Biomass Effect on Membrane Fouling Using a Hybrid Membrane Bioreactor for Palm Oil Mill Effluent

Z. Ahmad*, Z. Ujang** and G. Olsson***

*Universiti Tun Hussein Onn Malaysia, 68400 Parit Raja, Batu Pahat, Johor Malaysia
(Email: zul@uthm.edu.my)
**Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia
(Email: zaini@utm.my)
*** Lund University, SE-22100 Lund, Sweden
(Email: gustaf.olsson@iea.lth.se)

Abstract
The performance of a hybrid membrane bioreactor (MBR) for treating palm oil mill effluent (POME) has been studied. The objective of this study was to observe the effect of biomass on membrane fouling. Raw POME is difficult to degrade because it contains significant amounts of tryacylglycerols and degradative products such as di-and monoacylglycerols and fatty acids. The fatty acid composition (C_{12} – C_{20}) in each fraction is different from the other ones and this complexity contributes to the high pollution load from POME. A high strength POME with organic loading of 1.8 kgCOD/m^3 was introduced into a sequence of anaerobic, anoxic and aerobic processes in an MBR in order to achieve biological nutrient removal. The MBR was operated with constant flux of 15 l/m^2.h and mixed liquor suspended solid (MLSS) up to 8000 mg/L. Activated sludge from aerobic MBR was investigated to determine concentration of carbohydrate and protein in soluble microbial product (SMP) and extracellular polymeric substances (EPS). The values of protein in SMP and EPS were higher compared to carbohydrate. Particle size distribution measurements of the sludge were carried out to relate to the membrane fouling. The membrane surface was visualised by scanning electron microscopy (SEM) to compare the differences between the clean and the fouled membrane. The experiments have demonstrated that the fouling does not depend on the particle size. Rather, the fouling is mainly caused by the content of the protein in the SMP and EPS.

Key words
Hybrid Membrane Bioreactor; Palm Oil Mill Effluent; Soluble Microbial Product, Extracellular Polymeric Substances; Particle Size.

INTRODUCTION

Over the last few decades, the Malaysian palm oil industry has grown to be an important agriculture-based industry, where the country is today the world leading producer and exporter of palm oil. Since the 1950s the palm oil has been considered as a promising agriculture industry. Therefore, Malaysia's government was initiating the population of palm oil estate (Yusoff, 2006). Today, palm oil is the leading agriculture crop in Malaysia with about 4.3 million hectares of oil palm plantation land in the country. Palm oil products export revenue is projected to exceed RM50 billions in 2008 from last year's record of RM45.6 billions. With more than 500 palm oil mills, annually they produce some 13.9 million tonnes of crude palm oil and generate around 35 x 10^6 m^3 of palm oil mill effluent (POME) with a high pollution-load of 50,000 mg COD/L.

POME consists of high amount of oils; they are usually present in complex form that contains significant amount of triacylglycerides, di- and monoacyl glycerides and monoglycerides and some derivatives of fatty acids (Alias and Tan, 2005). These components are difficult to degrade so as to obtain short chain derivatives. Therefore, a series of anaerobic, anoxic and aerobic treatment steps have been proposed to reduce their compound characterized and to achieve biological nutrient removal.. An active biomass (sludge) inside aerobic membrane bioreactor (MBR) was investigated to observe the membrane fouling effect due to extracellular polymeric substances (EPS), soluble microbial products (SMP) and inert biomass. Most bacteria produce EPS of biological origin than participate in the formation of microbial aggregate whether the bacteria grow in suspended cultures or in biofilms. The biofilm or floc consists of bacteria cell enveloped by a matrix of large polymeric molecules where are located at or outside the cell surface (Crysi *et al*., 2001). According to Rittmann *et al* (1994) SMP are defined as soluble cellular components that are released during cell lysis, diffuse through the cell membrane, are lost during synthesis, or are excreted for some purposed. The objective of this study was to observe biomass characteristics and their effects to membrane fouling. This paper focuses on carbohydrate and protein in SMP and EPS; particle size distribution of sludge related to the membrane fouling; and visualizing membrane surface of fouled membrane using scanning electron microscopy (SEM).

