Evaluation of Hybrid Membrane Bioreactor (MBR) For Palm Oil Mill Effluent (POME) Treatment

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Abstract

The pollution load of palm oil mill effluent (POME) is in the range of 50,000 mg COD/L. With more than 500 palm oil mills, Malaysia produces some 13.9 million tonnes of crude palm oil annually and generates around 35 x 106 m3 POME. Typically, raw POME is difficult to degrade because it contains significant amounts of oil (tryacylglycerols) and degradative products such as di-and monoacylglycerols and fatty acids. The fatty acids composition (C12 – C20) of each of this fraction are different from one another and contribute to the high value of pollution load in POME. Thus POME has to be treated, usually in a series of anaerobic and aerobic treatment steps, for the organic matter to be degraded before the effluent is allowed to be discharged into public waterways. The objective of this study was to observe the performance of a hybrid membrane bioreactor (MBR) for POME. The raw POME was introduced into sequencing processes of anaerobic, anoxic and aerobic in order to achieve biological nutrient removal and the membrane modules were submerged into the aerobic zone. The critical flux of MBR using the flux-step method based on transmembrane pressure (TMP) was conducted as well as flux and permeability studies for assessing fouling in a membrane bioreactor operating at constant flux. The reactor was operated at a mixed liquor suspended solid (MLSS) concentration of 4000 to 8000 mg/l. The removal efficiency of COD, SS, TN and TP achieved were 94%, 98%, 83% and 64% respectively. The hybrid MBR was found to be able to degrade POME significantly and high quality effluent could be reused for various other applications.

Keywords: Flux, Hybrid MBR, Permeability, POME, TMP

1. INTRODUCTION

Over the last few decades, the Malaysian palm oil industry has grown to become a very important agriculture-based industry, where the country is today the world's leading producer and exporter of palm oil. Indigenous to Africa, the oil palm (*Elaeis guineensis Jacq.*) has been domesticated from the wilderness and transformed to become a plantation-based industry. 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 [20].

Today, oil palm is the leading agriculture crop in Malaysia, covering about three million hectares of the cultivated area and the area planted with oil palm increased 70 fold since 1960s. By the year of 2004, Malaysia remained the world's largest producer and exporter of palm oil with 13.9 million tons or 52% of world production and 12.2 million tons or 58% of total world exports, respectively [19], [14]. However, this important economic activity generates an enormous amount of liquid effluent POME [1]. It has been reported that for every ton of crude palm oil (CPO) produced, about 3.5 m^3 of POME is generated. In term of fresh fruit brunches (FFB), this amount of to about 0.7 m^3 POME/tonne FFB processed. This means that some 500 palm oil mills will produce more than 15 million tonnes of CPO annually. It is estimated that about 50 million m3 of POME is generated from the palm oil industry annually [16],[17],[8].

POME consists of high amount of oils; it is usually present in complex form that contains significant amount of triacylglycerides, di- and monoacyl glycerides and monoglycerides and some derivatives of fatty acids [2]. These forms 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. The objective of this study was to observe the performance of a hybrid membrane bioreactor (MBR) to treat POME. This paper has focused on short-term flux-step method to determine critical flux. TMP, fouling rate and permeability were measured to observe the fouling behaviour of membrane module for long-term operation.

2. MATERIAL AND METHODS

2.1 Experimental set-up and operating conditions

The experimental set-up is shown in Appendix 1. The hybrid MBR consists of an 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 by Kubota, Japan with nominal pore size of 0.4 μm and effective area of 0.1 m^2/pc. The working volume and operating condition of hybrid MBR are shown in Table 1. 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 into the anaerobic zone was controlled by the internal recycling from the anoxic to anaerobic tank. 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.

