BIOMETHANATION OF PALM OIL MILL EFFLUENT (POME) BY ULTRASONIC-MEMBRANE ANAEROBIC SYSTEM (UMAS)

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ABSTRACT

Palm Oil Mill Effluent (POME) is the wastewater produced during production process of palm oil. POME is a non-toxic thick brownish liquid waste, which has an unpleasant odor. It contains high amounts of total solids, oil and grease, with high concentration of COD and BOD. POME discharged at 80 -90°C and it is fairly acidic with pH ranging from 4.0-5.0. Palm oil mill effluent (POME) with average chemical oxygen demand (COD) and biochemical oxygen demand (BOD) of 70,000 and 30,000 mg/L, respectively, can cause serious environmental hazard if discharged untreated. In this study, methane gas is produced by process of biomethanation of Palm Oil Mill Effluent (POME) using 50L of ultrasonic-membrane Anaerobic System (UMAS). The operating pressure for this study is maintained at 2 bars. Reactor was operated under ambient temperature (30-35 ºC). POME is continuous up-flow feeding from the side flow into the anaerobic reactor. Effluent samples were taken after 5 hours of analysis of COD, pH, alkalinity, suspended solids and volatile suspended solids. Throughout the experiment, the removal efficiency of COD was 95.55% with HRT of 6 days. The BOD removal efficiency was 71.58% while TSS removal rate was from 91 to 99.5%.The methane gas production efficiency was 94.14%. The UMAS treatment efficiency was greatly improved by UMAS introduction. The membrane fouling and polarization at the membrane surface was significantly reduced.

***Keywords*: POME, biomethanation, UMAS, methane**

ABSTRAK

Pelepasan air pemprosesan kelapa sawit (POME) adalah air sisa yang dihasilkan semasa proses pengeluaran minyak sawit. Pelepasan air pemprosesan kelapa sawit (POME) merupakan sisa cecair yang berwarna coklat dan pekat, tidak bertoksik, dan mempunyai bau yang tidak menyenangkan. Ia mengandungi jumlah minyak dan gris yang tinggi daripada jumlah pepejal, , dengan kepekatan tinggi keperluan oksigen kimia COD dan keperluan oksigen biologi BOD. Pelepasan air pemprosesan kelapa sawit (POME) dilkeluarkan pada 80 -90 ° C dan ia agak berasid dengan pH antara 4.0-5.0. Kumbahan kilang minyak sawit (POME) mempunyai purata keperluan oksigen kimia (COD) dan keperluan oksigen biokimia (BOD) 70,000 dan 30,000 mg / L, masing-masing, dan boleh menyebabkan masalah kepada alam sekitar yang serius jika dilepaskan tanpa rawatan. Dalam kajian ini, gas metana yang dihasilkan melalui proses biomethanation pelepasan air pemprosesan kelapa sawit (POME) menggunakan 50L sistem membran anaerobik berultrasonik (UMAS). Tekanan yang beroperasi untuk kajian ini dikekalkan pada 2 bar. Reaktor telah beroperasi di bawah suhu ambien (30-35°C). Sampel efluen telah diambil selepas 5 jam untuk analisis COD, pH, kealkalian, dan jumlah pepejal (TSS). Sepanjang eksperimen, penurunan keperluan oksigen kimia (COD) adalah 95.55% dengan masa tahanan hidraulik (HRT) 6 hari. Penurunan keperluan oksigen biologi (BOD) adalah 71.58% manakala kadar penurunan TSS adalah 91-99.5% .Pengeluaran gas metana adalah 94.14%. Kecekapan rawatan UMAS telah bertambah baik dengan pengenalan UMAS. Masalah fouling dan polarisasi di permukaan membran telah dikurangkan dengan ketara.

Kata kunci : POME, biomethanation, gas metana, UMAS

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LIST OF SYMBOLS

V	Volume
Q	Flowrate
Cd	Solid Concentration in the digester
Cw	Solid Concentration in the waste
Qw	Volume wasted each day
D_1	Dissolved Oxygen value in initial sample
D_2	Dissolved Oxygen value in final sample

LIST OF ABBREVIATIONS

POME	Palm Oil Mill Effluent
UMAS	Ultrasonic Membrane Anaerobic System
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
TSS	Total Suspended Solids
HRT	Hydraulic Retention Time
EQA	Environmental Quality Act
CPO	Crude Palm Oil
AnMBR	Anaerobic Membrane Bioreactor
HRAS + AD	High Rate Activated Sludge + Anaerobic Digestion
MPOB	Malaysia Palm Oil Board
OLR	Organic Loading Rate
SRT	Solid Retention Time
VFA	Volatile Fatty Acid
NF	Nanofiltration
UF	Ultrafiltration
MF	Microfiltration
MW	Molecular Weight
PPME	Pulp and Paper Mill Effluent
PNS	Purple nonsulfur bacteria
SBR	Sequencing Batch Reactors
TCOD	Thermophilic Chemical Oxygen Demand
SVI	Sludge Volume Index
AAS	Anaerobic-Aerobic Sequence
ARG	Antibiotic-Resistant Genes
MFC-AFMBR	Microbial Fuel Cell and Anaerobic Fluidized Bed Membrane Bioreactor
MFC	Microbial fuel cells
GAC	Granular Activated Carbon
WAS	Waste-Activated Sludge

MEC	Microbial Electrolysis Cells
DO	Dissolved Oxygen
VSS	Volatile Suspended Solids

CHAPTER 1: INTRODUCTION

1.1 Background of the study

Palm oil mill effluent (POME) is the wastewater which is generated during the production process of palm oil. It is a thick brownish color liquid and discharged at a temperature between 80 to 90 °C. It is fairly acidic with pH ranging from 4.0 – 5.0. (N.H. Abdurahman, Priya Dharshini d/o Chandra, Biomethanation of Palm Oil Mill Effluent (POME) by Ultrasonic-Assisted Membrane Anaerobic System (UMAS), International Journal of Engineering Sciences & Research Technology, February 2015). Characteristics of palm oil mill effluent depend on the quality of the raw material and palm oil production processes in palm oil mills. POME is considered as non-toxic as no chemicals were added during the oil extraction process. (Parveen Fatemeh Rupani, Rajeev Pratap Singh, M.Hakimi Ibrahim, Norizan Esa, 2010).

Palm Oil Mill Effluent (POME) often discarded in disposal ponds, resulting in the leaching of contaminants that pollute the groundwater and soil, and in the release of methane gas into the atmosphere (Salman Zafar, June 23, 2015).

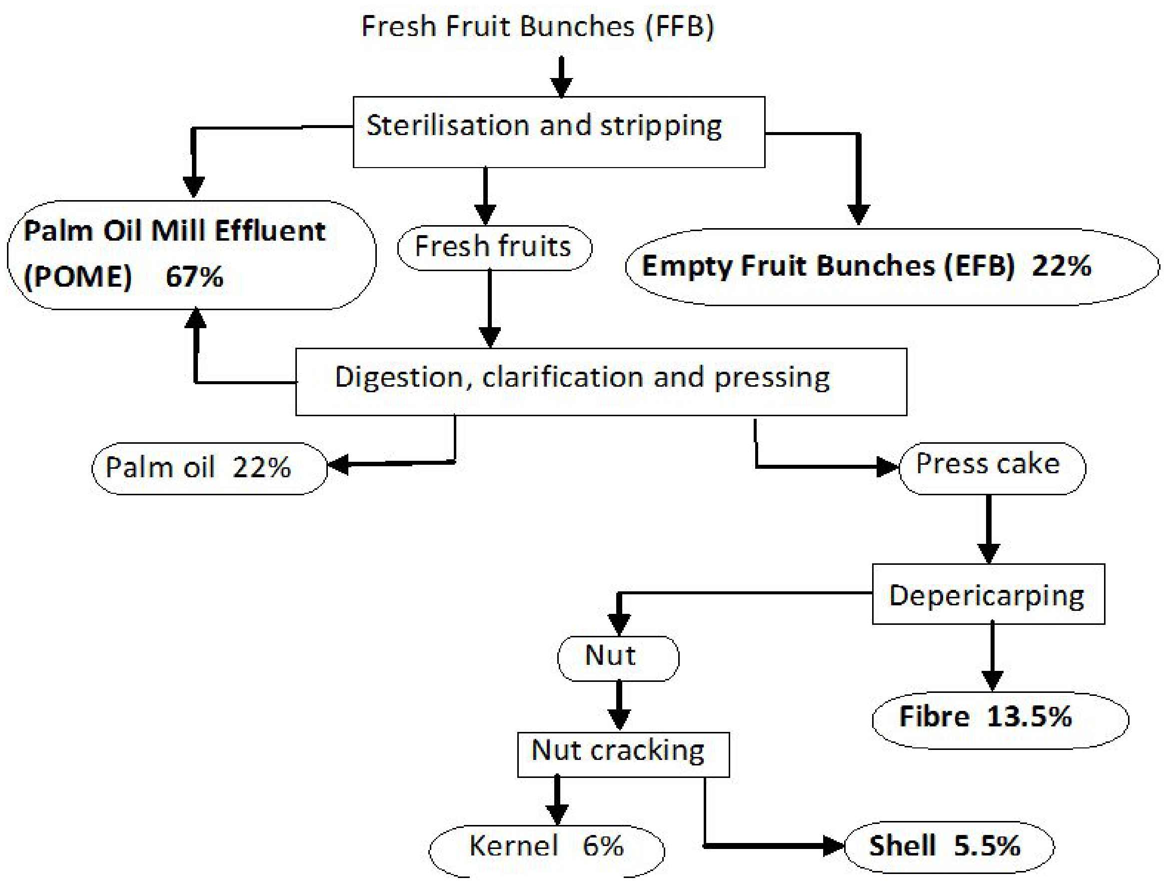

Figure 1.1: Process Flow Diagram of an oil palm mill (N. Abdullah and F. Sulaiman (2013). The Oil Palm Wastes in Malaysia, Biomass Now - Sustainable Growth and Use, Dr. Miodrag Darko Matovic (Ed.), InTech, DOI: 10.5772/55302. Available from: http://www.intechopen.com/books/biomass-now-sustainable-growth-and-use/the-oil-palm-wastes-in-malaysia)

