (High Range/High

Range Plus) is selected. The outside of the vials need to be cleaned with a damp towel followed by a dry one to remove fingerprints. 16 mm adapter is installed and the blank is placed into the adapter.

3.3.5.4 Determination of Total Suspended Solid (TSS)

The filter disk is dried in the oven at 103 °C to 105 °C for 1 hour, cooled in a desiccator and is weighed. Filtering apparatus is assembled, filtered and then began suction. The filter is wet with a small volume of distilled water to seat it. 50 mL of water sample is pipette (mixed to ensure homogeneity) onto centre of filter disk in a Bunchner flask by applying gentle suction (under vacuum). The filter is washed with three successive 10 mL volumes of distilled water, allowing complete drainage between washings and suction process is continued for about 3 min after filtration is complete. The filter is carefully removed from filtration apparatus and transferred to aluminium weighing dish as a support, then is dried at least 1 hour at 103 °C to 105 °C in oven, cooled in desiccators to balance temperature ad weigh. The cycle of drying, cooling, desiccating and weighing are repeated until a constant weight is obtained.

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 Results

The prepared syringe was used to measure the daily gas volume. The produced biogas contained only CO_2 and CH_4, so a portion sodium hydroxide solution (NaOH) was added into the syringe to absorb the CO_2 affectively by isolating the CH_4 gas. There are some different kinetics parameters were studied through this study such as COD, BOD and TSS. The biological treatment (anaerobic system) is incorporated with ultrasonic to treat POME and this combination gave high COD removal rate up to 88 % only in a short time.

Table 4.1: Initial Measurements of POME

Parameters	Initial Measurement
pH	4.93
Temperature (°C)	35.0
COD (mg/L)	2560.0
BOD (mg/L)	183.0
TSS (mg/L)	231.5
Methane Production (%)	0.0

4.1.1 Ultrasonic Membrane Anaerobic System (UMAS) Performance

Table 4.2: Summary Results of UMAS Performance

Steady State	1	2	3	4	5
COD permeate	906	1338	1518	1842	2010
% Methane	65.38	63.33	61.60	59.17	57.60
Ammonia Nitrogen	370.37	340.34	270.27	260.26	260.26
Nitrate	10.8	9.2	8.8	6.0	5.6
HRT	392.16	128.21	119.05	111.11	98.04
COD Removal (%)	83.34	84.04	84.53	85.01	85.30
TSS Removal (%)	88.36	88.62	89.05	89.17	89.02
BOD Removal (%)	72.01	67.52	68.35	68.17	66.02

All are unit mg/L except HRT (day), Methane and COD Removal in %

Table 4.2 summarizes UMAS performance at five steady states, which were established at different influent of COD concentrations. At first steady state, the TSS concentration was about 14.8 mg/L compared to the last run which is 18.7 mg/L. this indicates that the long solid retention time (SRT) of UMAS assisted the

decomposition of the suspended solids and their subsequent conversion to methane gas. The highest COD was recorded at the fifth steady-state (2010 mg/L). At this organic loading rate (HRT) the UMAS achieved 85.30 % COD removal. The color of treated POME (permeate) by UMAS was very clear compare to the raw POME as shown in **Appendix A.4.**

4.2 Discussions

4.2.1 Methane Production with Organic Loading Rate

Table 4.3: Percentage of Methane Produced versus OLR

Day	Initial Length (cm)	Final Length (cm)	Methane Produced (%)
1	21.0	12.2	60.1
2	16.5	10.2	61.9
3	20.0	12.8	64.0
4	23.0	15.8	66.7
5	23.5	16.4	69.8