Table 1: Operating conditions of the Hybrid MBR

Parameter	Anaerobic tank	Anoxic tank	Aeoribic (MBR) tank
Working volume, liters	50	30	20
HRT, hours	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, liters/min	-	-	10 to 15
Organic loading, kg COD/m^3.d		1.77 to 1.87	
Q_{in}, m^3/d		0.108	
Internal Recycle (IR)		3Qin	
Suction time (on/off), min		10/2	
Constant flux, LMH		15 (for long-term operation)	
MLSS, mg/l		4000 to 8000	
TN:COD		1:60	
TP:COD		1:31	

The hybrid MBR was seeded with activated sludge obtained from the algae pond, POME treatment plant at Kilang Kelapa Sawit Bukit Besar, Kulai, Johor. After 24 hours of acclimatisation, the membrane filtration was turned on progressively. The raw POME obtained from the same mill has a typical COD of about 67,000 mg/l and had to be diluted several times before feeding the reactor. The POME feed was pumped at designated rate into the sequencing processes of anaerobic, anoxic and aerobic zones in order to achieve biological nutrient removal. The feeding characteristics are shown in Table 2.

Table 2: Feeding characteristics

Parameters	Rate, mg/l
COD	1680 46
SS	680 30
TN	28 2
TP	55 3

2.2 Analytical methods

Laboratory experiments were carried out in the Environmental Engineering Laboratory, Universiti Teknologi Malaysia. Experimental analysis was conducted according to standard methods [3]. 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.

3. RESULTS AND DISCUSSIONS

3.1 Determination of Critical Flux

The critical flux concept has been defined in two distinct forms with no fouling and little fouling occurring at sub-critical operation for the strong and weak form [10],[7]. The flux obtained during sub-critical flux (strong form) equate to the clean water flux obtained under the same conditions. In the alternative weak form, the sub-critical flux is the flux rapidly established and maintained during the start-up of the filtration, but does not necessarily equate to the clean water flux [11].

To determine the critical flux, the membrane bioreactor was fed with raw POME with the organic loading of 1.78 kg COD/m3.d., MLSS of 4 to 8 g/l, to carry out the flux-step method experiments. Figure 1 shows the value of the step amplitude of 2 LMH and 15 min duration. TMP increases linearly until achieving the flux of 10 LMH and it ascends significantly beyond the flux of 16 LMH. The gradient of TMP can be observed to vary from 0.003 to 0.13 as shown in Table 3. The condition was due to the foul phenomena on the membrane surface. The trend of fouling has been extensively studied [5],[10],[12],[15],[9]. During this cycle test it was observed that the TMP values obtained during the descending phase were greater than the corresponding values recorded during the ascending phases. There the TMP values were observed for one hour before and after the peak point (Figure 1) and were found to be 0.25 bar of ascending and 0.65 bar of descending.

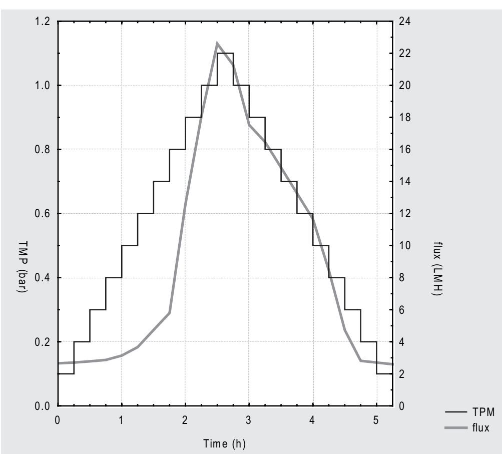


Fig. 1 Critical flux determination.

Figure 2 shows the experimental results obtained for different level of imposed permeate flow of POME and clean water. These results represent a linear variation between flux and TMP in which the slope is slightly above the one observed in flow of clean water through the membrane. There the gradient of POME ΦTMP is in the range of 0.003 to 0.02 and the gradient of clean water ΦTMP(CW) is 0.0005 as shown in Table 3. These are typical observations generally made for sub-critical flow rates. Then, above a flux value of 14 LMH, a clear break occurs in the curve with a substantial change in TMP where the ΦTMP varied from 0.02 to 0.05. The TMP rose significantly after flux of 16 LMH with its gradient ΦTMP of 0.13. This is characteristic of filtration where biological flocs are deposited on the membrane and thus of supra-critical condition. The results thus show a critical flux value ranging from 14 to 16 LMH, an interval corresponding to the values indicated by previous researchers [6],[15],[18].

