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The Performance Study of Ultrasonic-Assisted Membrane Anaerobic System (UMAS) in Palm Oil Mill Effluent (POME) Treatment

[1]N. F. A Shafie, [1]J. M. Uloi, [1,3]A. M. Som, [2]A. H. Nour, [2]Z. Hassan, [2]R. M. Yunus and [1]A. Yahya

[1]*Faculty of Chemical Engineering, Universiti Teknologi MARA, 45050 Shah Alam, Selangor.*
[2]*Faculty of Chemical Engineering & Natural Resources, Univesiti Malaysia Pahang, 26300 Gambang, Pahang.*
[3]*Accounting Research Institute, Universiti Teknologi MARA, 40450 Shah Alam, Selangor.*

Address For Correspondence:
A. Yahya, Faculty of Chemical Engineering, Universiti Teknologi MARA, 45050 Shah Alam, Selangor.
E-mail: asda@salam.uitm.edu.my, +60199854998

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ABSTRACT

The development of palm oil industry in Malaysia has turned into phenomena in which the area of plantation expands from year to year. In the meantime, rapid growth in its downstream and upstream processing activities has also caused detrimental effect to the environment. Therefore, a new technology needs to be sought to reduce the impact on environment and at the same time renewable form of energy can be generated as an alternative source for the palm oil mill. Throughout the decades, membrane bioreactors have been widely employed in POME treatment. However, its major drawback is central to membrane fouling problem. Thus, membrane cleaning is an essential part during the operation of membrane reactors since the membrane fouling is an unavoidable issue. Ultrasonic-assisted Membrane Anaerobic System (UMAS) is a promising technology through which an ultrasonic device is applied to the system so as to reduce the fouling of membrane and at the same time increase the COD removal efficiency. The UMAS operation was evaluated at HRT of 11 days. POME sample was taken from a palm oil mill in Sungai Tengi, Selangor and was evaluated in respective 1 hour and 2 hours of sonication period in order to observe their performances in terms of percentage COD removal efficiency and methane (CH_4) production. From the study, overall results demonstrated that 2 hours sonication in UMAS was better in operation compared to 1 hour operation as it produced higher COD removal efficiency and methane gas production. The 2 hours sonication operation showed steady rise and higher percentage of COD removal (98.75%) as compared to 1 hour sonication operation (97.71%). The total production of CH_4 gas in 2 hours sonication experiment was 32,595 mL whereas 1 hour sonication produced 15,900 mL of CH_4 gas.

INTRODUCTION

Palm oil is the most traded cooking oil in the world, and Malaysia is the second largest producer in the world. Rapid growth in the palm oil industry has caused negative effect on the environment. According to Awalludin *et al.* (2015), approximately 60 million tonnes of POME were generated in 2011. In the early ages, the residue from the production process was burned and the effluent was thrown into the airways which caused serious problem to the environment. The downstream product consists of 60% palm oil mill effluent (POME), 23% empty fruit bunch, 16% mesocarp fibre and 5% shell (Awalludin *et al.*, 2015; Choi *et al.*, 2013). Palm oil mill wastewater is low in pH (in the range of 4 to 5) because of organic acids produced in the fermentation process, also contains large amounts of total solids (40,500 mg/L), oil and grease (4000 mg/L), high temperature

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(80-90°C), and high organic content (COD 50,000 mg/L, BOD 25,000 mg/L) (Abdurahman and Azhari, 2013; Skouteris *et al.*, 2012).

Weakness in conventional way of waste water handling has caused detrimental effect to the environment. It creates major problem in disposing of the waste in appropriate ways. Local governments are forced to look for alternative technology for the palm oil mill effluent (POME) treatment because the demand of the palm oil increases with the increased awareness on environmental issue (Yunus *et al.*, 2015). Thus, several cost-effective treatment methods have been developed to treat POME over the past decades among which are; anaerobic, aerobic and facultative processes. However, these conventional treatments are not viable in terms of retention time, surface area required, facilities to capture biogas and producing good quality effluent. In contrast, high-rate and hybrid bioreactors are more effective in biodegradation because of shorter HRT and high production rate of methane (Visvanathan and Abeynayaka, 2012). Aerobic digestion and membrane separation are among alternatives to anaerobic digestion. Nevertheless, several major drawbacks are encountered in these processes such as high operational cost and fouling problem.

