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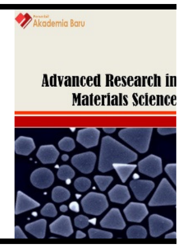

Performances of Sandwich Membrane in Reclamation of Water from Final Discharged POME

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ABSTRACT

An investigation was made to examine the performance of sandwich configurations of paired ultrafiltration membranes in reclamation of water from final discharged POME. Two membranes were sandwiched together in different configurations without spacer. Two types of membrane were used in this study which were PES and RC with MWCO 5kDa. The sandwich configurations were known as SS-Sandwich, SB-sandwich, where S indicates that the skin layer faces the feed and B indicates that support layer faces towards the feed. The result of single membrane was compared with both sandwich arrangement. SS-sandwich configuration showed the best permeate quality for PES MWCO 5kDa. The pollutant reduced range up to 80%-90% compared to single membrane which were 60%-70% range. The quality of permeate obtained for total dissolved solid (TDS), suspended solid (mg/L), turbidity, BOD5, COD, were 535 mg/L, <25 mg/L, 0.88 NTU, BOD5 23.3 mg/L, and 48 mg/L. The quality of permeate from SS-sandwich membrane of 5 kDa was beyond reuse standard and approaching drinking water standard for TSS, TDS and turbidity. Therefore it can be concluded that, water reclaimed from treating final discharged from palm oil mill effluent using ultrafiltration technique with right sandwich configuration at optimum operating conditions was successfully complied with WHO reuse water standard.

Keywords:
Ultrafiltration, Membrane Fouling, Sandwich Membrane, Reclamation

1. Introduction

Palm oil industry is a fast growing industry in Malaysia, as Malaysia is the world's largest producer and exporter of palm oil after Indonesia. However, the production of palm oil consumed tonnes of water and half of it end up as effluent. The raw effluent undergoes further treatment before being discharged to the river. The final discharged can be reused for the plant process and therefore reduced the consumption of fresh water and diminishing the amount of discharged effluent [10, 11, 9, 8, 1]. One of the promising technology to treat and reclaim water from final discharged is UF membrane.

In the last decade, ultrafiltration (UF) is a technology experiencing rapid growth and has been recognized as one of the advanced technology. UF membrane widely implemented in various field of

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industry such as production of pure water, fractionation or concentration in food, pharmaceutical, biotechnology, as well as wastewater treatment [5]. Therefore UF may work as reliable tool in treating final discharged effluent and the water reclaimed from this treatment could be reused for the plant process. Thus, the main advantage lie in reduction of cost for water supply for production process. However, based on previous study, the quality of treated POME does not clearly stated whether permeate achieved standard for water reclamation. For instance, study by Wu *et al.,* [14] combined physical conventional treatment with ultrafiltration to treat raw POME. They successfully achieved reduction of TSS, turbidty, TDS, and COD up to 97.3%, 88.2%, 3.1% and 46.9%. Nevertheless, the results was not clearly reported whether the permeate quality achieved standard of water reclamation. Another study by Ahmad *et al*., [2] treated POME with membrane technology which were ultrafiltration (UF) and reverse osmosis (RO). They successfully achieved standard discharged regulations, as the water reclaimed can be recycled back to the plant. However, the application of RO membrane increased the cost of application and maintenance. Hence, it not suitable for industrial application. Besides, most of the literature found, treated the raw POME.

Therefore, the idea of sandwich was proposed in this study, to compensate for the imperfection of the pore size distribution of the available commercial membranes. It has been recognised at the wide pore size distribution of most commercial membrane significantly limit the resolving power of the membranes [4] and the broad pore size distribution reduced the effectiveness of membrane in treatment of final discharged. Besides, as the application of UF membrane might reduce the cost compared to RO membrane. In this study, the effect of sandwich configurations of pair ultrafiltration membrane in treating final discharged to reclaim water were examined. The permeate quality and fouling study was compared with those single membrane configuration.

2. Materials and Methods

2.1 POME Sample

Samples of final discharged was taken from a local palm oil mill in FELDA Sungai Tengi, Kota Kubu Bharu, The effluent was collected from a pipe before being released into river. The samples was preserved and stored at a temperature of less than 4˚C to avoid biodegradation due to microbial action which may affect the result of the experiment. For the analysis and experimental purpose, the temperature of the sample was allowed to reach room temperature. The characteristics of analysis of final discharged was carried out to evaluate the pH, total solid, suspended solid, dissolved solid, chemical oxygen demand (COD), biological oxygen demand (BOD_5), and turbidity. The analytical methods were conducted based on procedures given in the APHA Standard Method for the Examination of Water and Wastewater [7]. Each analysis was performed duplicated.

