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Performance of Ultrasonic-assisted Membrane Anaerobic System (UMAS) on Palm Oil Mill Effluent (POME)

Shafie N. F. A.
Rahman A. I. S.
Yahya A.
Mansor U. Q. A.
Som A. M.
Faculty of Chemical Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor

Nour A. H.
Hassan Z.
Yunus R. M
Faculty of Chemical Engineering & Natural Resourses, Universiti Malaysia Pahang, 26300 Gambang, Pahang

ABSTRACT

Palm Oil Mill Effluent (POME) is hard wastewater that contains a high amount of Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD5), Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS). These vital parameters should be treated first before it is discharged into any water ways. There are many treatment methods implied until this decade with traditional method. Pond system is the most implied method due to its low cost. The performance of Ultrasonic-assisted Membrane Anaerobic System (UMAS) is evaluated on the ability of UMAS to treat these parameters. The UMAS must be operated daily for 5 hours operation per day with 3 hours sonication. The experiment is done when the UMAS is achieving a steady state. The steady state is achieved on day 7 with no gas was generated. The performance of UMAS showed high COD removal efficiency with 98.7%. The kinetic study is also evaluated by implying three models which are Monod, Contois and Chen and Hashimoto model.

Keywords: *Anaerobic Digestion, POME, Treatment, UMAS, Wastewater.*

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Introduction

POME is a traceable point source of water pollutant that consists of high COD and suspended solids [1]. These two parameters are the crucial point that if they are not treated thoroughly, they might result harm to people and environment [2]. POME is derived from palm oil production. POME is mostly produced in Indonesia, Malaysia and Thailand [3, 4]. The demand of palm oil has increased from year to year due to its beneficial value [5]. Logically speaking, as the demand of palm oil increases, the production of palm oil will linearly increase; yet, it will generate more POME as waste. Basically, POME consists of water, oil, suspended solid, dissolved solid and sand that needed to be treated before discharged into water ways [6]. Untreated POME could lead into a serious environment issue as it contains pollutant of BOD_5, COD, TSS and VSS. Table 1 shows the amounts of BOD_5, COD, TSS and VSS of untreated POME from various studies.

Table 1: Amounts of BOD_5, COD, TSS, VSS pH and temperature of untreated POME from various studies.

Parameters	**[6]**	**[7]**	**[8]**
BOD_5	21500 mg/l	25000 mg/l	25000 mg/l
COD	50500 mg/l	50000 mg/l	50000 mg/l
TSS	-	18000 mg/l	18000 mg/l
VSS	3657 mg/l	34000 mg/l	34000 mg/l
pH	5.32	4.7	4.7
Temperature	54 °C	80-90 °C	-

POME is produced through a sterilization of fresh fruits bunch of oil palm. Then the fruits is threshed or stripped to separate fruits from the sterilized bunch stalks before clarification of palm oil and effluent hydro-clone operations [9]. POME is generated about 0.6 ton to 0.7 ton for every ton of fresh fruits bunch being processed [10]. For 1 ton of crude palm oil milled, estimation of 1100 kilogram of carbon dioxide is generated [11]. By taking this as basis, Indonesia has produced more than 11,400,000 ton POME in 2008 while Malaysia has produced 10,641,000 ton POME which is approximately equivalent to 12,000,000 m^3.

POME is the most expensive in handling and it is managed by mill operators. The waste of POME from palm oil is greatly generated in volume in ton that makes the situation getting worst [12]. POME is playing a huge role in polluting inland water pollution when it is discharged to the water ways system [13]. POME has the physical appearance of yellowish acidic wastewater with properties of viscous brown liquid and fine suspended solid [14]. Even though POME is a waste, it is considered as non-toxic waste since it is produced from chemical free process. The extraction of palm oil from oil palm does not require any chemical. The high content of BOD, COD, SS and oil and grease in POME has the capability of depleting the oxygen content in aquatic system and destroying the aquatic life [15].

