Kinetic Study for Ultrasonic assisted Membrane Anaerobic System (UMAS) Treating Decanter Palm Oil Mill Effluent (POME)

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ABSTRACT

The discharge of Palm Oil Mill Effluent (POME) to river or sewage causes serious environmental problem and the use of Ultrasonic-assisted Membrane Anaerobic System (UMAS) is recommended as a solution. However, further use of UMAS in treating POME tends to give blockage on the membrane surface. Monod Model kinetic parameters of control, reacted and permeate samples of POME which contribute to membrane fouling were investigated. In this study, the treatment was operated in 5 hours at which three hours treatment was with ultrasonic application. The results show that the permeate sample has the lowest maximum specific growth rate, µmax which indicates the higher amount of biomass in UMAS reactor. The amount of biomass in UMAS was increased by using ultrasonic application which prevents the membrane from fouling problem. Therefore, it is recommended to employ UMAS in POME treatments.

Keywords: *UMAS, POME, Kinetic Study, Monod Equation, Anaerobic Treatment*

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Introduction

Palm oil industry has become one of the important agriculture-based industries in Malaysia. Basically, palm trees have height up to sixty feet and more. After 30 months of field planting, the oil palm trees will start producing fruits with weighing around 10 to 35 kilograms per bunch. The production of palm oil from fresh fruit bunch (FFB) will contribute to the generation of palm oil mill effluent (POME).

POME has high content of organic matter and pathogenic organisms. In palm oil milling, for every ton of crude palm oil (CPO) produced, about 0.9 – 1.5 m^3 of POME is generated [1]. Therefore, it is estimated that all palm oil mills in Malaysia produce more than 40 million cubic meters of POME annually [2]. POME is highly tended to give a negative impact to the environment and human health; thus, it must be treated first before discharge to the river in order to avoid environmental problem [3]. Anaerobic process is the important stage of effluent treatment in which the biodegradable materials and wastewater are decomposed by the bacteria without the presence of oxygen. The existing of oxygen acts to break down organic matter and other pollutants as they are suspended that involved in waste water samples. In this process, the reaction between the polluted effluent and bacteria happens which resulted in the production of biogas [4].

There are several methods to reduce pollution with POME such as chemical and physical pre-treatment and biological treatment. Membrane separation method is an effective biological method for separating biomass solids from digester suspensions. UMAS is a new technology that has been developed to reduce energy consumption in order to meet legal requirements on emission and for cost reduction including increased water treatment quality [5]. During treatment, the fouling on membrane occurred due to blocking mechanism that occurred at the membrane surface and inside the pores of the membrane. In order to avoid equipment breakdown and increase chemical oxygen demand (COD), the parameters which contribute to membrane fouling are determined in terms of volatile suspended solid (VSS), COD and μ_{max}. These parameters depend on the substrate type, microorganisms and temperature used.

The purposes of this study is to develop the kinetic parameters and simulate Monod growth equation in terms of COD, VSS and μ_{max}. The sample of POME is taken from decanter source at palm oil milling Jengka 21, Pahang. Level of solid residue of POME from decanter source is higher than sterilizer source. This is due to mesocarp fruitlets which are transformed into solid residue during the mechanical processes [6].

Methodology

POME sample

The sample of raw POME collected from Felda Jengka Palm Oil Mill in Pahang was treated by UMAS in Environmental Laboratory in Faculty of Chemical Engineering, UiTM Shah Alam with an effective 30-litre volume. The raw sample was collected from clarification process from the decanter. Decanter sample contains higher organic loading rate (OLR). Then, the raw samples undergo screening process before entering the bioreactor to avoid pump blockage during the treatment process. Let the sample in bioreactor one day before the experiment was run to ensure microbial adopts a new environment in the first day of the reactor.

Next, the experiment was run for 5 hours and three hours interval of ultrasonic waves onto the system. This study was conducted to determine some kinetic parameters for UMAS system. Thus, Monod equation is used to measure the growth rate of the microorganisms in three different samples which are in control, reacted and permeate samples. The control sample is collected from the raw sample before entering the reactor system, reacted sample is collected from valve at the bottom of the reactor after 5 hours treatment and the permeate sample is taken at permeate valve after treatment. The theory of continuous development of microorganisms has already been used to mathematically speak on behalf of kinetics of biological treatment [11].