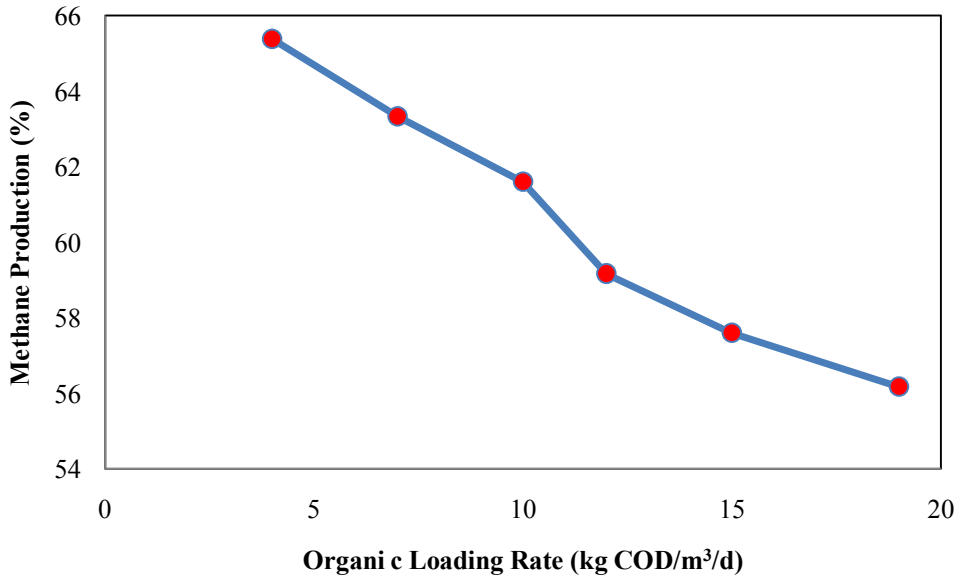

Figure 4.1: Methane Productions versus OLR

Figure 4.1 shows the percentage of methane gas collected in various organic loading rates. From the figure can be summarized that methane gas collected with increasing OLRs. Methane gas collected ranged from 57.60 % to 65.38 %. The decline in methane gas content may be attributed to the higher OLR, which favours the growth of acid forming bacteria over methanogenic bacteria. The formation of methane content of the biogas was reduced as the formation of carbon dioxide (CO_2) was higher.

4.2.2 Analytical Analysis

A portion of permeate was taken once in four days and some pre-experiment were done through this study such as TSS, COD, BOD, ammonia nitrogen and nitrate. In order to determine the TSS, a gravimetric was used with the aid of vacuum filtration apparatus. The weight of solids retained on the filter paper was determined after heating up in the oven about 1 hour. The temperature was set to 105 °C. The COD test was performed by calorimetric method using Spectrophotometer HACH Model DR/2800. In this COD pre-experiment, the amount of oxygen (O_2) required for complete oxidation of organic matter was measured using strong oxidation agent such as dichromate ion ($Cr_2O_7^{2-}$).

4.2.2.1 COD Removal with Hydraulic Retention Time

Table 4.3: COD Removal versus HRT

Day	Initial (mg/L)	Influent (mg/L)	Effluent (mg/L)	COD Removal (%)
1	1997	1784	333	83.34
2	1754	1675	280	84.04
3	1592	1234	247	84.53
4	1348	1204	202	85.01
5	1184	874	174	85.30

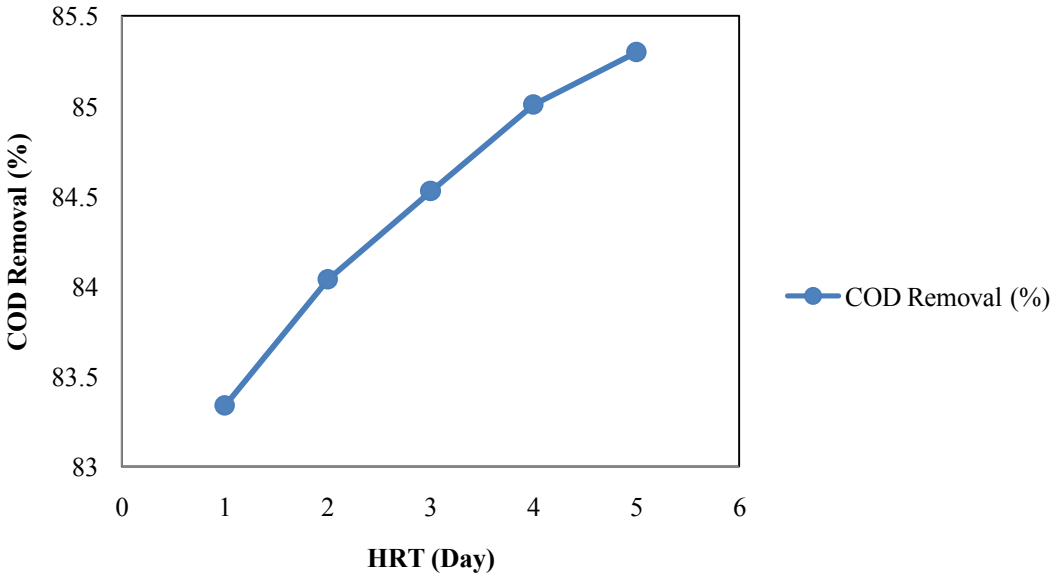

Figure 4.2: COD Removal by UMAS with various retention times

Figure 4.2 shows the COD removal by UMAS with various retention times. As the HRT increased from 98.04 to 392.16 days, the COD removal also increased. COD removal was reduced as the HRT decreased on the sixth steady state which is about 84 % as a result of washout phase in the reactor since the concentration in the system has increased. The COD removal observed for POME treatment reported by Razi and Noor (1999) was about 85 % by using anaerobic fluidized bed while 91.7-

94.2 % COD removal observed using MAS in treating POME was reported by Abdullah *et. al*. (2005).