Treatment process

Since the technologies of treating POME have not been practiced, for some reasons, the producer of palm oil discharged the POME to the river or any water ways system as the easiest and cheapest way to dump the effluent and disobeyed the Environmental Quality Act 1974 (EQA 1974) [12, 16]. The typical time taken to treat POME is about 20 days to 200 days for anaerobic pond with the typical pond size of 10,300.8 m^3 for 54 tons palm oil produced per hour [17, 18]. A quality treatment method can be achieved by UMAS by applying anaerobic treatment, ultrasound and bio-reactor that can generate valuable gas and has the ability to shorten retention time [17]. In addition, the ultrasound can be a material that enhances the treatment process to be more effective and efficient as it increases membrane permeability of solvent and permeates through membrane while improving the separation rate and mitigating membrane fouling effectively in cross flow filtration of macromolecules [2]. However, the performance of this treatment type is derived mainly from the membrane performance, operating pressure, temperature and pH control. The optimum condition to run the UMAS is to control the operating temperature from 30^{o}C to 35^{o}C and the pressure to operate UMAS for POME treatment is from 2 bar to 4 bar with pH value of 6.8 to 7 [1, 19].

Methodology

Materials

POME was collected from Felda Sungai Tengi Palm Oil Mill, Selangor and kept in refrigerator at 4^{o}C prior to use. One unit of UMAS available at Universiti Teknologi MARA (UiTM) Shah Alam was used and it followed the Occupational Health and Safety Management System (OSHMS) procedure.

Parameter test

The parameter test was conducted according to standard procedure available at Faculty of Civil Engineering, UiTM Shah Alam.

Determination of BOD_5

One liter of distilled water is pipetted with 1 ml of each phosphate buffer solution, magnesium sulfate solution, calcium chloride solution and ferric chloride solution; and it is saturated with dissolved oxygen by aerating it with organic free filtered air for an hour. The sample is then diluted in BOD bottle with 5 ml sample before the sample is incubated for 5 days at 20°C. The Dissolved Oxygen (DO) content is determined after 5 days.

Determination of COD

One ml sample is diluted with 199 ml distilled water in a beaker. The sample then pipets 2 ml into vial containing High Range COD solution. The solution is inverted to mix the solution. The vial is inserted into COD reactor for 2 hours. The solution is let to cool for 20 minutes before placed into spectrophotometer. The COD program is selected from spectrophotometer prior to take the reading.

Determination of TSS

1 ml of sample is diluted with 9 ml of distilled water and added into vial. The vial is placed in the spectrophotometer and TSS program is selected prior to measurement reading.

Determination of VSS

1 ml of sample is diluted with 9 ml of distilled water and added into vial. The vial is placed in the spectrophotometer and TSS program is selected prior to measurement reading.

Result and Discussion

UMAS

The UMAS is operated for 5 hours per day with 3 hours sonication for every 1 hour interval. As a result, the UMAS achieved a steady state on day 7 as the volume of permeate is constant from the previous day. The volume of gas recorded at 0 at day 7 also indicates the UMAS is at a steady state. While the gas generated, the POME is actually being digested by methanogens to break the POME into gas [20]. While the digestion happened, the metabolism of bacteria is reduced, yet it degraded organic material in POME [21]. Thus, when the digestion stops, the gas is not generated but simplifies the UMAS is at a steady state.

As to study the performance of UMAS, the UMAS itself needs to be designed efficiently. From the experiment, the UMAS encounters membrane (cross flow tubular type; d_o 1.25cm) clogging due to presence of excessive sludge [1, 2] from day 2 until day 4. Thus, the ultrasonic sound is used to ensure UMAS is operating efficiently as ultrasound has the ability to reduce membrane fouling on cross flow filtration yet increase membrane permeability [22].

Furthermore, the performance of UMAS can be better if the temperature is controlled. Operating temperature might affect the microbial rate of activity [23]; if the rate of activity is slow, then the process of digestion is slow. Failure to control temperature also affects the color of permeate due to accumulation of volatile fatty acid from inhibition of methanogenesis [17, 24].

Parameter test on Permeate

The parameter test should be conducted 5 hours after treatment session and kept below 4°C prior to use [25]. Figure 1 shows the result of parameter test on permeates. The performance of UMAS depends on removal efficiency parameter reading on permeate as final effluent.

