Kinetics Study of Membrane Anaerobic System (MAS) in Palm Oil Mill Effluent (POME) Treatment

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ABSTRACT

Increasing demands in palm oil industry resulting in the increase in production palm oil. It is then creating a major problem in disposing the waste to be treated in appropriate ways. The governments are forced to look for alternative technology for the palm oil mill effluent (POME) treatment because the demand of oil increases with the awareness on increasing environmental issue. Therefore, a new technology must be found in order to reduce energy consumption, to meet legal requirements on emission and for cost reduction and also increased quality of water treatment. Membrane Anaerobic System (MAS) is a promising alternative way to overcome these issues. In this study, the efficiency of the MAS performance increases to 99.03% in ten days operation. The application of Monod, Contois and Chen & Hashimoto models were used to analyze the performance of MAS for treating POME. The results from the experiment show the substrate removal model is well fits for estimation of kinetics membrane anaerobic system. Amongst them, the Contois and Monod models predicted the bio-kinetic reactions of the MAS very well with coefficient of determination (R^2>97%) values. The MAS bioreactor was created to be an improvement method as well as successful biological treatment since the graph shows linearized which is in good agreement with reported in literature.

Keywords: *MAS, POME, Kinetics, Anaerobic*

INTRODUCTION

Over 20 years, the methods offered for the management of POME are anaerobic tank and land application, anaerobic contact and aeration, ponding system and evaporation [2]. Among those methods, MAS bioreactor is going to be used in this research. The framework comprises of two technologies which are anaerobic digestive and membrane separation. Anaerobic processing is the degradation of complicated natural substances subject to the appearance oxygen where POME is degradable to the methane, carbon dioxide and water [3]. Anaerobic digestion is a standout amongst the most essential methods utilized for different industrial wastewaters and sewage treatments. This is due to combination of contamination reduction and vitality production.

Most researchers have found out chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solid (TSS), volatile suspended solids (VSS), pH value and methane always present in POME [4]. In this study, the data was used to construct the kinetics model based on Monod, Contois and Chen & Hashimoto model to observe the efficiency of removal. Most ordinarily, palm oil has officially recommended utilization of anaerobic digesters for the essential treatment. The conventional way for waste water handling is weakness and it is unsafe for the environment. Therefore, this study is to present strategy using membrane anaerobic system in treating POME.

Most commonly, palm oil mills have suggested the use of anaerobic digesters for the primary treatment. The three widely used kinetic models considered in this study are shown in Table 1. The traditional ways for wastewater treatment from both economic (high cost) and environmental (harmful) disadvantages. This paper aims to introduce a new design technique of MAS in treating POME and producing methane and to determine the kinetic parameters of the process, based on three known models; Monod [5], Contois [6] and Chen & Hashimoto [7].

Table 1: Mathematical Expressions of Specifics Substrate Utilization Rates for Known Kinetic Models

Kinetic Model	Equation 1	Equation 2
Monod	$\mu = \frac{kS}{k_s + S}$	$\frac{1}{\mu} = \frac{K_S}{K}\left(\frac{1}{S}\right) + \frac{1}{k}$ [5]
Contois	$\mu = \frac{\mu_{max} \times S}{Y\,(aX + S)}$	$\frac{1}{\mu} = \frac{aX}{\mu_{max}S} + \frac{Y(1+a)}{\mu_{max}}$ [6]
Chen & Hashimoto	$U = \frac{\mu_{max} \times S}{YKS_0 + (1-K)SY}$	$\frac{1}{\mu} = \frac{YKS_o}{\mu_{max}S} + \frac{Y(1-K)}{\mu_{max}}$ [7]

where,

μ_{max} = maximum value of specific growth rate
= specific substrate utilization rate (kg.m^3.VSS/kg.m^3.COD)
S = COD final concentration of limiting substrate (mg/l)
S_o = COD initial concnetration of limiting substrate (mg/l)
K = Rate constant
K_s = Rate constant
B = Concentration of organisms bacteria corrupting the substrate
Y = Yield
X = BOD microorganism concentration (mg/l)

METHODOLOGY

The sample of raw POME collected from Felda Sungai Tengi Palm Oil Mill in Selangor was treated by MAS in the Environmental Laboratory in Faculty of Chemical Engineering, UiTM Shah Alam with an effective 26-litre volume. Figures 1 and 2 show a schematic flow diagram of the membrane anaerobic system (MAS) that consists a membrane module which can only accommodate four pieces of membranes in the tubular form at one times, a centrifugal pump, and an anaerobic reactor.