Malaysia as one of the world's leading producer and exporter of palm oil had substantially contributed to the discharge of Palm Oil Mill Effluent (POME) in the process of Crude Palm Oil (CPO) production. In Malaysia, the oil palm planted area reached 5.00 million hectares, and a total of 92.9 million tons of oil palm fruit was harvested in 2011. (Rex T.L. Ng and Denny K.S. Ng, Ind.Eng.Chem Res, 2013). Approximately 53 million tons of POME had been produced in year 2008 in Malaysia, based on the fact that 3 tons of POME is being generated from a ton of crude palm oil produced in palm oil mills.

A set of well-designed environmental policies can be very effective in controlling industrial pollution in a developing country like Malaysia. The Environmental Quality (prescribed Premises)(Crude Palm Oil) Regulation 1977, promulgated under the enabling powers of 3 Section 51 of the EQA, are the governing regulations and contain the effluent discharge standards. Other regulatory requirements are to be imposed on individual palm oil mills through condition of license according to Environmental Quality Act 1974 (Pierzynski, 2005). In order to reach the requirement of standard discharge limit, POME needs to be treated with a cost-effective way.

1.2 Motivation of the study

POME is a highly polluting wastewater which poses detrimental effects if directly discharged into watercourses and it has been conventionally treated anaerobically with ponding system or open digesting tanks. High-rate anaerobic bioreactors have shown better treatment efficiency, producing better treated effluent with shorter retention times, as well as greater methane production. (Poh Phaik Eong, 2008). These anaerobic bioreactors also require less space. 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 mitigate membrane fouling effectively in-cross flow filtration of macromolecules (Okahata and Naguchi, 1983; Kabayash et al., 1999; Li et al, 2002; Kobayashi et al., 2003; Muthukumaran et al., 2005). The advantages of this process are the low-energy requirement involved in ultrasound and high binding capacity of the polymers (Chaufer and Deratani, 1988; Noble, R. D. & Stern, S. A., (1995).

Methane is of particular concern because it is 21 times more effective at trapping heat in the atmosphere than carbon dioxide. (Heather Rogers, Gone Tomorrow, 2005). Methane takes 21 tons of CO_2 to equal the effect of 1 ton of CH_4. Methane has short atmospheric lifetime (approximately 12 years), thus efforts to capture methane from anthropogenic sources provide more near-term climate change abatement than capturing or reducing comparable amounts of CO2, but less multi-decadal abatement. (Congressional Research Service, January 2011)

Thus, POME must be treated well to save the environment and also the future of next generation.

1.3. Problem Statement

The main problem statement is the high chemical oxygen demand (COD) and biochemical oxygen demand (BOD) of POME. The incomplete extraction of palm oil from palm nut also increase the COD level of POME. Although POME is non-toxic but it will pose environmental issues due to large oxygen depleting capability in aquatic system due to organic and nutrient contents (Zafar, 2013). Furthermore POME releases methane gas that is one of the greenhouse gasses that can cause global warming. Discharging POME into environment without purified or treated it can cause water and air pollution that can affect the environment and living things.

POME is an oily wastewater generated by palm oil processing mills and consists of various suspended components (Abdurahman.H.Nour and Nuri 'AdilahNashrulmillah, January 2014). The total suspended solids can reduce the membrane permeability and slow down the flow. The membrane can be suffered from fouling and degradation during it is continuous usage. The study should be conducted to solve all the problems arise during the treatment of POME.

1.4. Objectives of the study

This study aims to solve the problem statement by accomplishing the following objectives:

1. To enhance the treatment of POME using Ultrasonic Membrane Anaerobic System (UMAS)

2. To solve the membrane fouling problem using UMAS and increase the purity of methane gas

3. To compare the performance between Membrane Anaerobic System and Ultrasonic-Membrane Anaerobic System

1.5. Scopes of the study

This study is focused on enhancing the treatment of POME using Ultrasonic Membrane Anaerobic System (UMAS). The efficiency of the system were evaluated with analysis of COD, pH, alkalinity, suspended solids, volatile suspended solid, flow in the reactor and the purity of the product. To overcome membrane fouling problem, an ultrasonic device is used. The parameters such as pH and temperature are controlled and maintain in optimum operating condition.

CHAPTER 2: LITERATURE REVIEW

2.1 Palm Oil Mill Effluent (POME)

Palm oil mill effluent (POME) is the wastewater which is generated during the production process of palm oil. POME is a non-toxic thick brownish liquid waste, which has an unpleasant odour (N.H. Abdurahman, Priya Dharshini d/o Chandra, 2015). POME contains lignocellulolic wastes with a mixture of carbohydrates and oil. Its chemical oxygen demand (COD) and biochemical oxygen demand (BOD) are very high; COD values greater than 80,000 mg/l and; acidic pH values between (3.8 and 4.5) are frequently reported and the incomplete extraction of palm oil from the palm nut can increase COD values substantially (N.H. Abdurahman, Y.M. Rosli, N.H. Azhari, S.F.Tam, 2011).

The palm oil industry had developed vastly due to the increasing demand of vegetable oil. Malaysia as one of the world's leading producer and exporter of palm oil had substantially contributed to the discharge of Palm Oil Mill Effluent (POME) in the process of Crude Palm Oil (CPO) production (Poh Phaik Eong, 2008).

2.2 Applications of Ultrasound

Ultrasound is well known to have a significant effect on the rate of various processes in the food industry. Using ultrasound, full reproducible food processes can now be completed in seconds or minutes with high reproducibility, reducing the processing cost, simplifying manipulation and work-up, giving higher purity of the final product, eliminating post-treatment of waste water and consuming only a fraction of the time and energy normally needed for conventional processes. More effective mixing and micro-mixing, faster energy and mass transfer, reduced thermal and concentration gradients, reduced temperature, selective extraction, reduced equipment size, faster response to process extraction control, faster start-up, increased production, and elimination of process steps are the advantages of using ultrasound. (Farid Chemat , Zill-e-Huma, Muhammed Kamran Khan, 2011)

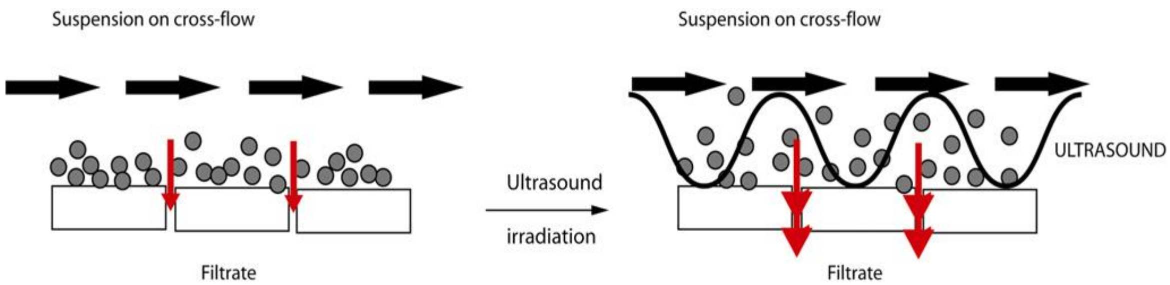

Figure 2.1: Enhancement of permeability using ultrasound

2.3 POME Treatment Methods

2.3.1. Ponding system

Pond systems have been applied in Malaysia since 1982. More than 85% of palm oil mills for POME treatment because of its low cost. In a ponding system it is basically divided into de-oiling pond tank, acidification ponds, anaerobic ponds and facultative pond or aerobic ponds (Poh P.E et al, 2009). But there are some disadvantages for this ponding system such as occupying a vast amount of land mass, long hydraulic retention time (HRT) bad odor and difficulty in maintaining the liquor distribution and biogas collection which results harmful effects to the environment.