Monod equation

The purpose of wastewater treatment is not only to grow cells, but also for the microbiological culture to utilize substrate in the form of organic matter in wastewater. Substrate utilization rate is closely related to biological growth and follows the Monod type equation as follows: [9]

Table 1: Mathematical expressions for Monod kinetic model

Kinetic Model	Equation 1	Equation 2
Monod	$\mu = \frac{\mu_{max} S}{K_s + S}$	$\frac{1}{\mu} = \frac{K_s}{\mu_{max}} (\frac{1}{S}) + \frac{1}{\mu_{max}}$

Where,

S = Substrate concentration (COD) ,kg COD/m^3

K_s = Half-saturation constant

μ_g = Biomass specific growth rate , kg COD/kg VSS.d

μ_{max} = Maximum specific growth rate, kg COD/kg VSS.d

First of all, graph of 1/μ against 1/S has been plotted by using linear relationship. The graph obtained will demonstrate a relationship between parameters in terms of y=mx + c according to equation 2 in Table 1.

Then, by comparing equation 2 with linearized Monod model (y=mx + c), the parameters of μ_{max} and K_s are obtained and substituted into new Monod kinetic model such as in equation 1. Therefore, graph of μ against S is plotted by using new (actual) Monod kinetic model.

Half saturation constant, K_s, is determined from the plot of rate μ_g versus concentration of growth-limiting substrate (S) as shown in Figure 2.

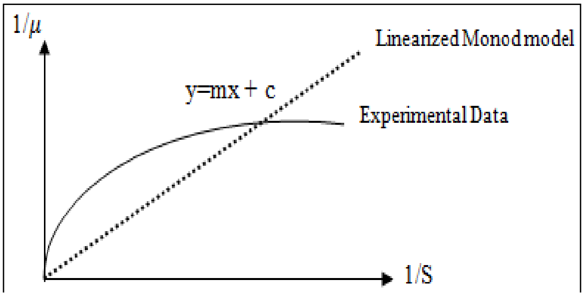

Figure 1: Graph of 1/μ vs 1/S

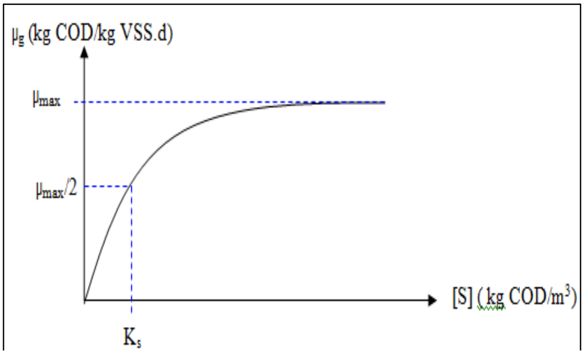

Figure 2: Graph of μ_g (kg COD/kg VSS.d) vs S (kg COD/m^3)

This equation and graphical method of Monod model are applied to three different samples which are control, reacted and permeate samples. In order to obtain the graphical Monod model as shown in Figure 2, the experimental graph of 1/μ against 1/S should be plotted first.

The experimental set-up in Figure 3 shows the source of samples that has been collected. Control, reacted and permeate samples are collected from feeder tank, anaerobic reactor and sample that comes out from membrane UF module respectively. Theoretically, the POME settles down in the feeder tank

24 hours before the treatment started; this is to let the microorganisms in the wastewater sample be in a good environment. After one day, the treatment is started and the sample goes through anaerobic reactor, the membrane module, and continuously repeated in 5 hours with three hours treatment of ultrasonic application. The three samples are collected after the treatment is done.