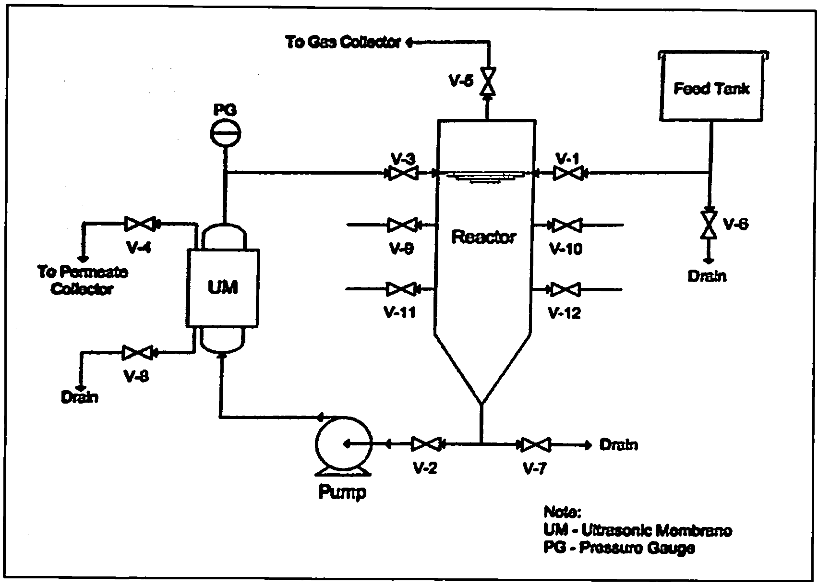

Figure 1: Schematic Flow Diagram for Membrane Anaerobic System (MAS)

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 m^2. The maximum operating pressure on the membrane was 55 bars at 70 °C, and the pH ranged from 2 to 12 [8]. 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 membrane part.

Figure 2: Membrane Anaerobic Reactor (MARS) System in Environmental Laboratory

Raw Material (Palm Oil Mill Effluent)

In this project study, POME sample was collected from palm oil mill Felda Sungai Tengi in Hulu Selangor. Figure 3 shows the fresh POME sample look-like. The wastewater was stored in a cold room at 4°C prior to use. Sample is used to analyse chemical oxygen demand (COD) for the MAS efficiency calculation.

Figure 3: Fresh POME Sample

Bioreactor Operation

The membrane anaerobic system, MAS performance was evaluated under ten days experiment. A 0.5L cylinder water displacement was used to measure the daily gas volume. The produced biogas contained only CO_2 and CH_4, so the addition of sodium hydroxide solution (NaOH) to absorb CO_2 effectively isolated methane gas (CH_4).

RESULTS AND DISCUSSION

Membrane Anaerobic Membrane (MAS) Efficiency

The COD reading after running the sample with MAS, the concentrations decrease from 61,660 to 35,700 mg/l and the first day running the sample in anaerobic reactor, the biochemical oxygen demand (BOD) shows the drastically decreases. This is because the microorganisms in the raw POME trying to adopt the new place from pond to reactor. Based on the reason, the sample must be put into the reactor 1 day before the experiment is operated. For the next day the value of BOD was consistently decrease. The efficiency of the MAS operation was determined using the COD value at beginning and last of the operation. The COD removal efficiency using this MAS equipment the efficiency of the performance increases to 99.03% in ten days operation. This result was higher than the 85% COD removal observed for POME treatment using anaerobic fluidised bed reactors [9] and the 91.7-94.2% removal observed for POME treatment using MAS [10]. The calculation below has prove that these MAS was more efficient compared to other existing MAS technology.

$$\%\text{COD Removal} = \left(\frac{\text{COD}_0 - \text{COD}_1}{\text{COD}_0}\right) \times 100\%$$
$$= \left(\frac{(61660 - 600)\text{mg/L}}{61660\text{mg/L}}\right) \times 100\% = 99.03\%$$

Kinetics Study

Three types of kinetics model have been considered. The theory of continuous development of microorganisms was used to mathematically which speak on behalf to kinetics of biological treatment [11]. Most of kinetics biological models are refers to fundamental microbial growth and substrate consumption rates. This is because they depends on growth-limiting substrate concentration. The kinetic equation that generally used in anaerobic treatment was processed using linear relationship.