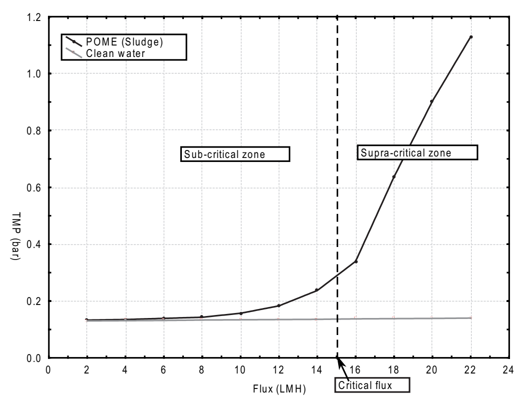


Fig. 2 Relation between TMP and Flux

Effect of permeability and fouling rate is shown in Figure. 3. For fluxes up to 10

LMH, permeability gradually increased up to 67 LMH/bar and fouling rate was nearly constant with its gradient ΦF of about 0.08 as shown in Table 3. At this stage it could be observed that the membrane was in good condition and no fouling occurred. The permeability increased achieving of 70 LMH/bar at a flux of 12 LMH and started decreasing to 67 LMH/bar at a flux of 14 LMH and then it dropped to 61 LMH/bar (about 6 LMH/bar) for the flux 16 LMH. Thereafter, the permeability dropped significantly from 61 to 38 LMH/bar for the next flux level of 2 LMH. The fouling rate rose significantly after flux of 14 LMH where its gradient ΦFR varied from 0.67 to 4.88 as mentioned in Table 3. Hence, the critical value fell in range of flux 14 to 16 LMH while permeability and fouling rate were in range of 61 to 67 LMH/bar and 3.5 to 5.0 mbar/min respectively. Permeability and fouling rate related to flux in a short-term flux-step method to determine critical flux was studied by Le Clech et al. in 2003.

Table 3: Values of ΦTMP, ΦTMP(CW), ΦFR, and ΦK with variable of flux

Flux (LMH)	Gradient: POME (sludge) (Φ_{TMP})	Clean Water ($\Phi_{TMP(CW)}$)	Fouling Rate (Φ_{FR})	Permeability (Φ_K)
0-10	0.003	0.0005	0.08	6.49
10-14	0.02	0.0005	0.67	
14-16/ 14-18*	0.05	0.0005	4.88	-6.96
16-22	0.13	0.0005	-	-