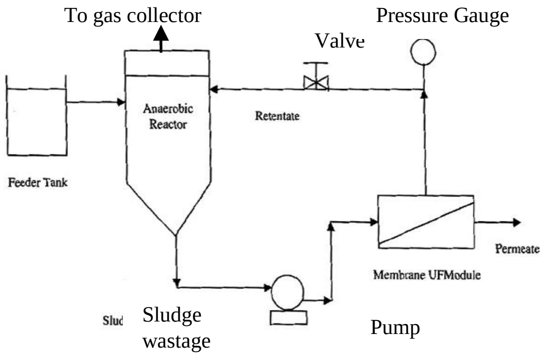

Figure 3: Flow Diagram of UMAS

Result and Discussion

Ultrasonic Membrane Anaerobic System (UMAS) efficiency

After treating POME with UMAS, the COD reading of permeate reduces from 75100 mg/L to 9200 mg/L. Before the experiment started, the raw sample was put into the reactor for one day before the experiment was run to make sure the microorganisms in the POME are acclimatized in a new place. This method will ensure the readings of COD, VSS and pH of the samples do not fluctuate. The efficiency of the UMAS operation can be determined by using the value at the beginning and the last of the operation. The removal efficiency of COD using the UMAS for three hours ultrasonic treatment was found to be 87.75% in twelve days of treatment. This result was higher than the 85% COD removal observed for POME treatment using anaerobic fluidized bed reactors [7]. The general calculation for the percentage removal of COD is shown as follows by taking COD permeate reading results from Table 2:

$$\%COD\ Removal = [COD_0 - COD_1)/COD_0] \times 100$$

Where;

COD_o = influent COD
COD_1 = effluent COD

= [75100−9200) mg/L /75100mg/L × 100%
= 87.75 %

Monod model analysis

Table 2 shows the result for kinetic parameters. Graph of 1/μ vs 1/S has been plotted for all the samples. The triangle symbols on the graph represent experimental data while the dotted illustrates the linearized Monod model. In order to estimate the values of the kinetic parameters, the experimental results were compared with Monod model in terms of y=mx+c. The estimation values were then substituted into Monod model in equations 1, 2 and 3. By using the new equation obtained, the graph of μ against S was plotted.

Table 2: Results for Kinetic Parameters

COD feed, mg/L	COD permeate, mg/L	VSS, mg/L	S, kg/m^3	X kg/m^3
73600	0	0	0	0
90000	9200	15305	9.2	15.305
96600	9400	16380	9.4	16.38
101800	9380	15210	9.38	15.21
109000	10600	17070	10.6	17.07
109600	18600	16820	18.6	16.82
206200	22200	15570	22.2	15.57
104800	27400	17320	27.4	17.32
150600	30600	13950	30.6	13.95
158600	34000	15470	34	15.47
145400	45200	13390	45.2	13.39
165200	51800	15140	51.8	15.14
144000	75100	17440	75.1	17.44

Monond model for three samples

Figure 4 shows the growth of Monod model from experimental data.

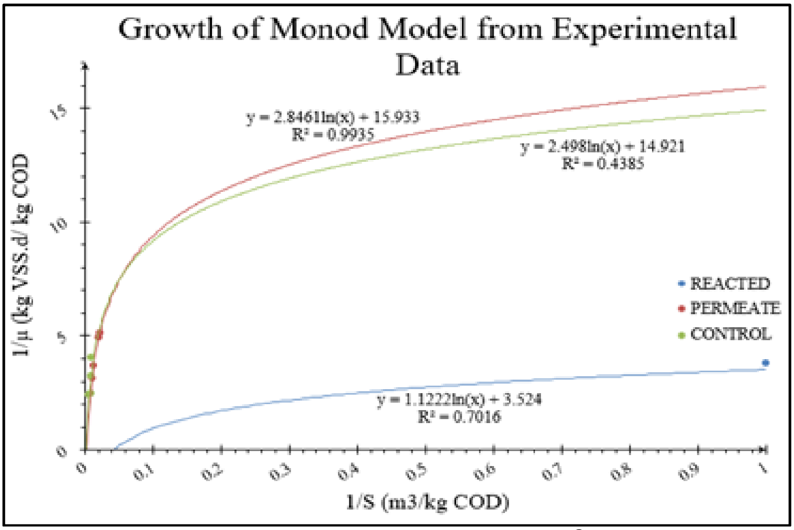

Figure 4: Graph of 1/µ (kgVSS.d/kg COD) vs 1/S (m^3/kg COD) for each samples

Monod model equation for each sample

The general equation of Monod model is as Equation 1 in Table 1. Then, the linearized equation is gotten from the experimental data graph in Figure 4.