Table 2 shows the data used in kinetics models. The graph for Monod, Contois and Chen & Hashimoto are interpreted in Figures 4, 5 and 6 respectively. In the investigation of MAS, the three different kinetic models have produced excellent result and has excellent relationship (R^2 > 50%) which is almost similar from what has been claimed in the report for treating sewage sludge POME [1].

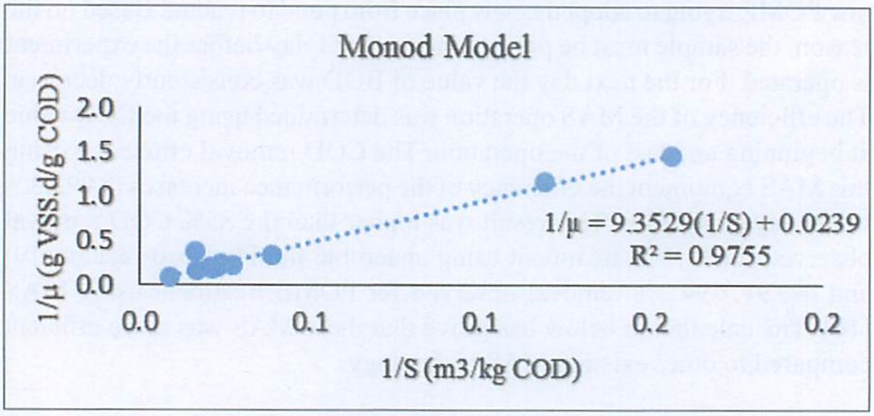

Figure 4: Monod Model

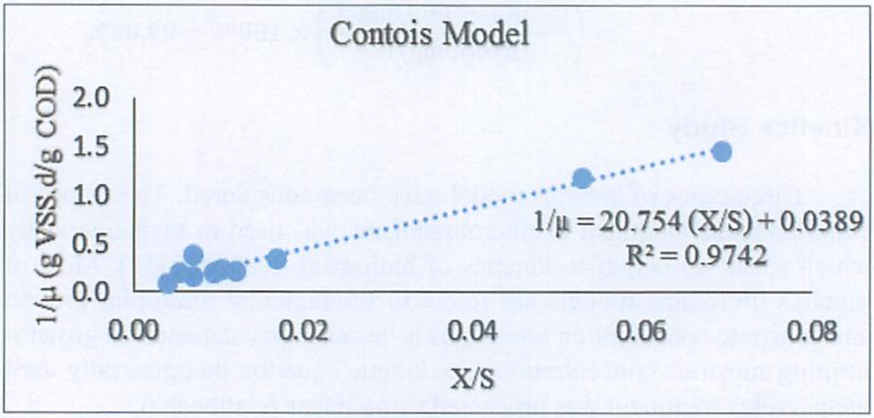

Figure 5: Contois Model

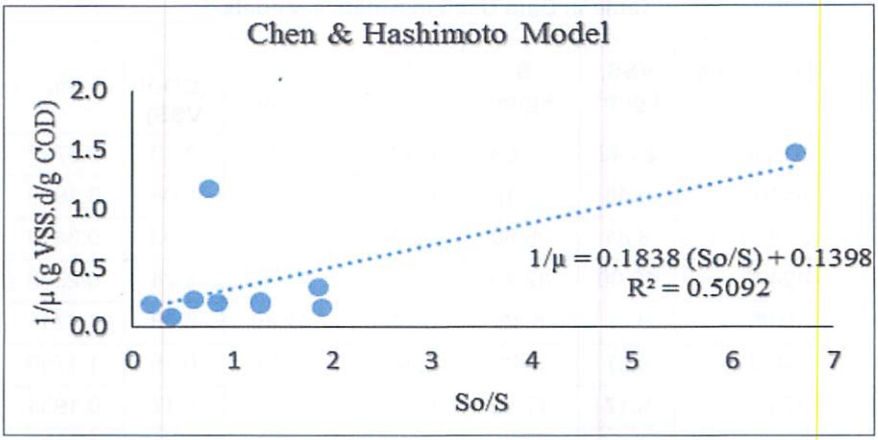

Figure 6: Chen & Hashimoto Model

Based on Figures 4, 5 and 6, it was found that the better performance is owned by Monod. Chen & Hashimoto model has the lowest percentage compared those two models since the value of R^2 is lower than 90%. The line plotted for the linear equation of the Contois and Chen & Hashimoto model had the percentage values R^2 are 97.39% and 50.91%, respectively which are lower than Monod model with R^2 of 97.47%. This is because the Monod model has made assumption the final COD concentration limiting substrate (S) is not dependent on initial COD concentration limiting substrate (So) meanwhile, Contois and Chen & Hashimoto models has made the prediction the concentration of S is a function of the initial concentration of S_o as claimed by Osman *et al.* [12] even the Monod shows the highest percentage of R^2. Hence, the outstanding line of this three models is Contois that are suggested to study since it is more suitable and applicable for formulating kinetics models and prediction of the effluent substrate concentration.

Table 2: Data Used in Kinetics Models

COD permeate, mg/L	VSS, kg/m³	S, kg/m³	X, kg/m³	So, kg/m³	μ (COD/ VSS)	1/μ
61660	23.42	61.66	0.4278	0.00	2.63	0.3797
48100	9.48	48.10	0.2586	61.66	5.08	0.1970
25800	8.81	25.80	0.4344	48.10	2.93	0.3413
42400	10.00	42.40	0.4380	25.80	4.24	0.2358
6400	9.42	6.40	0.4446	42.40	0.68	1.4711
8400	9.87	8.40	0.4458	6.40	0.85	1.1750
47400	9.17	47.40	0.4488	8.40	5.17	0.1934
37000	8.34	37.00	0.4434	47.40	4.44	0.2253
44000	9.15	44.00	0.4320	37.00	4.81	0.2080
114000	9.15	114.00	0.4494	44.00	12.46	0.0803