MATERIAL AND METHODS

Experimental set-up and operating conditions

The experimental set-up is shown in Fig.1. The hybrid MBR consists of anaerobic, anoxic, and aerobic reactors in series, where three modules of flat sheet membrane are immersed in the aerobic zone. The membrane modules are made from chlorinated polyethylene (Kubota, Japan) with nominal pore size of 0.4 μm and effective area of 0.1m^2/pc. The working volume and operating condition of the hybrid MBR are mentioned in Tables 1 and 2. The anoxic and aerobic conditions were controlled by the internal recycling of the mixed liquor directly from the aerobic zone to the anoxic zone. Returned sludge flow from the anoxic zone into the anaerobic zone was controlled. An airlift was installed underneath the membrane modules in order to provide aeration to the membrane and oxygen to the biomass. The anaerobic and anoxic tanks were agitated with a mixer.

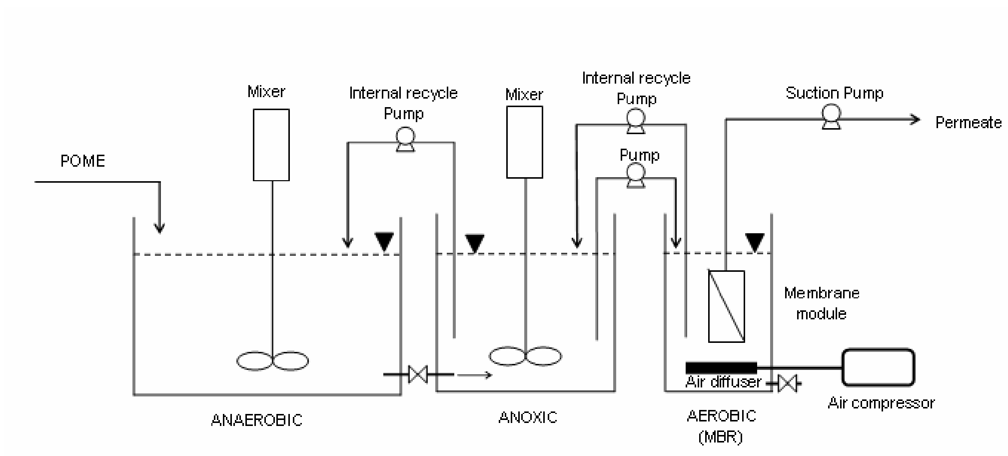

Figure 1. Schematic of Hybrid MBR

Table 1. Operating conditions of the Hybrid MBR

Parameter	Anaerobic	Anoxic	Aerobic (MBR)
Working volume, l	50	30	20
HRT, h	12	6	4
DO, mg/l	0 to 0.1	0.3 to 0.6	6 to 8
pH	5.5 to 6.5	7.2 to 8.5	7 to 7.5
Temp., ^{o}C	25 to 27	25 to 27	25 to 27
Airflow, l/min	-	-	10 to 15

Table 2. Operation parameter

Organic loading, kg COD/m^3.d	1.77 to 1.87
Q_{in}, m^3/d	0.108
Internal Recycle (IR)	$3Q_{in}$
Suction time (on/off), min	10/2
Constant flux, LMH	15 (for long-term operation)
MLSS, mg/l	4000 to 8000

The hybrid MBR was seeded with activated sludge obtained from the algae pond, POME treatment plant at Kilang Kelapa Sawit Bukit Besar, Kulai Johor, Malaysia. After 24 hours of acclimatisation, the membrane filtration was turned on progressively. The feeding was flowed into the sequencing processes of anaerobic, anoxic and aerobic zones in order to achieve biological nutrient removal. The feeding characteristics are showed in Table 3.

Table 3. Feeding characteristics

Parameter	Range
COD, mg/l	1680 $\pm$ 46
SS, mg/l	680 $\pm$ 30
TN, mg/l	28 $\pm$ 2
TP, mg/l	55 $\pm$ 3

Analytical methods

Laboratory experiments were carried out in the University of Technology Malaysia (UTM), Environmental Engineering Laboratory. Experimental analysis was conducted according to standard methods (APHA, 1998). The activated sludge was regularly tested for MLSS and MLVSS concentrations. Chemical oxygen demand, total nitrogen, total phosphorus were analysed using a spectrophotometer (HACH/DR 5000). Dissolved oxygen concentration and temperature were monitored using portable HACH kits measurement and pH was also monitored using portable LaMotte kits measurement. Soluble microbial products (SMP) and extracellular polymer substances (EPS) were evaluated in the biomass following the modified heating method (Zhang *et al*., 1999). Carbohydrate and protein concentrations of the SMP and EPS were measured using the method originally introduced by Dubois *et al*. (1956). The Carbohydrate and protein in the EPS and SMP were measured using spectrophotometer (HACH/DR 5000). The particle size distribution was analysed using the particle size analyzer (CILAS Model 1180). The surfaces of new membrane and fouled membrane were visualised using Analytical Scanning Electron Microscopy (SEM) model JEOL JSM-6380LA.