Open digester tank are used for POME treatment when limited land area is available for ponding system. Apart from that, in the investigation by Yacobs et al (2006), he proved that anaerobic system emitted higher amount of methane compare to the open digester tank with an average methane composition of 54.4% compare to open digester tank (Poh P.E et al, 2009).

2.3.2. Anaerobic Digestion

Anaerobic digestion is the process where consumption of organic material by microorganisms without the presence of oxygen. Through anaerobic digestion, biogasses such as methane and carbon dioxide will be produced. The process can take longer time because microorganisms need to adapt with the environment before start to consume the organic matters.

Anaerobic digestion includes few steps that are hydrolysis, acidogenesis (including acetogenesis) and methanogenesis (Gerardi, 2003). Hydrolysis is where the complex molecules will be converted into simpler molecules such as sugar and amino acid. In the acidogenesis process, acidogenic bacteria will break down the simpler molecules into acetic acid, hydrogen and carbon dioxide. Hydrogen and carbon dioxide will be utilized by hydrogenotropic methanogens while acetic acid and carbon dioxide will be utilized by acetoclastic methanogens to give methane as a final product (P.E. Poh, M.F. Chong, 2009). Methanogenesis step is the rate limiting step in anaerobic digestion of POME.

Table 2.1: Advantages and disadvantages of anaerobic and other alternative treatment methods

Treatment types	Advantages	Disadvantages	Reference
Anaerobic	Low energy requirements (no aeration), producing methane gas as a valuable end product, generated sludge from process could be used for land applications	Long retention time, slow start-up (granulating reactors), large area required for conventional digesters	Metcalf and Eddy (2003), Borja et al. (1996a)
Aerobic	Shorter retention time, more effective in handling toxic wastes	High energy requirement (aeration), rate of pathogen inactivation is lower in aerobic sludge compared to anaerobic	Leslie Grady et al. (1999), Doble and Kumar (2005)

		sludge, thus unsuitable for land applications	
Membrane	Produce consistent and good water quality after treatment, smaller space required for membrane treatment plants, can disinfect treated water	Short membrane life, membrane fouling, expensive compared to conventional treatment	Ahmad et al. (2006), Metcalf and Eddy (2003)
Evaporation	Solid concentrate from process can be utilized as feed material for fertilizer manufacturing	High energy consumption	Ma et al. (1997)

Typical reaction of anaerobic digestion:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + CO_2 \qquad [1]$$

$$C_2H_5OH + CO_2 \rightarrow CH_4 + 2CHOOH \qquad [2]$$

$$CH_3COOH \rightarrow CH_4 + CO_2 \qquad [3]$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \qquad [4]$$

The anaerobic digestion process has great potential for rapid disintegration of organic matter to generate biogas that can be used in electricity generation and save fossil energy. However, such biological practices are only applicable in the palm oil mills which acquire large area of lands. According to Ahmad *et al.* the treatment process that is based mainly on biological treatment is quite inefficient in treatment of POME, which may lead to several environmental pollution issues. This is largely due to the high BOD load and low pH of POME, together with the colloidal nature of the suspended solids, which renders POME treatments by environmental methods difficult.

2.4 Anaerobic Membrane Bioreactor (AnMBR)

Anaerobic Membrane Bioreactor can be used to treat domestic wastewater. AnMBR produce more net energy and have lower life cycle environmental emissions than high rate activated sludge with anaerobic digestion (HRAS + AD), conventional activated sludge with anaerobic digestion and aerobic membrane bioreactor with anaerobic digestion. It is assumed that at 15°C, AnMBR recovered 49% of biogas more than HRAS + AD. AnMBR considered most energy positive conventional technology but it has some disadvantages such as higher energy demands and environmental emissions. There are global warming impacts associated with AnMBR due to emissions of effluent dissolved methane.

AnMBR produces methane-rich biogas through anaerobic digestion by microbes. Fouling control in AnMBR contributes to overall energy demands and operational costs. About 86% of the overall energy demand is because of the fouling control in AnMBR. AnMBR capital costs are higher than HRAS+AD, but AnMBR produces less sludge than HRAS+AD.

The capital and operational costs of AnMBR can be decrease by increasing the flux from 10 to 20 LMH (liters/m^2/hour) assumes that chemical and energy use per unit membrane area remains constant.

In conclusion, with increased flux, low energy fouling control and well managed effluent methane emissions can make AnMBR competitive with HRAS+AD in future. Rapid advancements in AnMBR must continue to achieve full economic and environmental potential as an energy recovery strategy for domestic wastewater. (Adam L. Smith, Lauren B. Stadler, Ling Cao, Nancy G. Love, Lutgarde Raskin, and Steven J. Skerlos, Environmental Science & Technology, 2014)

2.5. Methane Gas for Electricity Production

The generation of power from methane is conceivable, in all cases the means that must be experienced are twofold, substance vitality to mechanical vitality, and afterward from mechanical vitality to electrical vitality. For these change procedures to be accomplished, reasonable motor is required, and on a basic level there are two sorts of motor which have been utilized for biogas digester power generation that is gas motor and steam turbine. As per the Malaysia Palm Oil Board (MPOB), 0.65 m3 POME is created from each prepared ton of Fresh Fruit Bunch. In view of an investigation of the potential for power generation from POME that have done by MPOB, if there was 38,870,000 m3 of POME created for each 59,800,000 tons of Fresh Fruit Bunches prepare yearly. The yearly vitality substance of the produced methane gas can be computed to 7.07E+09 kWh. In view of a transformation productivity of 38 percent (gas motor), the potential yearly electrical power generation would be 2.69E+09 kWh. Thus, Palm Oil Mill Effluent has a tremendous potential for power generation (N.A Ludin et al, 2004)

2.6. Anaerobic Digestion Operation

2.6.1 PH

PH is the essential variable that figure out if the Membrane anaerobic framework is working. The microbial group in anaerobic digester is sensitive to pH change. The pH influences the process in 2 ways that are influencing the enzymatic movement by changing their proteic structure which may happen definitely as a consequence of changes in the pH and influencing the danger of various mixes in a roundabout way eg sulfide harmfulness. The ideal pH for methane producing microorganism to accomplish ideal development is 6.6 and 7.4. Methane producing microscopic organisms require a neutral to alkaline environment (pH 6.8 to 8.5) keeping in mind the end goal to deliver methane (D.A Burke et al, 2001). Acid forming microbes develop much quicker than methane forming microorganisms. If acid-producing bacteria grow too fast, they may produce more acid than the methane forming bacteria can consume. Overabundance acid develops in the system. The pH drops, and the system may get to be distinctly lopsided, repressing the movement of methane forming microscopic organisms. Methane generation may stop completely.

Furthermore, the methanogenesis is firmly influenced by pH and will be restrained by the corrosive condition. The ideal pH for the methanogenesis stage is pH between 7.2-8.2 .If the pH fall underneath the pH of 6, anaerobic degradation rate will diminish and the lipids are not degraded (Ling,L.Y., 2007). The Acetic and butyric acids are great substrate for methanogens which frame under unbiased and acidic condition. In addition, sudden pH change (pH stun) can unfavorably influence the procedure, and recoup rely on upon arrangement of components, identified with the kind of harm brought on to the microorganism (either lasting or transitory). The cradle limit utilized must be comprehended to maintain a strategic distance from changes in pH.

2.6.2 Mechanical Mixing

Mixing will gives great contact amongst substrate and organisms guarantee the temperature is uniform, diminish resistant to mass transfer, minimized develop of inhibitory middle of the road and stabilize environment conditions (N.H Abdurahman et al, 2011). A similar hypothesis is proposed by Leslie Grady et al (1999) also where mixing ready to carry microbes consortia into contact with nourishment. The disturbance of the mixing will likewise lessen the molecule estimate which advances the release of biogas from mixing (Karim et al, 2005). The bioreactor with stirrer have been applied by a factory under Keck Seng (Malaysia) Berhad in Masai Johor since 1980s.The palm oil process effectively accomplished 83% COD removal and creation of 62.5% methane generation (Poh P.E et al, 2009). In addition, mechanical mixing is likewise show a positive outcomes in creating methane gas in the research of Choorit W. et al where a Mesophilic continuous stirred tank reactor is being utilized. Another motivating case is research done by Ugoji (1997), the trials show an aftereffect of COD removal in between of 93.6 to 97.7% (Poh P.E, 2009). However, the total blended framework is more sensitive to temperature changes (Kim M.et al, 2002). Mixing amid start up is not valuable as the digester pH will be brought down bringing about performance instability and also prompting to a delayed start-up period.(Poh P.E, 2009).However there are no systematic research on mixing in treatment of POME.

2.6.3 Organic Loading Rate

Organic Loading rate is a measure of the anaerobic digestion biological conversion capacity. Various studies have proven that Organic Loading Rate (OLR) will reduce COD removal efficiency. However, it give a positive impact on the gas production where increase of with OLR until a stage when methanogens could not work quick enough to convert acetic acid to methane which in return increased the hydrogen partial pressure concomitantly decreased the methane yield. (N.H Abdurahman et al, 2011), (H.Patel et al,2002).