*Flux for ΦFR and ΦK

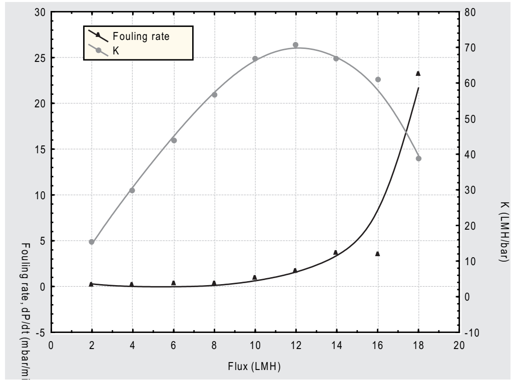


Fig. 3 Permeability and fouling rate as function of flux

3.2 Long-term operation

Figure 4 shows the effect of permeability after cleansing process for long-term operation. The Hybrid MBR operated with TMP of 0.53 bars, flux of 19.6 LMH and MLSS kept growing from 4 to 6 g/l within 8 days. Permeability declined from 37 LMH/bar to 24 LMH at day 7 and was slightly constant until day 8. Hence, membrane was significantly fouled, and it could be observed that TMP kept increasing up to 0.66 bar and flux dropped from 19.6 to 16 LMH. Then the membrane modules were taken out from the reactor and dipped in 0.5%w/w NaOCl solution for an hour and dipped in distilled water for 30 minutes [13]. The membrane modules were placed in the reactor to proceed with the next operation. After the cleansing, TMP rose to 0.53 bars, the flux dropped slightly to 19 LMH and the permeability also dropped only slightly to 35.5 LMH/bar. Permeability gradually decreased to 22.5 LMH/bar at day 15 and 16, TMP kept ascending up to 0.66, flux was constantly of 15 LMH and MLSS reached 7 g/l. At day 16, the membrane was fouling again. The difference in values of permeability at day 1 and day 9 was because of the intrinsic membrane resistance and the fouling resistance due to the irreversible adsorption and pore blocking. These membranes resistance were related to the cake resistance [18].

The Hybrid MBR was further operated for another 7 days with MLSS up to 8 g/l and the flux was kept constant at 15 LMH. Figure 5 shows the result of permeability and fouling for long-term operation. The membrane revealed significant fouling at day 5 to 7 that the gradients of fouling rate varied from 0.56 (day 1 to 4) to 4.72 (day 5 to 7) and permeability was about 20 LMH/bar at day 7.

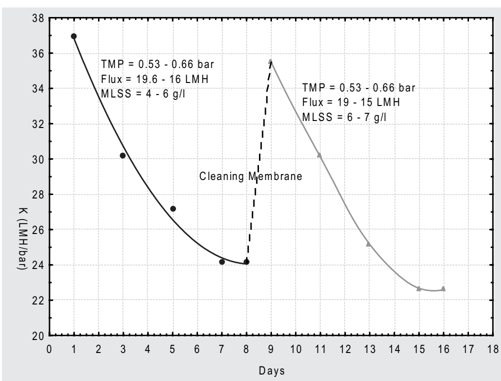


Fig. 4 Effect of permeability after cleaning the membrane

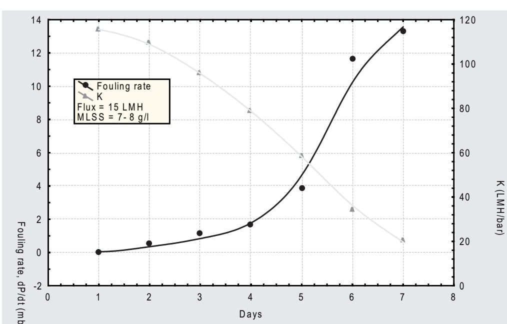


Fig. 5 Fouling rate and permeability for long-term operation

3.3 REMOVAL EFFICIENCY

Feeding and permeation were analysed every week for a period of 5 weeks. The concentration of feed and permeate are shown in Table 4. The average COD removal was about 94%. At an average the total removal was 98% for suspended solids, 83% for total nitrogen and only 64% for total phosphate. The COD removal is better compared to the value of 91-97% removal that reported by Xing *et al* in 2000 and Chang *et al* in 2001. Therefore this experiment has proven that a better result has been achieved.

Table 4: Concentration of feed and permeate

Feed (mg/l)				Permeation (mg/l)			
COD	SS	TN	TP	COD	SS	TN	TP
1728	667	26	52.7	111	10	4.0	19.1
1682	681	28	57.7	92	16	4.7	20.6
1643	654	30	53.6	98	12	5.4	21.4
1637	691	27	55.7	102	13	5.1	19.6
1654	713	28	51.9	128	28	4.8	17.6

Table 5 : Performance

	Performance (%)			
	COD	SS	TN	TP
	94	99	85	64
	95	98	83	64
	94	98	82	60
	94	98	81	65
	92	96	83	66
Average (%)	94	98	83	64