RESULTS AND DISCUSSION

Influence of Biomass

Activated sludge inside aerobic compartment of a hybrid MBR was started-up with MLSS concentration of 2792 mg/l. The system was fed continuously with raw POME for 54 days and biomass kept growing until they achieved steady-state condition with MLSS maintained about 8000 mg/l. The average MLVSS/MLSS ratio during the period of the experimentation was 0.63.

Figure 2 represents the relationship between SMP and MLSS. Concentration of protein (SMPp) at started-up reveal very high if compared to concentration of carbohydrate (SMPc) with 380 mg/gVSS and 60 mg/gVSS respectively. The concentration of SMPp decrease to 80 mg/gVSS and 50 mg/gVSS for SMPc when MLSS increase up to 8000 mg/l. It is noted that the amount of SMP tends not change much when the level of MLSS achieving certain value. In this case of study, when MLSS is about 7000 mg/l, value of SMPp and SMPc are consistently to a certain value. Hence, protein was found to be the dominant component if compared to carbohydrate in the SMP.

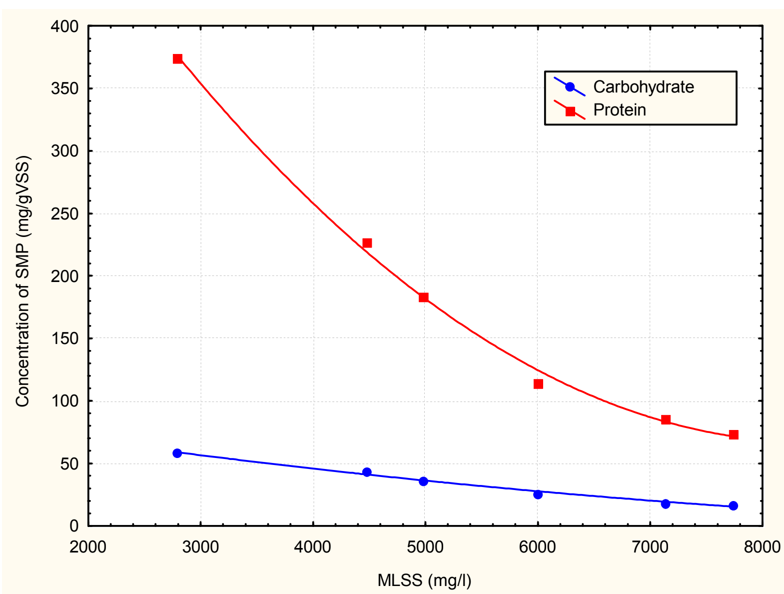

Figure 2. Relationship between Concentration of SMP and MLSS

The relationship between EPS and MLSS is shown in Figure 3. Protein (EPSp) reveals high concentration of 240mg/gVSS at the early stage and descends abruptly to 60 mg/gVSS for the MLSS 2800 mg/l to 8000mg/l. While, Carbohydrate (EPSc) decreases slightly from 60 mg/gVSS to 40 mg/gVSS for the same ranges of MLSS of EPSp. As same as SMP, EPS was also found that the values of EPSp and EPSc are consistently to a certain value when the MLSS increases to 7000 mg/l. In this case of study, protein still revealed dominant component if compared to carbohydrate. According to Cho *et al*. (2005), EPS tends to unchanged above a certain of MLSS concentration (5000 mg/l) using synthetic wastewater in their treatment.

Figure 4 is compared concentration of protein in SMP and EPS correlate to MLSS. The protein in SMP reveals slightly higher than concentration of protein in EPS. When the concentration MLSS is high (7000mg/l), the concentrations of protein in SMP and EPS are narrow to similar values of 70 mg/gVSS for SMP and of 60mg/gVSS for EPS. The trend of narrow variation region was indicated by Cho *et al*. (2005).