Membrane separation offers numerous advantages to the industrial application; however, this technology needs to bear serious limitations associated to fouling (Skouteris *et al.*, 2012; Wang *et al.*, 2014). Recently, a new approach has been developed to assist in reducing these unfavourable phenomena by applying ultrasound device. A new design is proposed in which an ultrasonic device is added into the MAS system in treating POME and producing methane (Abdurahman *et al.*, 2011). The introduction of ultrasonic device eliminates the presence of membrane fouling in the system and high COD removal percentage is achieved in a shorter time. UMAS depicted better performance as compared to MAS in treating the sugarcane mill effluent (SCME) as it achieved higher percentage removal efficiencies for COD, BOD and TSS which were 97%, 96% and 100%, respectively (Mahendran *et al.*, 2014). Thus in this present work, UMAS model is used for higher organic loading rates of POME to study its performance in terms of percentage COD removal and CH_4 production.

Methodology:

A. Palm Oil Mill Effluent (POME):

Raw POME was collected from Felda Sungai Tengi, Palm Oil Mill in Selangor. Samples were screened through strainer to remove coarse particles so as to avoid pump damage and membrane fouling. The samples were kept in a container and stored in a cold room at 4°C prior to the actual experiment so as to avoid deterioration and contamination of the sample. 40 L of the sample was fed inside an anaerobic reactor and allowed to stay inside the reactor for 2 days before the experiment started. The sample was analysed for biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), volatile suspended solids (VSS) and pH as shown in Table 1.

Table 1: Raw POME characteristics

Parameter	1 Hour Sonication	2 Hours Sonication
Biological Oxygen Demand (BOD)	403.32 mg/L	437.31 mg/L
Chemical Oxygen Demand (COD)	47600 mg/L	42800 mg/L
Total solid (TS)	16030 mg/L	11740 mg/L
Volatile Suspended Solid (VSS)	13170 mg/L	13270 mg/L
Temperature	54 °C	55 °C
pH	4.09	3.97

B. Bioreactor operation:

The sieved POME was fed into the reactor and left for 2 days to ensure the microorganisms present were fully acclimatized in the 40-litre reactor volume located at the Faculty of Chemical Engineering, UiTM Shah Alam. Raw POME was fed into the anaerobic reactor and was left in the reactor for 2 days to ensure the microorganisms was fully acclimatized with the reactor's environment. The reactor was covered with aluminum foil to prevent algae formation from the penetration of direct sunlight into the reactor. (Mahendran *et al.*, 2014). It is also to ensure the microorganisms are not affected by extreme sunlight. After the acclimation period, the reactor was left to operate for 5 hours. During this period, the POME from the digester was pressurized into the ultrafiltration membranes simultaneously. As for the ultrasonic application, it was operated at the first and third hours of the experimental run for one hour sonication period. On the other hand, the ultrasonic device was operated at the second and fourth hours of the experimental run for two hours sonication period. The treated POME (permeate) was taken from the collection tank after 24 hours for the purpose of analysis at each batch of hydraulic retention time (HRT). According to Abdurahman and Nuri (2014), the UMAS system has successfully separated the HRT and solid retention time, SRT by equipping membrane in the system whereby the filtrate was discharged and the sludge was recycled back into the system. The UMAS performance was evaluated at HRT of 11 days. It has been fixed accordingly as the variations in HRT may change the membrane fouling propensity (Ozgun *et al.*, 2013). A 0.5L cylinder water displacement was used to measure the daily biogas volume. The produced biogas contained CO_2 and CH_4, thus sodium hydroxide (NaOH) solution was added to absorb CO_2

effectively so as to isolate the CH_4 (Abdurahman *et al.*, 2011). Figures 1 and 2 show a schematic flow diagram of the UMAS which consists of namely; a membrane module accommodating four pieces of membranes in tubular form at once, a centrifugal pump, and an anaerobic reactor.