4.2.2.2 TSS Removal with Hydraulic Retention Time

Table 4.4: TSS Removal versus HRT

Day	Initial (mg/L)	Influent (mg/L)	Effluent (mg/L)	TSS Removal (%)
1	215.5	167.9	28.9	88.35
2	176.6	169.0	26.8	88.62
3	153.7	148.1	16.9	89.05
4	131.9	141.4	15.7	89.17
5	107.1	97.3	13.5	89.02

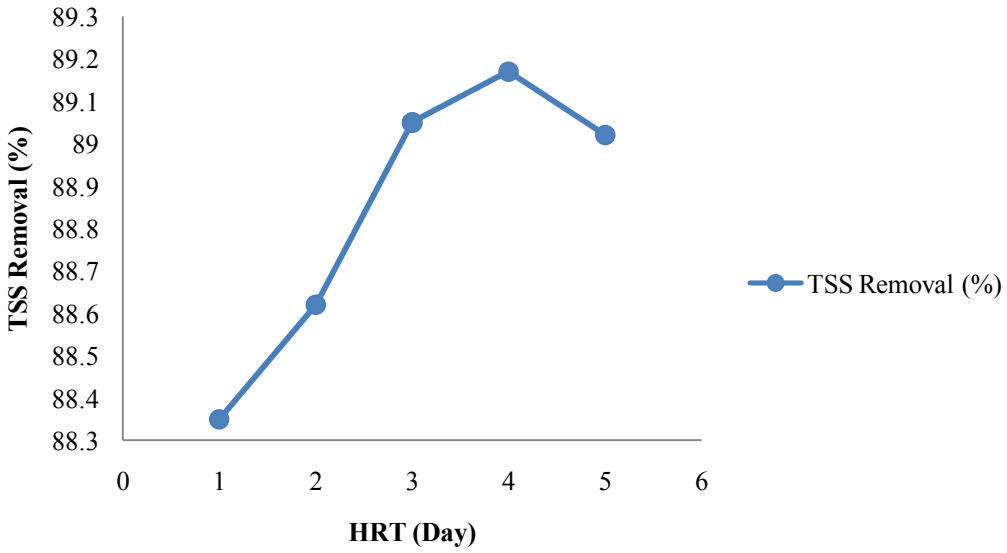

Figure 4.3: TSS Removal by UMAS with various retention times

Figure 4.3 shows the data for TSS permeate collected of UMAS under steady-state conditions with various hydraulic retention times. At first steady state, the TSS removal was about 88.35 % compared to the last run which is 89.02 %. This indicates that the long solid retention time (SRT) of UMAS assisted the

decomposition of the suspended solids and their subsequent conversion to methane gas.

4.2.2.2 BOD Removal with Hydraulic Retention Time

Table 4.5: BOD Removal versus HRT

Day	Initial (mg/L)	Influent (mg/L)	Effluent (mg/L)	BOD Removal (%)
1	194.2	189.4	54.6	72.01
2	147.2	135.2	48.9	67.52
3	136.5	131.6	44.2	68.35
4	130.6	116.2	41.5	68.17
5	118.8	102.1	39.1	66.02