2.6.4 Temperature

The temperature range for anaerobic digestion can be categorized into Psychrophilic (<25˚C), Mesophilic (25 to 40˚C) and thermophilic (<45˚C).Methane production have been documented most productive in either mesophilic conditions, at 30-35˚C or in the thermophilic range at 50-55˚C. The maximum specific growth rate of microbial population rises as the temperature increase. However, maintaining a uniform temperature in the reactor is important, because the anaerobic process is considered very sensitive to abrupt temperature changes, which may cause unbalance between the two largest microbial population and consequently result in process failure (the usual limit is about 2 ˚C per day).

The temperature affects the biological enzymatic reaction rate and influencing substrate diffusion rate. There are several research successfully produce methane in Mesophilic temperature such as K.M Ostrem et al proved that for the mesophilic digester to operate to the optimum, the temperature have to be maintained at 30-35˚C(K.M. Ostrem et al,2004). Besides, N.H Abdurahman et al conducted their experiment in the Mesophilic temperature range and shown positive result in the production of methane (N.H Abdurahman, 2011).

As mentioned before, methane production is productive in thermophilic condition as well. However, in a thermophilic digester, the start up period is much longer than mesophilic digester to allow mesophilic sludge to acclimatize with the substrate as well as temperature swift (Poh P.E et al, 2010). Besides, the external effects of the temperature on bacterial cell are important. For example, the degree of dissociation of several compound depend on temperature such as specific case of ammonia. The thermodynamic of several reactions are also affected such as the dependence of the hydrogen pressure in anaerobic digesters where fermentation occurs in appropriate manner. Methane production almost ceased after the increase of temperature indicating the importance of a stable temperature of the process.

As a result, Mesophilic digester would be chosen as the digester in this experiment to produce methane in a steady performance with the minimum constraint.

2.6.5 Hydraulic Retention time

Hydraulic Retention Time (HRT) is the number of days the sample stays in the tank. The Hydraulic Retention Time equals the volume of the tank divided by the daily flow (HRT=V/Q). The hydraulic retention time is crucial since it establishes the time available for bacterial growth especially for the growth of hydrolytic acidogenic bacteria and subsequent conversion of the organic material to gas (D.ABurke., 2001) The HRT is closely related to the OLR and substrate concentration, thus a good balance have to be maintained for good digester operation. (N.H Abdurahman, 2011).

2.6.6 Solid Retention time

Solid Retention Time (SRT) is the average time the activated-sludge solids are in the system. The SRT is an important parameter for the activated-sludge process and is usually expressed in days. (Lenntech, 2010) Although the calculation of the solids retention time is improperly stated, it is the quantity of solids maintained in the digester divided by the quantity of solids wasted each day as shown in equation below:

$$\boldsymbol{SRT = \frac{(V)(Cd)}{(Qw)(Cw)}} \qquad \textbf{(2.1)}$$

V = Digester Volume

Cd = Solid Concentration in the digester

Cw = Solid Concentration in the waste

Qw = Volume wasted each day

In a conventional completely mixed, or plug flow digester, the HRT equals the SRT. At a low SRT, sufficient time is not available for the bacteria to grow and replace the bacteria lost in the effluent. If the rate of bacterial loss exceeds the rate of bacteria growth, "wash-out" occurs. The SRT at which “wash-out” begins to occur is the "critical SRT". (M. Clara et al, 2004).

2.6.7 Volatile Fatty Acid

Fatty acid had been use as the process balance indicator. The volatile fatty acid accumulation reflects a kinetics uncoupling between acid producers and consumers and is typical for stress situations. (B.K Ahring et al, 1995). Review back to the fermentation stage, the acidogenic bacteria convert the less soluble organic compounds to organic acids such as acetic acid, propionic acid and butyric acid which known as volatile fatty acids, alcohol and other intermediates. (Husnul Azan T. et al, 2006). Hence, accumulation of VFA indicates that the further digestion of methanogenic stage is affected. Besides, the imbalance can be seen by pH, volatile solid reduction and gas composition. The VFA concentration results in pH drop in turn causing toxicity in the system. However, several studies shown that high concentration of VFA have no effect on the biogas process.

2.7. Membrane Technology

Membrane separation shows accelerated market growth result by the stringent environmental legislation and water scarcity around the world. Application of membrane technology in waste water treatment can produce high quality effluent and retain the biomass concentration within the reactor at the same time. There are 5 types of membrane filtration process, that are conventional filtration, microfiltration, ultra filtration, nanofiltration and reverse osmosis. The selection type of membrane process depends on the particles size that requires separation. Table 2.3 shows the filtration processes with their properties and applications.

Table 2.2: Filtration process with their properties and applications

Filtration Process	Pore Size	Separation Capability	Pressure (bar)	Application examples
NF	1-10nm	Mw of 200-20000	5-25	Purification of sugar and salts, water treatment
UF	5-100nm	Mw of 10K-500K	0.5-5	Pharmaceutical industry, waste water treatment
MF	50nm-5µm	Bacteria and colloids	0.5-3	Prefiltration in water treatment, sterile filtratic

(Source: Ramakrisha et al, 2011)

Table2.3: Apparent Dimensions of various Particles

Particle	Dimensions (μm)
Yeast, Fungi	1-10
Bacteria	0.3-10
Viruses	0.03-0.3
Protein (10^4-10^6 molwt)	0.002-0.1
Enzymes	0.002-0.005
Antibiotics, Polypeptides	0.0006-0.0012
Sugars	0.0008-0.001
Water	0.0002

(Source: N.H.Abdurahman et al, 2011)

Membrane characteristics are relied on the geometry, flow direction, pore size and materials which determining its properties such as the surface charges, hydrophobicity and porosity. As the molecular weight reduces, the mean pore diameter for most UF is decreased. Besides, the materials of the membrane have great influence on performance. Synthetic polymer can be dividing into two classes that are hydrophobic and hydrophilic. The fouling potential for the hydrophobic membrane is highly due to the high binding affinity of the proteins and humic substances.

2.7 Membrane Fouling

A major obstacle for the application of membrane in UMAS is the rapid decline of the permeation flux as a result of membrane fouling. Fouling refers to blockage of membranes pores during filtration caused by the adsorption particulates onto membrane surface and within the membrane pore. This blockage of the pores causes a flux decline over time when all other parameter kept constant. The predominant fouling mechanisms observed with ultrafiltration and micro filtration membranes are classified into three categories: the build-up of a cake layer on the membrane surface, blocking of membrane pores, and adsorption of fouling material on the membrane surface or in the pore walls (M.O.Laminen, 2004). To establish strategies for fouling control, understanding of the fouling mechanisms is indispensable. Sludge characteristics are significant parameters that can affect membrane fouling in UMAS. Fouling can be broadly classified into backwashable and irreversible. Backwashable can be removed either by backwashing or chemical cleaning while the irreversible type neither of the method can recover the original flux. Fouling can also be classified according to type of the fouling materials. There are four types of membrane fouling:

a) Inorganic fouling

b) Particle /colloidal fouling

c) Microbial fouling

d) Organic fouling

2.9. Improvement of Biohydrogen Production through Combined Reuses of Palm Oil Mill Effluent Together with Pulp and Paper Mill Effluent in Photofermentation

To produce biohydrogen through photofermentation process, Rhodobacter sphaeroides and Palm Oil Mill Effluent (POME) were used as purple nonsulfur bacteria and substrate respectively. Since POME has a dark colour and has higher turbidity, pulp and paper mill effluent (PPME) was used as diluting agent to reduce the turbidity of the substrate and improve light penetration. The highest biohydrogen yield of 4.67mL H_2/mL medium was obtained using 25% of POME and 75% of PPME. 28.8% of total COD removal was obtained after 3 days of photofermentation.

There are some advantages of the photofermentative biohydrogen production. The process reuses waste materials, has high theoretical biohydrogen yield, lack of oxygen evolving activity and has the ability to utilize a wide spectrum of light. Purple nonsulfur bacteria (PNS) such as Rhodobacter sp., Rhodopseudomonas palustris, and mixed culture bacteria have the ability to convert organic acids into biohydrogen through nitrogenase activity because they have high biohydrogen-producing potential. Kornochalert et al. reported that in latex rubber sheet wastewater treatment using fermented pineapple extract inoculated indigenous PNS, 91% of COD removal was achieved.

In Malaysia, about 50 million tons of POME generates annually through crude palm oil extraction and it can cause severe pollution because of its high biochemical oxygen demand and high colloidal nature of the suspended solids. Photofermentation is one of the processes to treat

POME. POME contains organic acids, carbohydrate, lipids, minerals and nitrogen that can helps the growth of several microorganisms. Budiman et al. reported that concentration of 25% POME was the best to reuse as growth medium for R.sphaeroids due to the presence of nutrients and adequate light penetration. PPME was selected as diluting agent because of its lighter color than POME.