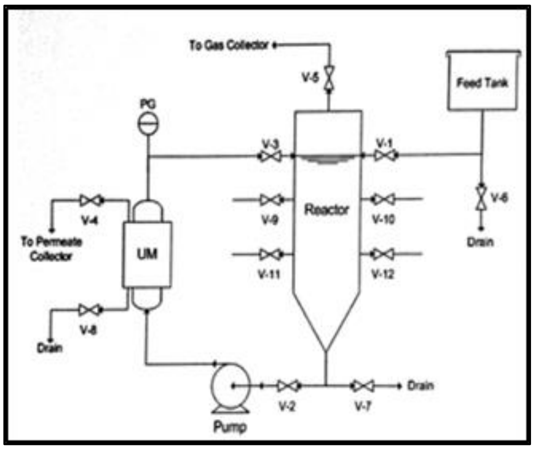

Fig. 1: Schematic flow Diagram of Ultrasonic Membrane Anaerobic System (UMAS)

Fig. 2: Ultrasonic Membrane Anaerobic System (UMAS)

The ultrafiltration (UF) membrane module had a molecular weight cut-off (MWCO) of 200,000, a tube diameter of 1.40 cm and an average pore size of 0.1μm. The length of each tube was 30 cm. The total effective area of the four membranes was 0.185 m². The optimum operating pressure on the membrane was 1.5-2 bars at 25-37ºC, and the pH ranged from 6.8-78. The pH was increased to the optimum condition by adding base solution (sodium hydroxide). The reactor was composed of a heavy-duty reactor with an inner diameter of 30 cm and a total height of 97 cm. The operating pressure in this study was maintained between 2 bars by manipulating the gate valve at the retentate line after the membrane assembly.

It is very important to maintain the neutral pH value in order to reduce the CO_2 formation inside the reactor because the increase of fatty acids will cause more production of CO_2, and will decrease the production of CH_4 (Youngsukkasem *et al.*, 2013). Thus in this study, the UMAS pH was maintained in an optimum range (6.8-7) to minimize the effects on methanogens that might influence biogas production. Many factors such as mixing, operating temperature, nutrient availability and organic loading rates must be adequately controlled alongside with pH to ensure the performance of anaerobic digesters and prevent failure in the digester. Mixing provides good contact between microbes and substrates, reduces the resistance to mass transfer, minimizes the build-up of inhibitory intermediates and stabilizes environmental conditions (Abdurahman and Azhari, 2013). Hence, this UMAS study adopted biogas recirculation. Besides, the temperature gauge was installed in UMAS with the purpose of monitoring the operating temperature and keeping it constant throughout the experiment to maintain active microbial activity. The volume of POME sample in the UMAS is maintained at 35L throughout the process by topping up raw POME after each experiment so as to ensure the nutrient availability and ideal organic loading rates in the digester.

C. Analytical Method:

The POME samples before and after the experiment were determined according to the method approved by USEPA for wastewater analysis. All experimental analyses were conducted at the Environmental Engineering Laboratory 1, Faculty of Civil Engineering, UiTM Shah Alam. The COD of samples was determined according to colorimetric method (HACH Method 8000). The TSS and VSS were determined according to Standard Method 2540 D and E, respectively. The pH and temperature were measured by using a HACH Sension3 pH meter with temperature probe. Dissolved oxygen (DO) was measured by using a DO meter (YSI model 5000, USA).

RESULTS AND DISCUSSION

A. COD Removal Efficiency:

The efficiency of UMAS can be determined by identifying the COD removal efficiency of treated POME or permeate at different hydraulic retention times. The percentage removal of COD was reflected in the rise of biomass concentration, as the dissolved organics were converted into new cells (Poh and Chong, 2010).The hydraulic retention times were determined to be crucial design criterion, particularly for the treatment of POME effluent with concentrated influent COD (Abdurahman and Zafiqah, 2014). Figure 3 shows the COD removal efficiencies profile achieved on the 11th day for 2 hours (98.75%) and 1 hour (97.71%) of sonication periods, respectively. The 2 hours sonication operation shows higher percentage and steady rise of COD removals compared to 1 hour sonication operation. This has proven that sonication helps to make ease on the membrane cleaning, efficiently and effectively throughout the experiment. Sudden rise of biomass concentration in the reactor has caused the formation of biofilm layer onto the surface of the membrane which might result in membrane fouling over extended periods. By having 2 hours sonication operation, more contact times were employed for cleaning the fouled membrane as compared to 1 hour sonication operation.