600	9.67	60.00	0.4236	114.00	6.20	0.1612

Amongst them, the Contois and Monod models predicted the bio-kinetic reactions of the MAS very well with coefficient of determination (R^2>97%) values. Between Monod and Contois kinetic model, it is recommended that Contois model would be more suitable than a Monod model for representing the flow of anaerobic digestion process [13]. This is because Contois kinetics was made assumption there is direct relationship between influent and effluent concentration of substrate but this facts has very little distributed information about treating liquid waste using anaerobic digestion. In addition, Monod and Chen & Hashimoto kinetic model are categorized as unstructured rate model and they are depending on substrate concentration. Meanwhile, Contois kinetic model is also category as unstructured rate model however it is depending on cell or substrate concentration or both [14].

CONCLUSION

In conclusion, the results from the experiment show the substrate removal model is well fits for estimation of kinetics membrane anaerobic system. The membrane anaerobic system, MAS seemed to be adequate for the biological treatment of undiluted POME, since reactor volumes are needed which are considerably smaller than the volumes required by the conventional digester. The overall COD removal efficiency was very high-about 99.03%. The gas production, as well as the methane concentration in the gas was satisfactory and it could be considered as an additional energy source for the use in the palm oil mill. Monod, Contois and Chen & Hashimoto models can be used to explore or analyze the performance of MAS for treating POME. The excellent fit of these three models ($R^2 > 50\%$) in this study suggests that the MAS process is capable of handling sustained organic loads. Amongst them, the Contois and Monod models predicted the bio-kinetic reactions of the MAS very well with coefficient of determination (R^2>97%) values. The graph of Monod, Contois and Chen & Hashimoto was shows linearized which is good agreement with reported in literature.

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