Photofermentation of biohydrogen production was conducted in 100mL Schott bottle. Fluorescent lamps were used as light source. Constant temperature was used. Produced biogas collected using water displacement method. The content of biohydrogen and carbon dioxide in biogas was measured with gas chromatography equipment. The loss of organic matters were calculated by measuring COD_{total} and $COD_{soluble}$ values. (Pretty Mori Budiman, Ta Yeong Wu, Ramakrishnan Nagasundara Ramanan, and Jamaliah Md. Jahim, ACS Publications, July 23, 2015)

2.10 Effects of Temperature on Aerobic Treatment of Anaerobically Digested Palm Oil Mill Effluent (POME)

Palm Oil Mill Effluent (POME) can cause deleterious hazards to environment because of its high chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Presently, ponding system is used to anaerobically treat the POME. Subsequent aerobic post-treatment is vital to bring the anaerobically treated POME to within the effluent discharge standard. POME is discharged at high temperatures (75-85°C), therefore making it possible to be treated thermophilic (45-60°C) temperatures.

Thermophilic aerobic process has stable COD removal and good ability to tolerate varying organic loading rates at short hydraulic retention time ranging from 6 to 30 h. Thermophilic process also has faster microbial growth and lower net sludge yield.

Thermophilic process use lab scale sequencing batch reactors (SBR) operated at 45, 50 and 55°C. A magnetic stirrer used for intermixing and all SBRs were covered with aluminium foil to minimize evaporation. The thermophilic aerobic treatment was capable of achieving promising treatment efficiencies in terms of TCOD and biochemical oxygen demand (BOD) removals, which exceeded 72% and 76%, respectively, at an OLR of 2.8 (0.3 kg COD/m3 · day.

The thermophilic sludge also showed good settling characteristics, as reflected by the low sludge volume index (SVI) values (<100). (Yi Jing Chan, Mei Fong Chong, and Chung Lim Law, American Chemical Society, 2010)

2.11 Ultrasound-assisted Transesterification of Refined and Crude Palm Oils using Heterogeneous Palm Oil Mill Fly Ash Supported Calcium Oxide Catalyst

Biodiesel can be produced through ultrasound-assisted transesterification of refined and crude palm oils using palm oil mill fly ash supported by calcium oxide catalyst. With the use of ultrasound, the reaction time can be reduced from 360 minutes to just 30 minutes.

Calcium oxide catalyst can be reused up to three consecutive cycles after regeneration using methanol washing followed by recalcination at 850°C for 2 h. The catalysts also can be easily separated from reaction mixture and have higher activity, stability and selectivity as well as longer lifetime.

The heterogeneous route can lowers the overall biodiesel production costs and minimizes environmental impacts through simpler production and purification steps. The major drawback of this heterogeneous route is its low reaction rate due to weak interactions between oil, alcohol and catalyst because of their immiscibility. The use of ultrasound can overcome this drawback by effective mixing of solutions, disruption of immiscible liquid layers and promotion of mass transfer at the liquid-solid interface.

Ultrasound-assisted transesterification reactions carried out in a customized three-neck jacketed reactor equipped with an ultrasound transducer and a probe. Cooling water allowed too flow through the jacket to control reaction temperature. After the reaction, the sold catalyst will be filtered out from the mixture using vacuum pump. At the end of experiment, the effects of ultrasonic amplitude, reaction time, catalyst loading and methanol to oil molar ratio will be investigated. (Wilson Wei Sheng Ho, Hoon Kiat Ng, Suyin Gan & Wai Loon Chan, Energy Science & Engineering 2014)

2.12 Metagenomics shows that Low-energy Anaerobic-Aerobic Treatment

Reactors Reduce Antibiotic Resistance Gene Levels from Domestic Wastewater

Domestic wastewater need to treat to prevent transmission of infectious waterborne disease and to defense against poor quality of water. Presently, there are wastewater treatment plants that can remove organic matter such as COD, nitrogen and bacteria. However, activated sludge processes require high operating costs.

There is one energy-saving treatment, anaerobic-aerobic sequence (AAS) reactors. Anaerobic step will pretreat the water and reduce COD levels while produce biogas. Aerobic processes will polish the effluents to meet effluent discharge standards. AAS reactors have lower capital costs, smaller footprints, lower sludge production and reduced energy use because of lower oxygen demand. AAS reactors able to reduce aminoglycoside, tetracycline and β-lactam antibiotic-resistant genes (ARGs) levels. AAS reactors show promise for future applications because they can reduce more ARGs for less energy (32% less energy). (Beate Christgen, Ying Yang, S. Z. Ahammad, Bing Li, D. Catalina Rodriquez, Tong Zhang, and David W. Graham, Environmental Science & Technology, January 20, 2015)

2.13 A Two-Stage Microbial Fuel Cell and Anaerobic Fluidized Bed Membrane Bioreactor (MFC-AFMBR) System for Effective Domestic Wastewater Treatment

Microbial fuel cells (MFCs) are energy-efficient treatment for domestic wastewater. But the effluent quality has not been sufficient for discharge without further treatment. Hence, a two-stage laboratory-scale combined treatment process, consisting of microbial fuel cells and an anaerobic fluidized bed membrane bioreactor (MFC-AFMBR) was introduced to produce high quality effluent with minimal energy demands.

MFCs are sustainable energy technology, as they can produce electricity from wastewater. MFCs have lower sludge production than other aerobic treatment processes, which can reduce treatment and disposal costs of sludge. MFCs have one major drawback that is MFCs ineffective to COD removal because they are more effective for soluble than particulate COD removal.

The anaerobic fluidized membrane bioreactor (AFMBR) is the effective approach for achieving high quality effluent when used as post-treatment method. In AFMBR, membrane fouling is controlled using granular activated carbon (GAC) as the fluidized particles. Hence, the membrane will not require frequent cleaning and high maintenance costs can be reduced.

By using two-stage microbial fuel cell and anaerobic fluidized bed membrane bioreactor system, the effluent COD can be reduced about 92.5% and nearly complete removal of total suspended solids (TSS). The AFMBR can operates at a constant high permeate flux over 50 days without the need to clean the membrane. The total electrical energy required by the AFMBR also less than the electricity produced by MFCs. The combined MFC-AFMBR system can effectively treat domestic wastewater at ambient temperature while producing high quality effluent with low energy requirements. (Lijiao Ren, Yongtae Ahn, and Bruce E. Logan, Environmental Science & Technology, February 25, 2014)

2.14 Biocathodic Methanogenic Community in an Integrated Anaerobic Digestion and Microbial Electrolysis System for Enhancement of Methane Production from Waste Sludge

Treatment for waste-activated sludge (WAS) is the major concern in wastewater treatment plants. WAS disposal represents about 50% of current operating costs. WAS digestion involves hydrolysis, fermentation, syntropic acetogenesis and methanogenesis. Methanogens are the main sources for the methane production. There are two types of methanogens, hydrogenotrophs and methylotrophs.

Acetoclastic methanogens grow extremely slow and very sensitive to inhibitory factors such as ammonia concentration, liquid upward velocity and hydraulic retention time. Hydrogenotrophic can grow faster than acetoclastic methanogens.

Bioelectrochemistry introduces new pathway for hydrogen evolution from organic compounds which depends on electrolysis reaction and microbial catalysts in microbial electrolysis cells (MECs). MEC oxidizes organic compounds at anode and transfers the electron and proton to cathode where hydrogen evolution is boosted. Hence, biocathodes in the MEC can potentially catalyze methane production and stimulate growth of hydrogenotrophic methanogens.

The methane production in hybrid reactor, which coupled bioelectrolysis and anaerobic digestion nearly double than in anaerobic reactor without bioelectrochemical device. Hence, by utilizing biochemical system with the regulated microbial community, methane production from waste-activated sludge can be enhanced. (Weiwei Cai, Wenzong Liu, Chunxue Yang, Ling Wang, Bin Liang, Sangeetha Thangavel, Zechong Guo, and Aijie Wang, ACS Sustainable Chemistry & Engineering, July 19, 2016)

CHAPTER 3: METHODOLOGY

3.1. Chapter Overview

In this chapter, the materials and methods to conduct the research study are described in brief. It covers the materials and methods used for biomethanation of POME study and product analysis.

3.2. Materials

3.2.1. Chemicals to be used for Biomethanation and Product Analysis

The chemicals and their respective uses are tabulated below:

Table 3.1: Chemicals and their uses

No	Chemical	Uses
1	Potassium Hydroxide	To absorb carbon dioxide
2	Sodium Hydroxide	To absorb carbon dioxide
3	COD Digestion Reagent Vials	For COD Determination
4	Phosphate Buffer Solution 1M	For BOD Determination
5	Magnesium Sulfate Heptahydrate, MgSO4.7H2O	For BOD Determination
6	Calcium Chloride, CaCI2	For BOD Determination
7	Iron(III) Chloride Hexahydrate, FeCI3.6H2O	For BOD Determination
8	Concentrated Sulfuric Acid, H2SO4	To adjust PH

3.3. Experimental Procedures for Biomethanation of POME by Ultrasonic-Membrane Anaerobic System

Wastewater Preparation

POME will be preserved at a temperature less than 4°C and higher than freezing point to prevent biodegradation and stored in PVC container. Before the experiment, POME will be filtered to remove suspended materials.