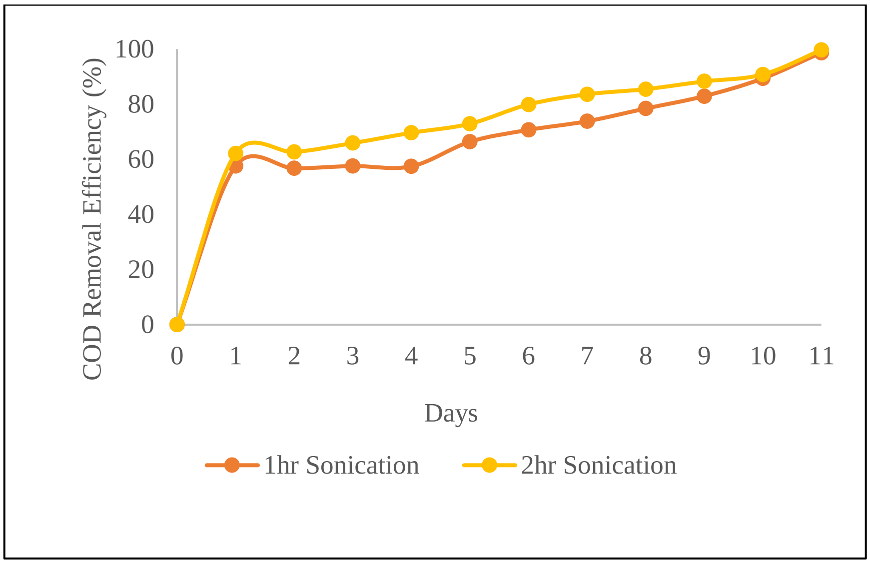

Fig. 3: COD Removal Efficiency (%)

Although the COD removal efficiency varied marginally as the HRT increased, the COD removal rates continued to increase. This was due to unacclimatised POME, which consisted of mostly anaerobic bacteria needed time to adapt to new environment in the reactor prior to breaking down the influent COD by larger population of bacteria at the later stage (Abdurahman *et al.*, 2013; Borja *et al.*, 1996). This result was higher than of 94% COD removal using anaerobic filtration (Abdurahman and Chandra, 2015) and 91.7%-94.2% COD removals using membrane anaerobic system (MAS) (Stuckey, 2012). In previous study conducted by Abdurahman *et al.* (2013), 94.8% - 96.5% of COD removals were achieved using UMAS with HRT from 5.7 to 400.6 days, respectively. The removal of COD was reflected in the rise of biomass concentration, as the dissolved organics were converted into new cells at which the COD removal efficiency increased as the HRT increased from 5.7 to 400.6 days (Abdurahman and Azhari, 2013). This presence study has shown a higher COD removal efficiency than that of the previous studies. Thus, it proves that UMAS is the most suitable treatment for POME along with 2 hours of sonication operation.

The fouling effect is overwhelmed by the presence of ultrasonic wave which avoids the accumulation of particle at the membrane surface in UMAS, resulting in smooth and gradual increases in overall COD removal efficiency trend. This incremental data on the samples were also in agreement with (Abbas *et al.*, 2001) who concluded that increasing the HRT caused slight increasing in the removal efficiency of COD. The optimum HRT was found to be 11 days, which gave the highest average percentage COD removals. Besides, the biogas production was also at the highest for 11th day of HRT. The HRTs were mainly influenced by the ultra-filtration (UF) membrane influx rates, which directly determined the volume of influent (POME) to be fed to the reactor (Abdurahman and Azhari, 2013). At low HRTs with high OLRs, the organic matter was degraded to volatile fatty acids (VFAs).

B. Methane Production:

For the stability and sustainability of the anaerobic reactor, it is important to determine the composition of CH_4 gas inside the reactor. Figure 4 shows the CH_4 gas production rates increase almost linearly. Zhou *et al.* (2014) described the CH_4 production rate gradually increased with different gas production peak time in the reactor. The results are in agreement with the theory in which the amount of microorganisms available will be higher with higher HRT due to the organic conversion of the substrate into biogas (Sulaiman *et al.*, 2009). According to Yacob *et al.* (2006), the total biogas production rate improved gradually as the organic loading rate increased due to good steadiness and high microbial activity. The constant uniform trend in last 3 days of 1 hour sonication and last 2 days in 2 hours sonication sample data indicates that the CH_4 gas production has reached its steady state. The obtained result was in agreement with Abdurahman *et al.* (2013) who stated that the steady-state conditions were established at different HRTs and influent COD concentrations.