4. CONCLUSIONS

The performance of hybrid MBR was evaluated to determine critical flux for short-term operation and to observe the trend of fouling for long-term operation. For short-term operation, The critical flux can be observed where TMP and fouling rate increased significantly with increasing flux and permeability started to descend with increasing of flux. The membrane modules started to foul at the flux of 14 LMH, the fouling rate increased significantly from 3 to 8mbar/min and the permeability descended from 64 LMH/bar to 61 LMH/bar. For long-term operation, the membrane modules revealed fouling after one week of operation. After membrane cleansing, the initial permeability dropped slightly due to the irreversible adsorption and pore blocking to the membrane modules. The removal efficiency of COD, SS, TN and TP achieved of 94%, 98%, 83% and 64% respectively. The hybrid MBR, POME can be degraded significantly and high quality effluent could be reused for various applications.

REFERENCES

[1] Ahmad, A.L., Ismail, S. and Bhatia, S. (2005) 'Membrane treatment for palm oil mill effluent: effect of transmembrane pressure and crossflow velocity', *Desalination*, Vol. 179, pp.245-255.

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

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

[4] Chang, I.S., Gander, M., Jeffreson, B. and Judd, S. (2001). 'Low-cost membranes for use in a submerged MBR', *Trans IChemE*, vol.79, pp.183-188.

[5] Cho, B.D. and Fane, A.G. (2002) 'Fouling transients in nominally sub-critical flux operation of a membrane bioreactor', *Journal of membrane science*, vol.209, pp.391-403.

[6] Defrance, L. and Jaffrin, M.Y. (1999) 'Comparison between filtrations at fixed transmembrane pressure and fixed flux: application to membrane bioreactor used for wastewater treatment', *J. Membrane Sci*., Vol.152, pp.203-210.

[7] Jefferson, B., Brookes, A., Le Clech, P. and Judd, S.J. (2004) 'Methods for understanding organic fouling in MBRs', *Water Sci. Technol*, Vol.49, pp.237-244.

[8] Gressel, J. and Hoh, R. (2005) 'Malaysia oilseeds and products update (Oct) 2005. GAIN Report: USDA Foreign Agricultural Service', *Global Agriculture Information Network*, MY5045, pp.1-8.

[9] Guglielmi, G., Chiarani, D., Judd, S. J., and Andreattola, G. (2007) 'Flux criticality and sustainability in a hollow fibre submerged membrane bioreactor for municipal wastewater treatment', *Journal Membrane Science*, Vol.289, pp.241-248.

[10] Le Clech, P., Jefferson, B., Chang, I. S., and Judd, S. (2003) 'Critical flux determination by the flux-step method in a submerged membrane bioreactor', *Journal of Membrane Science*, Vol.227, pp.81-93.

[11]Le Clech, P., Chen, V., Tony and Fane, A.G. (2006) 'Review Fouling in membrane bioreactor used in wastewater treatment', *Journal Membrane Science*, Vol.284, pp.17-53.

[12]Lim, L.P. and Ujang, Z. (2004) 'Critical flux of membrane bioreactor (MBR) for digested palm oil mill effluent (POME) treatment', *Proceedings of the Water Environment-Membrane Technology (WEMT2004)*, June 7 – 10. Seoul, Korea, pp.793-799.

[13]Lim, L.P. and Ujang, Z. (2004b) 'The operating strategy for treatment of digested palm oil mill effluent (POME) in a flat sheet aerobic membrane bioreactor under tropical condition', *Conference Asia Water 2004*, Kuala Lumpur.

[14]Malaysia Palm Oil Board (2005) 'Palm Oil Update – for the Latest Information on Palm Oil. 25(09/05)', Ministry of Plantation Industries and Commodities Malaysia.