Operating Procedure

50litres Ultrasonic-Membrane Anaerobic system will be used for this study. The filtered POME will be left in feeder tank for 5 days for acclimation process. Some of the POME will be collected and analyzed for the parameters such as pH, COD, BOD, TSS, VSS, color and temperature to obtain initial characteristic of POME. PH will be controlled in the range of 6.8 to 7.4, pressure will be set to be 1.5 to 2 bars and temperature will be maintained within 25°C to 37°C. The reactor will be left to operate for 5 hours. After 5 hours, the permeate will be collected and tested for various parameters. The gas produced will be collected using designated syringe. The experiment will be conducted for every of the subsequent days.

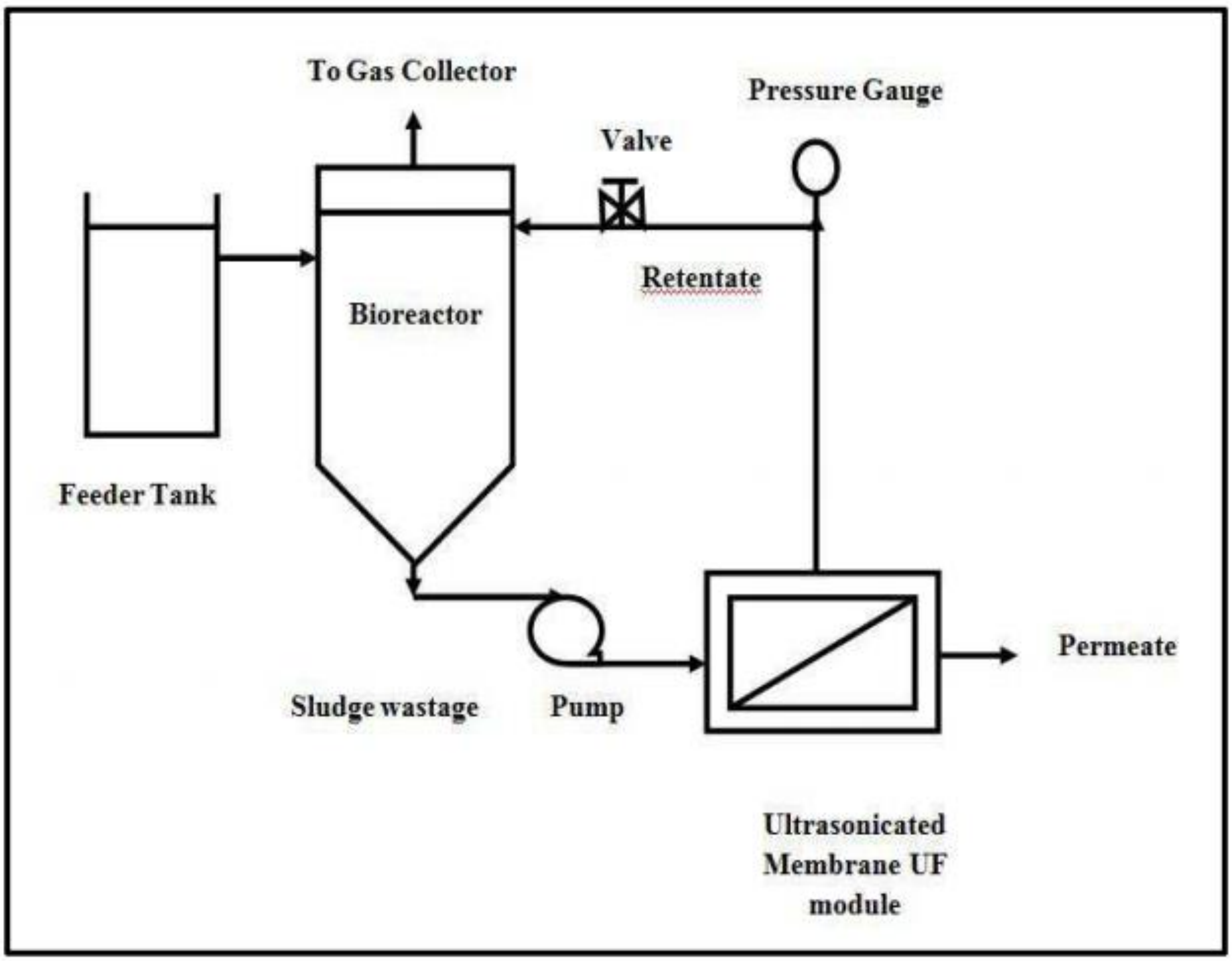

Figure 3.1: Experimental Set-up

3.4. Analysis of Products

Methane gas measurement

J-tube gas analyzer will be used for the measurement of methane gas component. 0.5M of potassium hydroxide (KOH) will be drawn into the syringe to absorb carbon dioxide. The end of the glass tube will be immersed into the water to prevent gas escape. The biogas column will be measured.

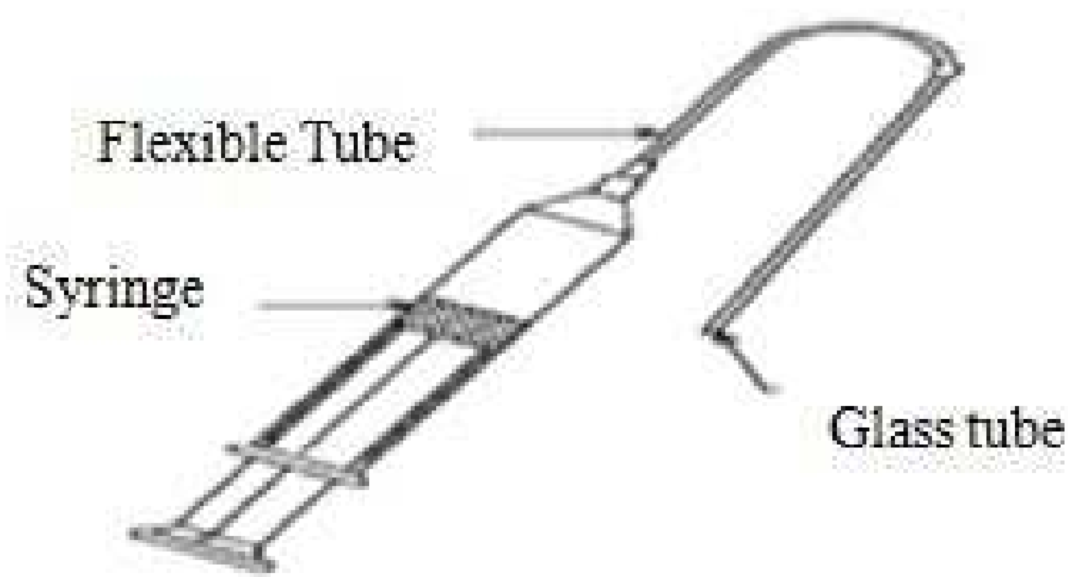

Figure 3.2: J-Tube Gas Analyser

Calculations for gas measurement

Percentage of methane gas (%) = $\frac{\textit{Final gas column length}(cm)}{\textit{Initial gas column length}(cm)} \; x\, 100$ **(3.1)**

Determination of Chemical Oxygen Demand

COD digestion reactor will be reheated to 150°C. 2.00 mL of the POME will be added to the COD Digestion Reagent Vials. The prepared sample and blank vial will be heated for two hours in the COD reactor. After two hours, the vials will be let to cool to 120°C. The reading will be taken by placing the vials in the spectrometer, HACH DR/2400.

Determination of Biochemical Oxygen Demand

Phosphate buffer solution, Magnesium sulfate solution, Calcium chloride solution and Ferric chloride solution will be prepared at the beginning of the experiment. 1mL of each of the solutions will be added to 1L volumetric flask and distilled water will be added to 1L. 10mL of POME will be added into 500mL beaker and dilution water will be added up to 300mL. The prepared sample will be put in 300mL incubation bottle. The DO concentration will be measured using Dissolved Oxygen Meter. After water is added to the flared mouth of the bottle it will be covered with aluminium foil. The bottle will be put in BOD incubator for five days and temperature will be set to 20°C. The final DO value will be measured after five days.

Calculations

$$\textbf{BOD}_5\textbf{, mg/L} = (D_1 - D_2) \times \textbf{Dilution factor} \qquad (3.2)$$

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

D_1 = Dissolved Oxygen value in initial sample

D_2 = Dissolved Oxygen value in final sample

Determination of Total Suspended Solids (TSS)

A filter paper will be dried at 103°C and weighed. In a Buchner flask, 50mL of POME will be pipetted onto centre of filter paper. The filter will be washed with three successive 10mL volumes of distilled water. The filter paper will be dried at least one hour at 103°C and weighed. The cycle of drying, cooling and weighing will be repeated until a constant weight is obtained.