For control sample, the linearized equation is as below;

$$y = 329.52x + 0.1648 \quad [3]$$

For reacted sample, the linearized equation is as below;

$$y = 0.579x + 2.9681 \quad [4]$$

For permeate sample, the linearized equation is as below;

$$y = 171.89x + 1.295 \quad [5]$$

To get the constant value of µmax and Ks from the linearized equation of experimental data, the comparison with Equation 2 in Table 1 must be done as shown;

$$\frac{1}{\mu} = \frac{K_S}{\mu_{max}}\left(\frac{1}{S}\right) + \frac{1}{\mu_{max}} \quad [2]$$

1/µmax = 0.1648; Ks/µmax = 329.52

Therefore,

µmax= 6.0680; Ks= 1,999.51

The same step is done for the reacted and permeate samples. Table 3 shows the kinetic constant value for experimental result gotten from each sample.

Table 3: Kinetic Constant Value from Experimental Data

Parameter	**Type of sample**		
	Control	**Permeate**	**Reacted**
$\boldsymbol{\mu_{max}}$	0.1648	0.7722	0.3369
Ks (kg COD/m^3)	1,999.51	132.73	0.1951

The actual result is where the theoretical method was used. By getting the values of µmax and Ks from the experimental data, use the values into Equation 1 to get the value of µ calculated. Next, plot the graph of µ against S.