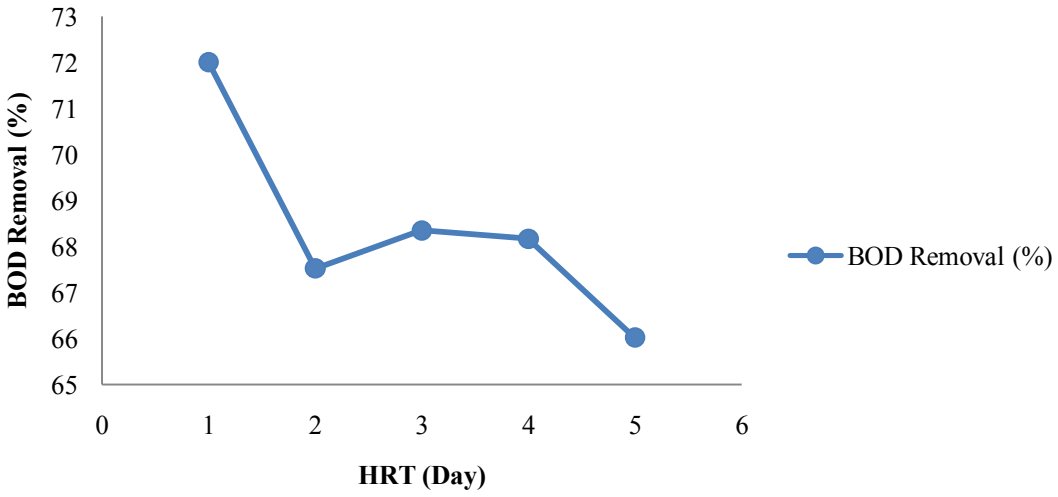

Figure 4.4: BOD Removal by UMAS with various retention times

Figure 4.4 shows the BOD collected of UMAS under steady-state conditions with various hydraulic retention times. The BOD removal collected for once in each 4 days was decreased as HRT increased from 98.04 to 392.16 days and was in the range of 72.01 – 66.02 %. As the HRT decreased, the BOD will be decreased (Barr, 1995).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The functions of UMAS through this study are to treat high organic load wastewater, to reduce anaerobic treatment time as well as to reduce biomass sludge discharge. Developing the Ultrasonic Membrane Anaerobic System (UMAS) was found to be an effective method in treating POME as the volume of reactor needed is smaller than conventional method. This combination treatment is successfully treated POME by removing COD about 85 % only in a short time.

5.2 Recommendations

The following are recommendations to understand and take into consideration in order to improve the research in the future. These recommendations represent

suggestions which would improve the results obtained in this experiment or represent areas which did not receive enough attention in the present experiment:

5.2.1 Hydraulic Retention Time

Corresponding with the decrease in HRT, the COD removal increased linearly. So, in order to achieve higher conversion, the hydraulic retention times should be shortened.

5.2.2 Acclimatization Phase

The acclimatization period should be extended to allow the anaerobic bacteria which comprise in mixed liquor entirely more acclimatize to the new environmental in the reactor.

5.2.3 pH

In POME treatment, many factors such as pH, mixing, and availability of the nutrient as well as the organic loading rates into the digester must be controlled to ensure the performance of anaerobic digesters and preventing any failures. The microbial community of the anaerobic digester in this study were highly sensitive to pH changes. Thus, the pH should be maintained in an optimum range about 6 to 7 in order to minimize the effect on methanogens that might effect the biogas production.

Since the pH is strongly effect to the methanogenesis process, thus the methanogenic activity will decrease as the pH in the digester deviates from this optimum value.

5.2.4 Mixing

Mixing factors provides good relation between substrates and microbes, minimizes the build-up of inhibitory intermediates and stabilizes the environmental conditions as well (Abdurahman *et al.,* 2011). Mixing time taken before analyzing the permeate characteristics should be increased to ensure the substrate (POME) and microbes are well mixing.

5.2.5 Membrane

The membrane need to be clean from time to time to improve the permeate flux and permeate flow rate.

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APPENDICES

Figure A.1 Membrane Fouling

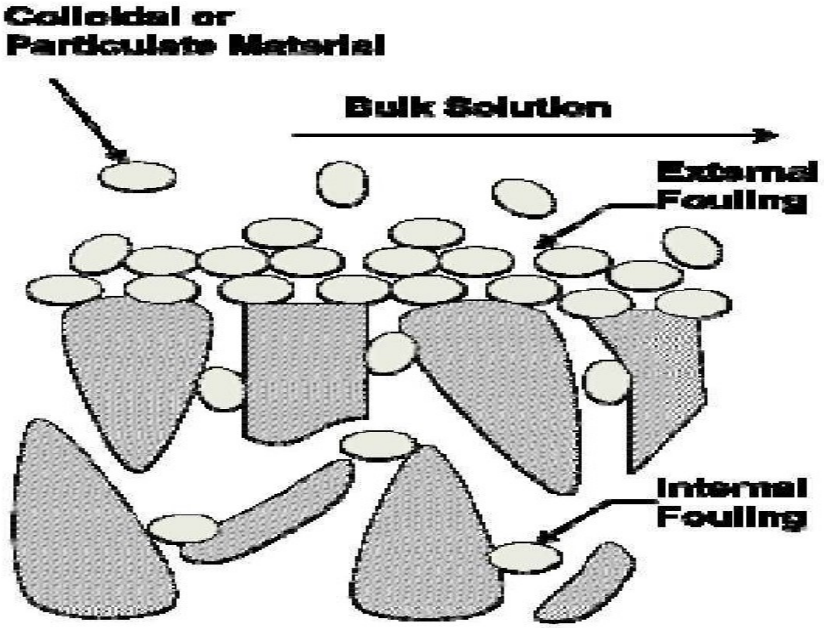

Figure A.2 Mechanism in Membrane Fouling

Figure A.3 Syringe for Collecting Methane Gas

Figure A.4 Treated POME (permeate)