[15]Ognier, S., Wisniewski, C., and Grasmick, A. (2004) 'Membrane bioreactor fouling in sub-critical filtration condition: a local critical flux concept', *Journal of Membrane Science*, Vol.229, pp.171-177

[16]Salmiati, Ujang, Z., Salim, M.R., Md Din, M.F. and Ahmad, M.A. (2006) 'Recovery Technology for Renewable Organic-Based Products from Palm Oil Mill Effluent (POME)' *Asia Water 2006*. Kuala Lumpur.

[17]Yacob, S., Hassan, M.A., Shirai, Y., Wakisaka, M. and Subash, S. (2005) 'Baseline study of methane emission from open digesting tanks of palm oil mill effluent treatment', *Chemospher*, Vol.59, pp.1575-1581.

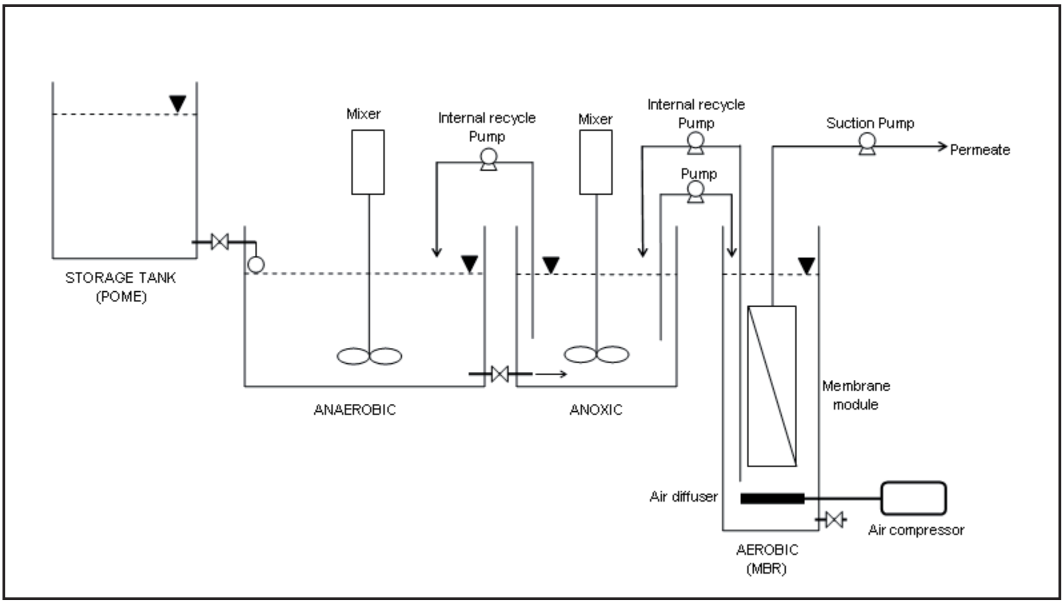
[18]Yang, Q., Chen, J. and Zhang, F. (2006), 'Membrane fouling control in a submerged membrane bioreactor with porous, flexible suspended carriers', *Desalination*, Vol.189, pp.292-302.

[19]Yeoh, B.G. (2004) 'A Technical and economic analysis of heat and power generation from biomethanation of palm oil mill effluent', *Electricity Supply Industry in Transition: Issues and Prospect for Asia*. Pp.20-63

[20]Yusoff, S. (2006) 'Renewable energy from palm oil-innovation on effective utilization of waste', *Journal of Cleaner Production*. Vol.14, pp. 87-93.

[21]Xing C.H., Tardieu E., Qian Y., and Wen X. H. (2000).Ultrafiltration membrane bioreactor for urban wastewater reclamation. *Journal of Membrane Science*, 177: 73-82.

Appendix 1


Mixer
Internal recycle Pump
Mixer
Internal recycle Pump
Suction Pump
Permeate
Pump
STORAGE TANK (POME)
ANAEROBIC
ANOXIC
Membrane module
Air diffuser
Air compressor
AEROBIC (MBR)