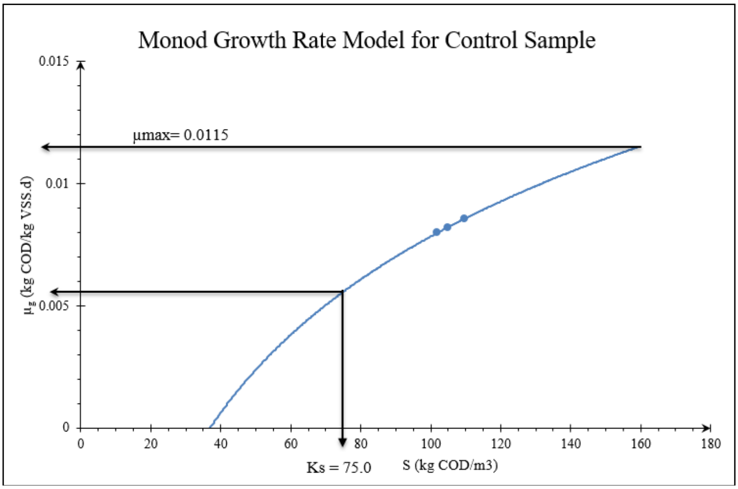

Figure 5: Graph of µ (kg COD/kg VSS.d) vs S(kg COD/m3) for Control sample

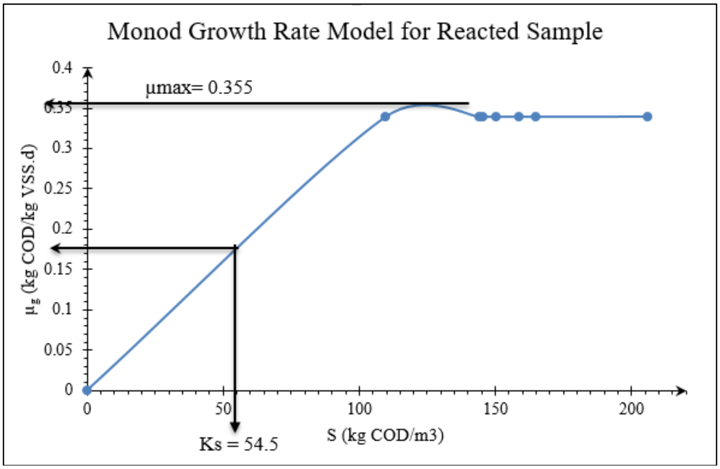

Figure 6: Graph of μ (kg COD/kg VSS.d) vs S(kg COD/m3) for Reacted sample

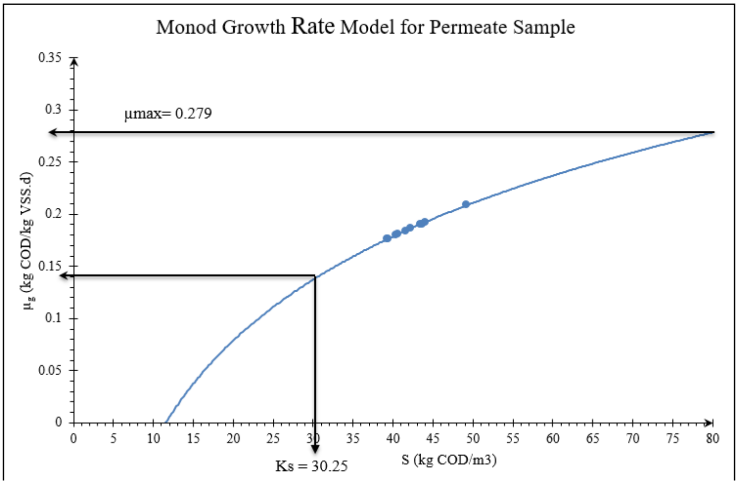

Figure 7: Graph of μ (kg COD/kg VSS.d) vs S(kg COD/m3) for Permeate sample

The graph in Figure 5, 6 and 7 show how the Monod Model theoretical constant value is collected. The calculated value of growth rate, μ gotten from Equation 1 is plotted against COD value for each sample. Actually, Monod Model explains the growth rate of microorganism or bacteria inside the wastewater especially POME when increasing the supply of food or susbtrate to a certain level where the growth rate will become constant with the increase of substate concentration. As we can see, three graphs above in Figure 5, 6 and 7 show us the graph follows the standard Monod Model Graph in finding the constant value.

Summary of kinetic parameters

The theoretical values of μmax and Ks of each sample are shown in Table 4. The value of μmax is 0.0115, 0.355 and 0.279 kg VSS/kg COD.d for control, reacted and permeate samples respectively. While, the value of Ks for control sample is 75 kg COD/m3, 54.5 kg COD/m3 for reacted sample and 30.25 kg COD/m3 for permeate sample. Based on the kinetic parameters obtained in Table 4, it can be seen that the μmax of control sample has the highest value compared to the other two samples.

Table 4: Summary of theoretical kinetic parameters in three different samples

Parameter	**Type of sample**		
	Control	**Permeate**	**Reacted**
μ_{max}	0.0115	0.279	0.355
Ks (kg COD/m^3)	75	30.25	54.5

From the previous research, treatment POME with one hour using ultrasonic device gives the R2 value of around 97% [10]. But in this study, the treatment with three hours ultrasonic application for the entire 5 hours treatment of POME gives the R2 value of 99.35% for permeate sample whcih is higher than last research study. In addition, the Ks value explains the amount of substrate needed to get the maximum value for growth rate. In other words, the lowest value of Ks represents the high amount of substrate removal. Table 4 shows that the value of Ks for permeate sample is in the lowest amount. Thus, it will be resulting in higher COD removal for permeate samples. The values of μmax are indicative of amounts of biomass in the UMAS [5]. The rate of substrate utilization increases as the reactor substrate concentration, S increases for a given biomass concentration [8]. Therefore, the μmax occurs at high substrate concentrations.

Referring to the all figures in Monod Model, the growth rate, μg was increased as substrate increased until one time the growth rate was constant while the substrate was feeding because more microorganisms in the sample cannot stand the life caused by excess of substrate. This is due to higher COD values which contribute to higher foods source to microorganisms. Microorganisms tend to grow well when there are sufficient food sources not in excess of food. Hence, the membrane blockage can be avoided since the bacteria grow actively in samples. Besides that, the performance of ultrasonic device in 3 hours will increase the waste water treatment quality in which its gentle movement avoids cake formation at membrane surface; thus, preventing the blocking of the membrane because the ultrasonic wave acts as cleaning agent in this system.

Conclusion

Three different samples (namely control, reacted and permeate) of POME were investigated. The comparison between these samples shows that the reacted sample contains a high amount of biomass in UMAS. It can be concluded that the use of ultrasonicated device in treating POME will reduce the membrane fouling of UMAS. This is due to the function of ultrasonic as membrane cleaning. By using UMAS, the membrane will be cleaned automatically for 1 hour in every 1 hour in total of 5 hours of POME treatment. Therefore, the blockage on the membrane can be avoided and the efficiency of POME treatment will increase as well.

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