Calculations

$$\textbf{mg TSS/L} = \frac{(A - B) \times 1000}{\textbf{Sample volume, mL}} \qquad (3.3)$$

where;

A = weight of filter + dried residue, mg

B = weight of filter, mg

Determination of Volatile Suspended Solids (VSS)

The filter used for total suspended solids testing will be ignited at 550°C for 30 minutes. The weight lost on the ignition of the solids will represent the volatile solids in the sample.

Determination of PH, Temperature and Color

The color changes before and after the experiment will be observed. Temperature and pH will be measured using thermometer and pH meter respectively.

CHAPTER 4 : RESULTS AND DISCUSSIONS

4.1. Initial Measurements of POME

Table 4.1: Initial Measurements of POME

Parameters	Initial Measurement
Ph	4.00
Temperature (°C)	60
COD (mg/L)	3463
BOD (mg/L)	264
TSS (mg/L)	28
VSS (mg/L)	26
Methane Production (%)	0,0

4.2. Summary Results of UMAS Performance

Table 4.2: Summary Results of the Experiments

Hydraulic Retention Time	COD Permeate	% Methane	COD Removal (%)	TSS Removal (%)	BOD Removal (%)	VSS Removal (%)	pH of Permeate
1	3239	-	29	78.78	96.88	75.42	5.86
2	1999	-	8.72	83.45	66.66	82.22	8.23
3	2045	-	13.35	84.64	46.67	80.33	8.16
4	1970	83.61	49.10	90.27	35.84	88.35	8.16
5	1953	62	55.05	92.16	18.69	86.03	8.08
6	1870	65.3	52.05	92.34	17.46	89.77	6.59
7	1859	70.8	55.44	88.24	13.39	87.66	7.91
8	2068	51	59.74	91.68	6.98	91.54	7.78
9	1868	67.11	58.53	90.75	1.41	88.49	7.6
10	1953	67.11	53.99	92.09	1.15	90.79	7.7

From the table above, it can be conclude that methane gas can be collected on fourth day of the experiment when using Ultrasonic Membrane Anaerobic System. The highest amount of methane gas was obtained on the fourth day that is about 83.61%. The amount of methane gas decreases from fourth day to the tenth day because the amount of biodegradable matters in the POME inside the reactor already converted into biogas.

4.2.1. Chemical Oxygen Demand

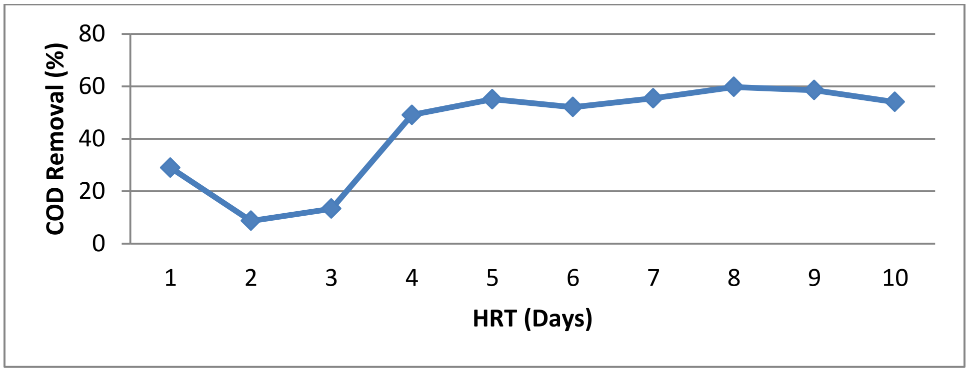

Figure 4.1: Removal Efficiency of chemical oxygen demand

The above graph shows that the chemical oxygen demand (COD) removal efficiency increases and become constant after fifth day. The COD removal efficiency is very low on 2nd and 3rd days. Since hydraulic retention time is experimented in this project, the microorganisms have no sufficient time to acclimatize and produce new cells. The sudden increase in graph after 3rd day shows that microorganisms already acclimatize and new bacteria were produced. The constant COD removal efficiency after fifth day explains that most of the biodegradable matters in POME already reduced.

4.2.2. Biochemical Oxygen Demand

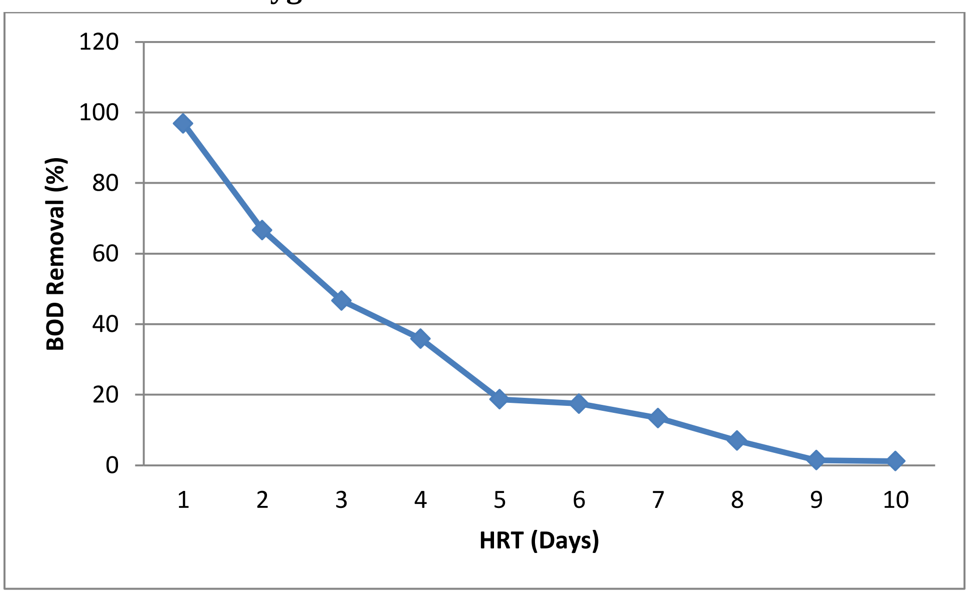

Figure 4.2: Removal efficiency of biochemical oxygen demand

The above graph shows the decrease in BOD removal efficiency as days passes. Biochemical oxygen demand only focuses on biodegradable matters. As days pass, the amount of biodegradable matters change to biogas also increase. Hence, the amount of biodegradable matters in the POME inside reactor also reduced. These can explain the reason of the decrease in BOD removal efficiency as time passes.

4.2.3. Total Suspended Solids

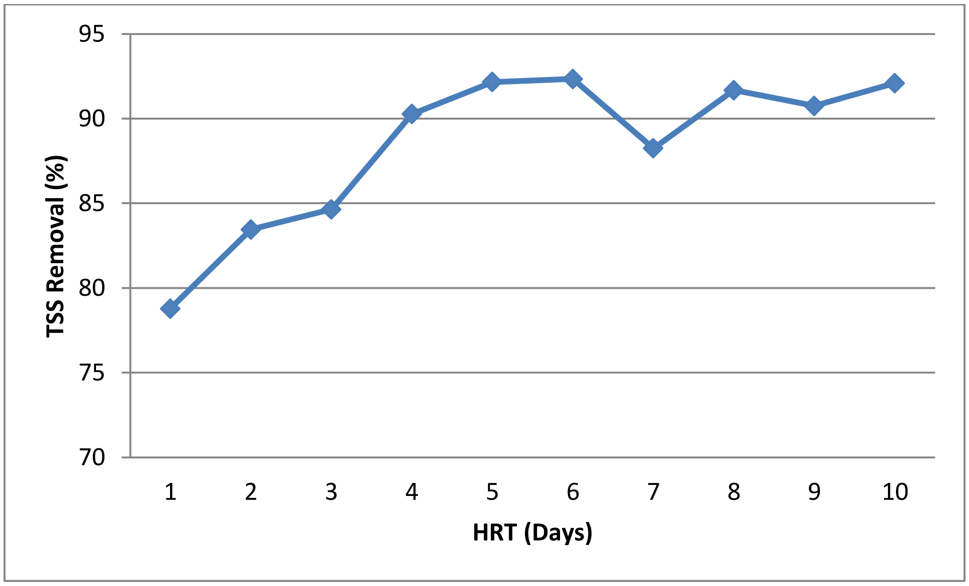

Figure 4.3: Removal efficiency of total suspended solids

The above graph shows the relationship between total suspended solids (TSS) removal efficiency and hydraulic retention time. The trend of the graph is increasing. This shows that the amount of solids hydrolyze, dissolve and turn into biogas also increasing as days pass. Apart from that, it also indicates that the microorganisms inside the reactor are increasing.