SMP and EPS levels as well as protein and carbohydrate (Reid *et al* 2008), protein was found to be the dominant component in EPS and SMP for five MBR plants, with SMP values consistently lower than the EPS one. But in this case study, EPS values is slightly lower than the SMP. However, in both cases protein is dominant component that contributes to fouling membrane mechanisms.

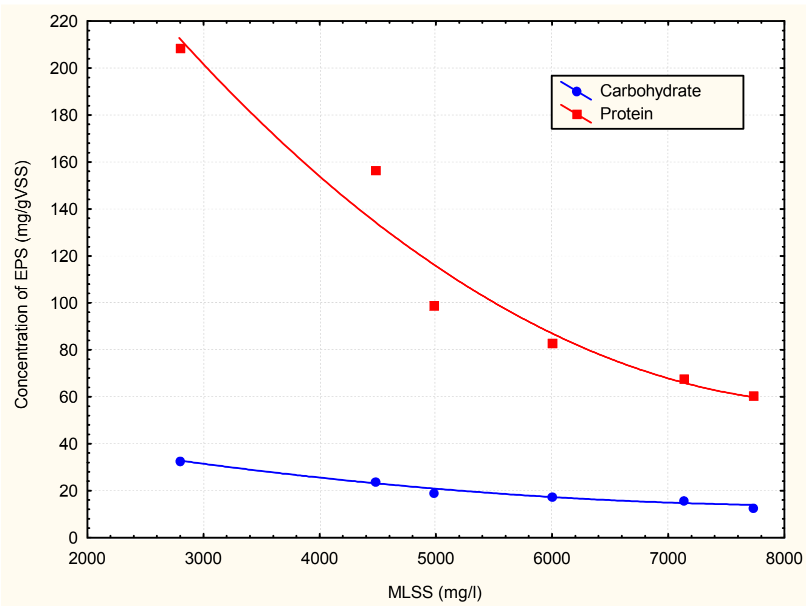

Figure 3. Relationship between Concentration of EPS and MLSS

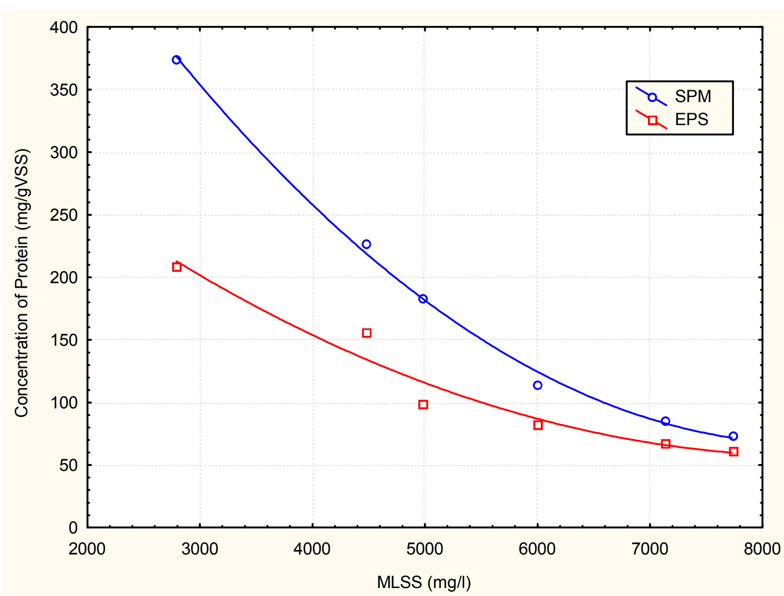

Figure 4. Relationship between Concentration of Protein and MLSS

Influence of sludge particle size

Figure 5 shows the relationship between diameter of sludge particle and MLSS. Particles size of sludge were investigated to determine diameter for 10% (d10), 50% (d50) and 90% (d90) of sludge diameter. The smallest diameter for d90 is 41 µm with MLSS of 6000mg/l. For the smallest diameter of d50 and d10 with MLSS of 8000 mg/l are 22 µm and 6 µm respectively. According to data of the particle size analyzer table 4 the percentage of passing for diameter 0.4 µm is approximately 0.92%. It meant that some particle less than 1% are smaller than diameter of membrane pore size which tends to influence to membrane fouling. Zhu *et al*. (2007) was reported that the particle of diameter less than 1µm were the main fouling factor for 0.45 µm pore membrane.