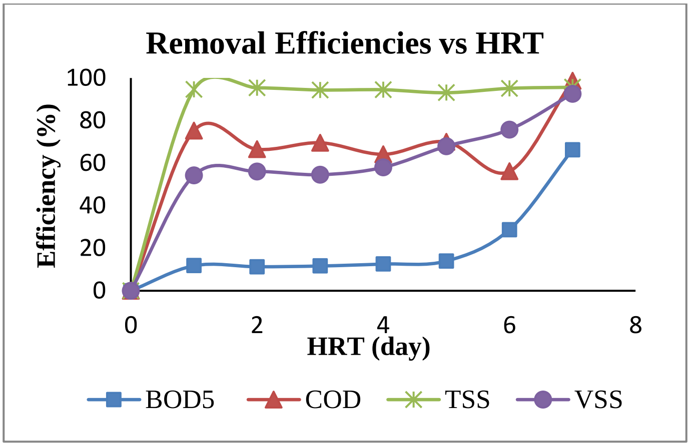

Figure 1: Removal efficiencies for permeate

Figure 1 shows that as Hydraulic Retention Time (HRT) increases, the removal efficiency increases. However, the efficiency drops from day 2 until day 4. This is because UMAS is having some bubble pressure problem while operating. The BOD_5 is reduced for 66% efficiency from 516 mg/l to 174 mg/l. This shows that the bacteria are well-lived in UMAS with enough food. Meanwhile, the removal efficiency for COD is at 98.7 % with initial value of 46000 mg/l to 600 mg/l in 7 days. The ability of UMAS to remove nearly 99% COD reflects a good performance compared to other methods such as fluidized bed reactor and anaerobic filtration that removed COD in the range of 94% to 98% [17, 24].

However, the final value of 600 mg/l of COD indicates that there are still substrates not being degraded by the microorganism. The high amount of substrate can be related to high amount of mixed liquor suspended solid [1, 17]. This situation can be related to the microbial study that the bacteria suffers from too much food that later affects the microorganism activity. The excess food will result the bacteria to grow too fast and tends to build pin floc that is hard to settle [26]. Thus, the unsettled floc will remain suspended in permeate that can be seen through the color of supernatant.

High substrate content in POME reflects the removal of TSS at 340 mg/l and VSS at 980 mg/l as in the final day compared to initial day at 7800 mg/l for TSS and 13200 mg/l for VSS. However, the performance of removing TSS and VSS is quite high at 95.6% for TSS and 92.5% for VSS in just 7 days. Since the UMAS process of treating POME produces biogas through bacteria digestion, UMAS is a beneficial method. Currently, the waste water treatment plant treated the POME by time and did not collect the biogas. The collected biogas can be channeled into another energy sources. Thus, the UMAS has an advantage compared to the conventional way since the UMAS is able to collect this valuable gas.

Kinetic study

A kinetic study was conducted on the anaerobic digestion in this research project whereby the results of BOD_5, COD, TSS and VSS were evaluated to define the microbial growth. Three models [27] are used to describe the kinetic of anaerobic digestion which are Monod (Figure 3), Contois (Figure 4), and Chen and Hashimoto (Figure 5). The kinetics biological models such as Monod, Contois and Chen & Hashimoto refer to fundamental microbial growth and substrate consumption rates. This is because they depend on growth-limiting substrate concentration. Therefore, these three models were chosen because of its common and simple basic microbial kinetics model used in anaerobic wastewater treatment. The kinetic equations are always used in anaerobic treatment process by using linear relationship. Thus, the experimental results will be compared with these 3 different linearized kinetics model to estimate the values of kinetics parameters by obtaining the best fit data [28, 29].

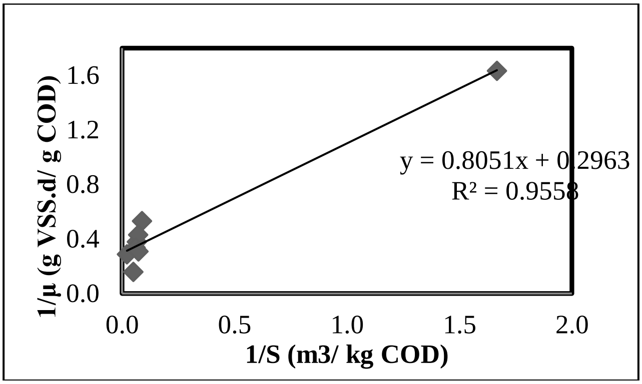

Figure 3: Monod model

From these figures, all the models showed a good linear relationship as R^2 is more than 95%. However, the Contois model showed some favorable result where its R^2 was the highest among these three models with 97.17% as compared to Monod model with 95.58 % and Chen and Hashimoto model with 96.62%. Monod model showed the lowest R^2 followed by Chen and Hashimoto and Contois model even when the Monod model assumed that the final COD concentration limiting substrate (S) is independent to its initial (S_o) [25]. The Chen and Hashimoto and Contois seems to be favorable especially Contois model that indicates organic loadings should be considered for the digester performance with the assumption of the final concentration of S is dependent on the initial concentration of S_o [30].