4.2.4. Volatile Suspended Solids

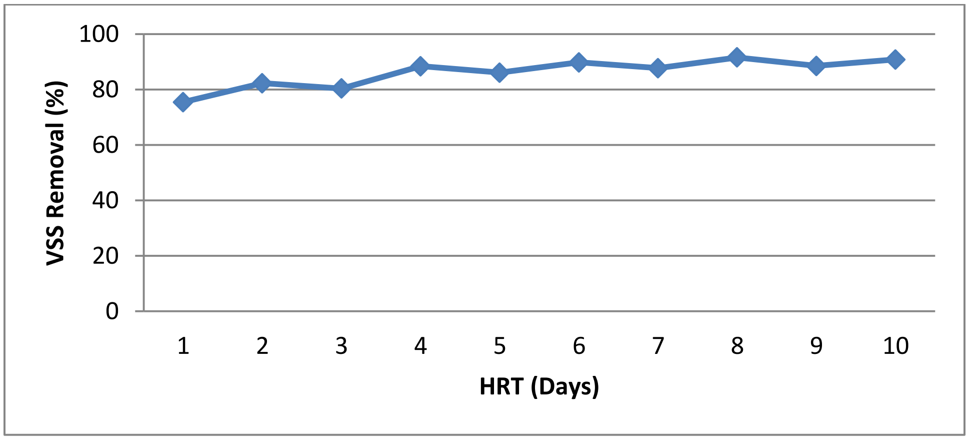

Figure 4.4: Removal efficiency of volatile suspended solids

The above graph shows that the volatile suspended solids (VSS) removal efficiency almost constant as time passes. The graph shows that not all the solid mass participates in the conversion of the organic fraction. There is also some inorganic compound that does not play active role in biological treatment. When total suspended solids removal increases, the volatile suspended solids removal also increases. This indicates that the UMAS system facilitates decomposition of suspended solids well. It can be concluded that microorganisms acclimatize well with UMAS system environment.

4.2.5. PH of Permeate

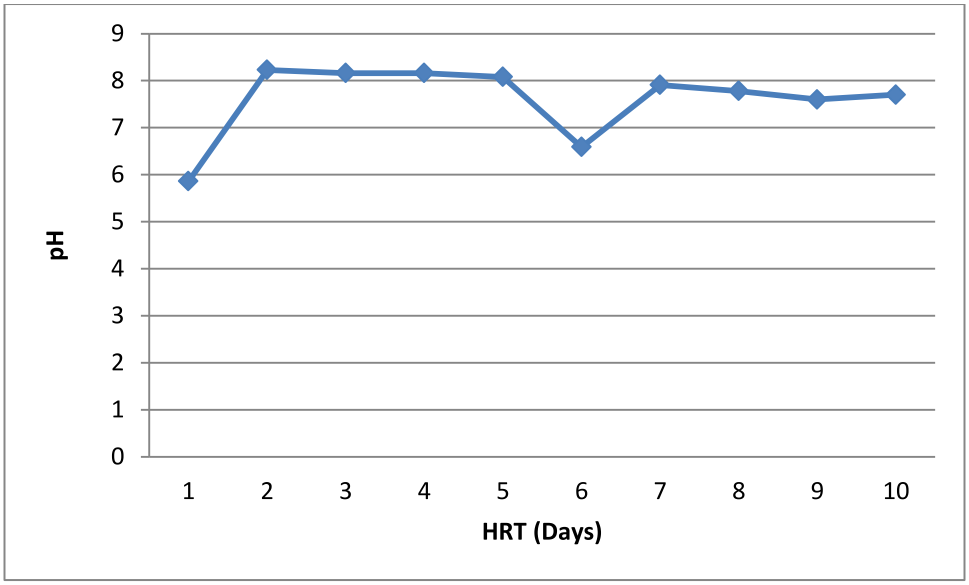

Figure 4.5: PH of permeate against hydraulic retention time

The above figure shows the relationship between pH of permeate and hydraulic retention time. PH inside the reactor need to maintain between 6.5 to 8 for the UMAS system operates effectively. From the figure, it can be seen clearly that there is sudden pH drop on the 6th day. It can be concluded that the amount of carbon dioxide gas inside the reactor is increasing. So, a specific amount of sodium hydroxide was added to increase the pH.

4.3. Comparison between performance of Membrane Anaerobic System (MAS) and Ultrasonic Membrane Anaerobic Treatment (UMAS)

Table 4.3: Comparison between UMAS and MAS

Parameters removal efficiency	MAS	UMAS
COD (%)	50.29	59.74
BOD (%)	64.32	96.88
TSS (%)	75.72	92.34
VSS (%)	94.44	91.54

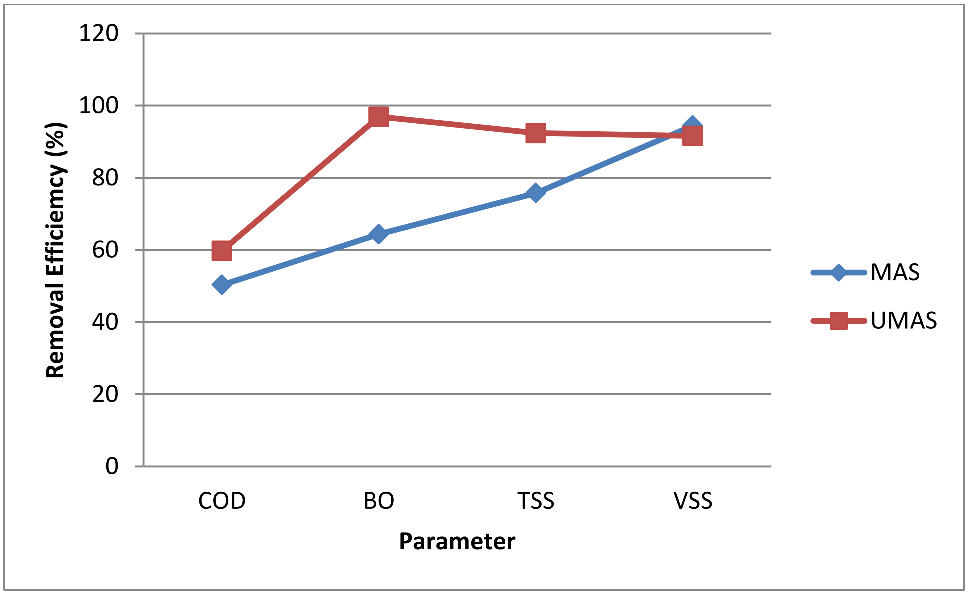

Figure 4.6: Comparison between MAS and UMAS

From the graph above, it can be clearly seen that the performance of Ultrasonic Membrane Anaerobic System (UMAS) better than Membrane Anaerobic System (MAS). The removal efficiency of COD, BOD, TSS and VSS of UMAS are higher than MAS. This shows that UMAS successfully overcome membrane fouling problem.

CHAPTER 5 : CONCLUSION AND RECOMMENDATION

5.1. Conclusion

UMAS was found as an effective method to treat the POME. The highest removal efficiency of COD was about 59.74%. Furthermore, the highest removal efficiency of BOD and TSS were 96.88% and 92.34% respectively. The methane composition produced from the treatment of POME using UMAS also quite high that is 83.61%. This clearly shows that membrane fouling problem found in MAS was solved when using ultrasonic in the treatment. The ultrasonic device constantly cleans the surface of membrane and increases the lifetime of membrane while increase the effectiveness of the Ultrasonic Membrane Anaerobic System. When compare UMAS with MAS, the removal efficiency of COD, BOD and TSS are 9.45%, 32.56% and 16.62% respectively higher than MAS. Hence, it can be concluded that UMAS is a cost-effective alternative to treat high strength wastewater when compared to other conventional methods. The objectives of this study were attained where the treatment of POME using UMAS was enhanced and membrane fouling problem also solved.

5.2. Recommendations

Firstly, the pH inside the reactor must be maintained between 6.5 to 7.8 for the microorganisms to degrade the organic matters efficiently. A small amount of sodium hydroxide and sulphuric acid can be added to increase and decrease the pH. The temperature inside the reactor must be maintained constant at 35°C because high temperature can denatured the bacteria inside thee POME.

Furthermore, before put the POME sample inside the reactor, the reactor need to be covered with aluminium foil fully to prevent sunlight enter the equipment. Methane gas can only be produced from an anaerobic reaction. Other than that, after the gas collected, the gas valve need to be closed tightly to prevent the leakage of the biogas into atmosphere. Lastly, the dilution water used for BOD experiment need to be prepared precisely to get the results accurately.

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APPENDIX

Figure 7: Reactor covered with aluminium foil during acclimatization phase

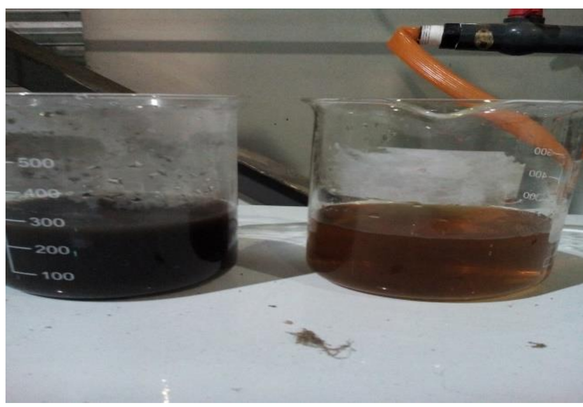

Figure 8: Comparison of color between raw POME and permeate

Figure 9: TSS test on 10th day