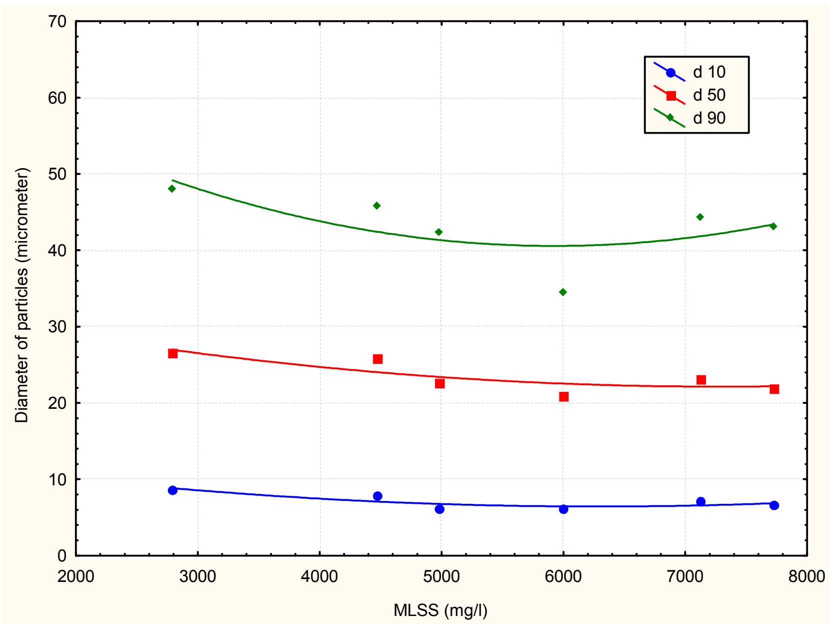

Figure 5. Relationship between Particle Size and MLSS

Table 4. Diameter of particle size less 1 µm for MLSS of 8000mg/l

Diameter of Sludge Particle (µm)	% Passing
0.03	0.00
0.04	0.00
0.07	0.06
0.10	0.15
0.20	0.65
0.40	0.92
0.50	1.22
0.60	1.46
0.70	1.62
0.80	1.73
0.90	1.81
1.00	1.89

SEM image of the fouled membrane

Scanning electron microscopy (SEM) was used to investigate directly the surface of the new membrane and fouled membrane. Figure 6(a), it clearly can be seen the membrane surface of new membrane or unused membrane. The membrane modules were used in the Hybrid MBR for long-term operation until they were significantly fouled. Then the fouled membrane modules were taken out from system for SEM images observation. Figure 6(b), the surface of membrane module was completely covered with microbial flocs (sludge) forming a cake layer and none of membrane pores could be seen. The SEM images of the surface of membrane are quite valuable in understanding the identities of foulant and revealing the shapes of depositions. Kweon and Lawler (2005) compared the SEM images of surfaces of fouled membrane using dextran water and alginic acid water. Yang *et al.* (2006) used the SEM images to investigate the efficiency of suspended carriers.