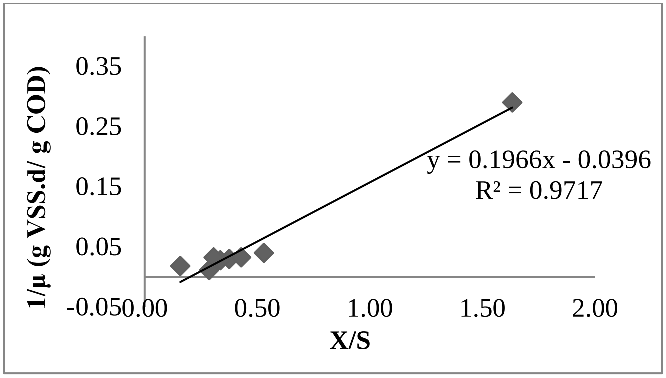

Figure 4: Contois model

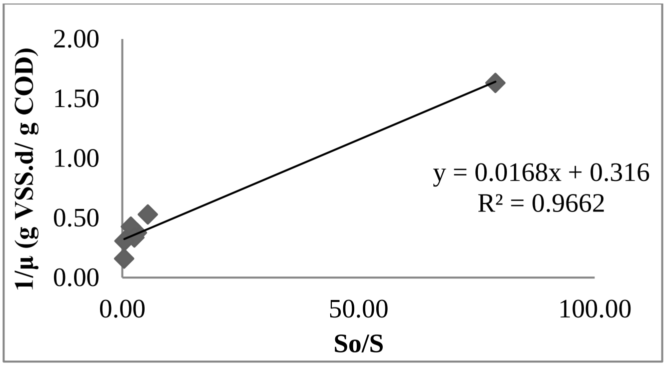

Figure 5: Chen and Hashimoto model

Based on kinetics results in this study, it was found that the best performance is owned by Contois Model compared to Monod and Chen & Hashimoto for both experiments. The outstanding R^2 line of Contois suggested that it is more suitable and applicable for formulating kinetics models and prediction of the effluent substrate concentration. These data are in the agreement of the studies documented by [31] and [32] which stated that Contois model was shown to give a better agreement with data than other growth rate expressions. Thus, with the highest value coefficient of determination of R^2, the Contois model is the most favourable and suitable for formulating this kinetics model and prediction of the substrate concentration.

Thus, with the highest value coefficient of determination of R^2, the Contois model is most favorable and suitable for formulating this kinetics model and prediction of the substrate concentration. Furthermore, according to [33], the Contois model is the most suitable to represent the kinetics of anaerobic digestion flow process since the Contois model has come with a direct relationship between influent and effluent concentration of substrate. Since the Contois model depends on cell or substrate concentration, it is categorized as unstructured rate model.

Conclusion

The ability of UMAS in treating POME can be doubtful but its efficiency and effectiveness is proven as good as gold. In this research project, the performance of UMAS in treating POME was well conducted and the BOD_5, COD, TSS, VSS and pH were successfully evaluated. As the experiment evaluated on the effluent which is the permeate, the efficiency of removing the COD is higher at 98.9%, TSS and VSS removal is greater than 93% which is considered high and well treated. Furthermore, the COD removal in reacted sample collected from the reactor is achieving high removal efficiency at 93%. Meanwhile, the efficiency of removing BOD_5 is not high at 66% on permeate but something needed to be highlighted as the UMAS is able to reduce the BOD content as low as 174 mg/l which is nearly the benchmark of EQA 1974 on effluent standard. To achieve the high efficiency of removing the important pollutant of COD and BOD_5, the UMAS only needed to be operated in 5 hours per day for 7 operating days. In terms of kinetic study, the substrate removal model is well studied in UMAS. Three models were used for which Monod, Contois and Chen and Hashimoto were studied. These three models can be used to evaluate the performance of UMAS and capable to handle sustained organic loads since the R^2 for these three models were above 95%. Among these three models, the Contois model seems fit to be used with the highest coefficient of determination R^2 for 97.17%. This research project can be a highlight on how performance of UMAS in treating POME is preferable compared to the existing method in treating POME. Thus, the performance of UMAS in treating POME is considered a great success since it is able to reduce the crucial parameter of

BOD_5, COD, pH, TSS and VSS for high removal efficiency in a short period of time at 7 days with 5 hours operating time per day.

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