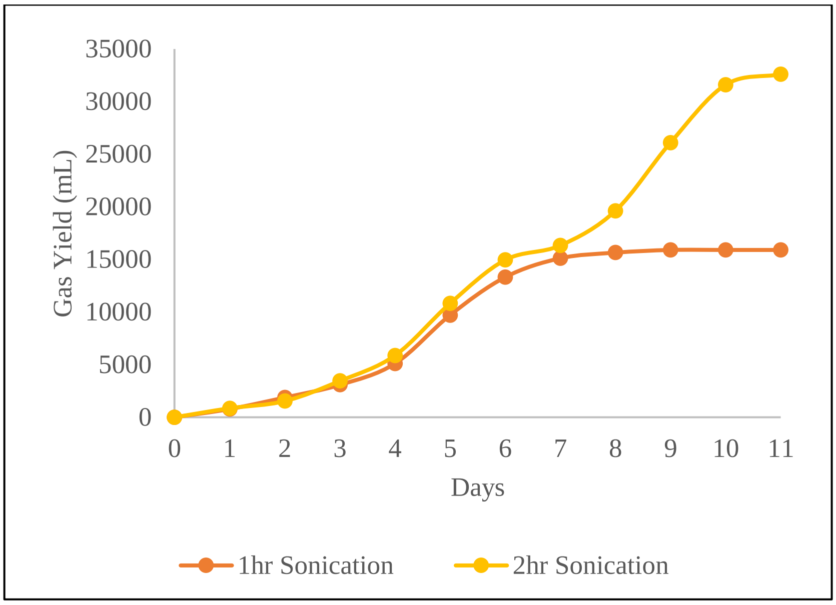

Fig. 4: Methane Gas Production

Figure 4 shows the CH_4 gas production rate obtained from 1 and 2 hours of sonication in UMAS treatment. The total production of CH_4 gas in 2 hours sonication experiment was 32,595 mL whereas 1 hour sonication produced 15,900 mL of CH_4 gas. Higher production of methane gas obtained in 2 hours operation is caused by the presence of more ultrasonic wave in UMAS system which minimizes the formation of cake layer on the membrane surface and retains the organic particles back into the reactor (Fakhru'l-Razi and Noor, 1999). This will speed up the degradation process and provide more substrates at the same time. Besides, the increase of fatty acids will cause more production of CO_2, and will decrease the production of CH_4 (Osman *et al.*, 2014). Thus, it is very important to maintain the neutral pH value in order to reduce the CO_2 formation inside the reactor.

In this study, the effectiveness of the ultrasonic device can be seen from the permeability yield and permeate quality. The permeability yield improvement can be seen from the permeate volume collected in the experiment which was direct proportional to the membrane flux (Abdurahman and Nuri, 2014). The flux of the membrane throughout the experiment have calculated by measuring the quantity of permeate collected in 5 hour period and divided by the effective membrane area for filtration which was 0.048 m^2 for four membrane (Wu *et al.*, 2007). It was found that the flux reduction accounted for 47.96 % and 55.03 % in 11 days operation for 1 hour and 2 hours of sonication operation respectively compare with the flux in the beginning of the experiment.

Table 2: POME characteristics on day 11

Parameter	1 Hour Sonication	2 Hours Sonication
Biological Oxygen Demand (BOD)	337.13 mg/L	252.55 mg/L
Chemical Oxygen Demand (COD)	4900 mg/L	4000 mg/L
Total solid (TS)	130 mg/L	93 mg/L
Volatile Suspended Solid (VSS)	5578 mg/L	2390 mg/L
Temperature	54 °C	55 °C
pH	4.83	5.00
Permeate Volume	482 mL	543 mL

Conclusion:

From the data obtained from the treatment process (Table 2), the 2 hours of sonication in UMAS operation seemed to be adequate for the biological treatment of undiluted POME over a short period of time. The UMAS bioreactor is found to be an improvement over the existing techniques. Apparently, it would become a highly potential biological treatment in which a high COD removal efficiency is achieved in a short period of time. The overall COD removal efficiency has been obtained at 98.75% for 11 days HRT. This means that UMAS is very effective and efficient compared to MAS. The gas production is also higher which can be considered to be used as additional energy source for the palm oil mill.

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