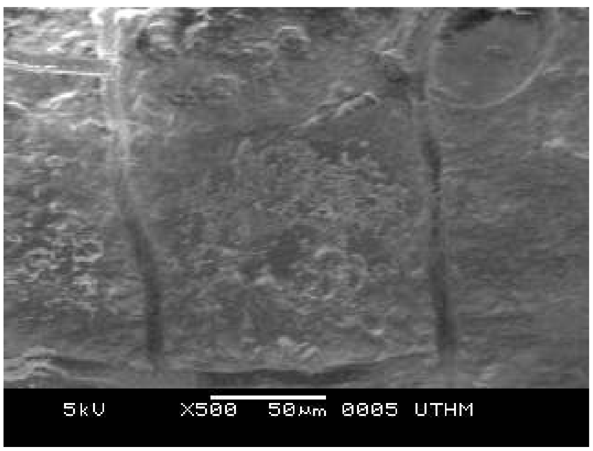

Figure 6(a). The SEM image of the new membrane surface

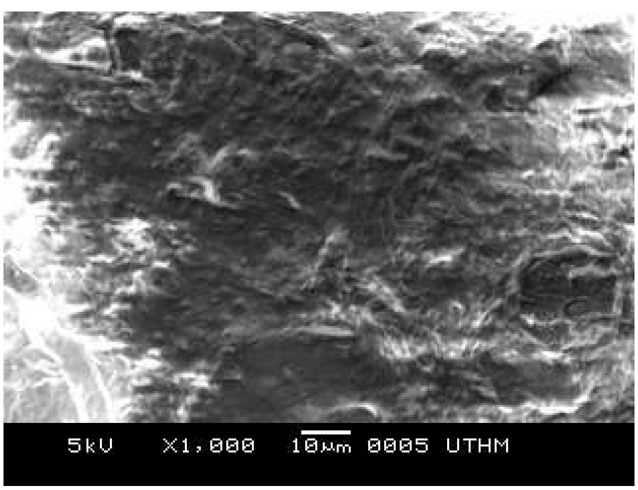

Figure 6(b). The SEM image of the fouled membrane surface

CONCLUSIONS

Biomass characteristics and effects on membrane fouling were investigated in a hybrid MBR for POME treatment. SMP and EPS are two major components of active biomass that contribute to membrane fouling. Protein is the dominant component in the SMP and EPS that causes the fouling membrane mechanism. In this case of studies were founded that the protein in SMP was slightly higher than the protein in EPS. Particle size of sludge that contributes to membrane fouling is less than 1% for diameter of sludge of 0.4μm for MLSS of 8000mg/l. Scanning electron microscopy (SEM) assists to visualize the images of the surface of membrane modules in order to understand the nature of foulant. The experiments have demonstrated that the fouling does not depend on the particle size. Rather, the fouling is mainly caused by the content of the protein in the SMP and EPS.

ACKNOWLEDGEMENT

The authors would like to thank to Faculty of Civil and Environmental Engineering, UTHM and Institute of Environmental & Water Resource Management, UTM for giving full supports and commitment of this research.

REFERENCES

Alias, Z. and Tan, I. K. (2005). Isolation of palm oil-utilising, polyhydroxyalkanoate (PHA)-producing bacteria by an enrichment technique. *Bioresource Technology.* 96 (11): 1229-1234.

APHA, AWWA, WEF (1998). Standard Methods*,* American Public Health Association, American Water Works Association and Water Environment Federation, Washington D.C, USA.

Cho, J., Song, K.G., Ahn, K.H. (2005). The activated sludge and microbial substances influences on membrane fouling in submerged membrane bioreactor: unstirred batch cell test. *Desalination* 183: 425–429.

Chrysi, S., Laspidou, Rittmann B.E. (2001). A unified theory for extracellular polymeric substances, soluble microbial products, and actives and inert biomass. *Water Research*. 36:2711-2720.

Dubois, M., Gilles, K.A., Hamilton, J.K., Rebers, P.A., and Smith, F. (1956). Colorimetric methods for determination of sugars and related substances. *Analytical Chemistry*. 28:350-356.

Kweon, J.H. and Lawler, D.F. (2005). Investigation of membrane fouling in ultrafiltration using model organic compounds. *Water Science and Technology*. 51(6-7): 101-106.

Reid, E., Xingrong Lui, Judd S.J. (2008). Sludge characteristics and membrane fouling in full-scale submerged membrane bioreactors. *Desalination*. 219: 240-249.

Rittmann, B.E., Regan, J.M. and Stahl, D.A. (1994). Nitrification as a source of soluble organic substrate in biological treatment. *Water Science and Technology*. 30:1-8.

Yusoff S. (2006). Renewable energy from palm oil-innovation on effective utilization of waste. *Journal of Cleaner Production*. 14: 87-93.

Zhang, X., Bishop, L.P., and Kinkle, B.K. (1999). Comparison of extraction methods for quantifying extracellular polymers in biofilms. *Water Science and Technology.* 39(7): 211-218

Zhu T, Xie Y.H., Wang Y.D., Wang Y.X, Zhang H.J. (2007). Study on Treatment of Domestic Wastewater by Submerged Flat MBR. *Second IEEE Conference on Idustrial Electronics and Application*. 1404-1408.