2.2 Ultrafiltration Membranes

Membrane used were flat sheet regenerated cellulose (RC) membrane (Merck Milipore USA) with 28.7 cm^2 effective membrane area and diameter 63 mm and polyethersulfone (PES) with membrane (Sartorius) 28.7 cm^2. Molecular weight cut-off of the membrane used were 5 kDa.

2.3 Experimental Set-up and Procedure

The experiments were mainly carried out at a fixed conditions, stirring speed 600 rpm, pressure 1.0 bar and pH 8 the. Two flat ultrafiltration membranes of same type were sandwiched together without a spacer, in several different configurations as shown in Figure 1 below, by varying the arrangement of the skin layer (S) and support layer (B) in the sandwich. For SS-sandwich configuration both skin layer facing up, meanwhile for SB-sandwich configuration the upper layer facing up and the bottom membrane skin layer facing down.

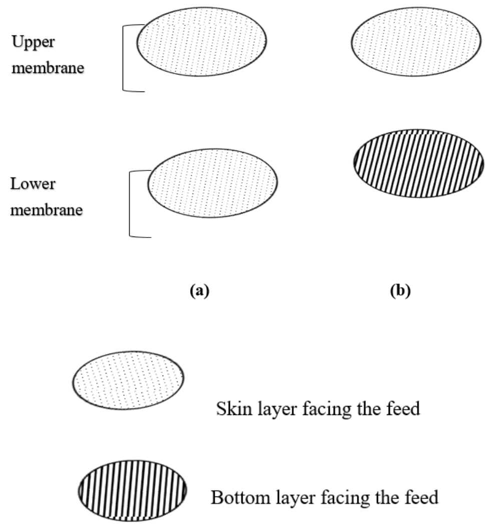

Fig. 1. Ultrafiltration membrane configurations: (a) SS-sandwich membrane (b) SB-sandwich membrane

180 ml of final discharged POME was prepared for each run in ultrafiltration treatment. The experiment performed in batch mode using stirred ultrafiltration cell (Amicon 8200, Milipore USA). For each cycle, the experiment was run in 120 min. The permeate flux was observed by collecting every 20 minutes. The permeate was then further analysed for dissolved solid, turbidity, suspended solid, COD and BOD_5. The details of all analytical methods conducted were based on procedure given in APHA Standard Method for the Examination of Wastewater [7]. Each analysis was done twice.

2.4 Resistance-in-Series Model [13]

Darcy's law is used to determine filtration resistance in permeate transport through porous membranes

$$J = \frac{\Delta P}{\mu R t} \quad (1)$$

where J is the permeate flux ΔP is the trans-membrane pressure (TMP), μ is the viscosity of permeate, and R_t is the total filtration resistance.

R_m is the membrane intrinsic resistance characterized by mainly the pore size and membrane thickness as determined by manufacturing process. Membrane resistance was calculated with the following equation

$$R_m = \frac{\Delta P}{\mu J w} \quad (2)$$

where R_m is membrane resistance, ΔP is the trans-membrane pressure (TMP), μ is the viscosity of water and J_w pure water flux.

$$R_f = \frac{\Delta P}{\mu p J p} - R_m \quad (3)$$

R_f is the most important because it can be reduced by proper techniques in practical application. Here R_f is membrane fouling, ΔP is the trans-membrane pressure (TMP), μ is the viscosity of permeate and J_w flux of final discharged POME at the end of filtration

$$(R_m + R_p) = \frac{\Delta P}{\mu J a} \quad (4)$$

where ΔP is the trans-membrane pressure (TMP), μ is the viscosity of permeate and J_w water flux after membrane was rinsed with distilled water and cleaned with backwash.

Pore blocking resistance was calculated using equation below

$$R_p = (R_m + R_p) - R_m \quad (5)$$

while cake resistance was calculated by following equation

$$R_c = R_f - (R_m + R_p) \quad (6)$$

3. Results and Discussion

3.1 Effect of Sandwich Configurations on Permeate Flux

The efficiency of the SS-sandwich and SB-sandwich to treat final discharged POME was evaluated. Figure 2 (a) and (b) compared the permeate flux changes with time between single, SS-sandwich and SB-sandwich membrane for PES and RC membrane. The trend for both configuration of both type of membrane seems to be similar as the permeate flux decreased at early stage of filtration. SS-sandwich membrane experience greater flux decline compared to SB-sandwich, for instance, permeate flux reduction from early to end stage for PES membrane were 30.29% (SS) and 20.7% (SB) respectively and for RC membrane were 31.3% (SS) and 23.2% (SB). It shows that for both type of membrane SS-sandwich experience greater flux decline compared to SB-sandwich membrane. It also suggested that fouling is most likely to occur in SS-sandwich ultrafiltration. The arrangement of SS-configurations which the skin layer of bottom membrane facing the feed increased the possibilities of the solid particles to accumulate on membrane surfaces [3].

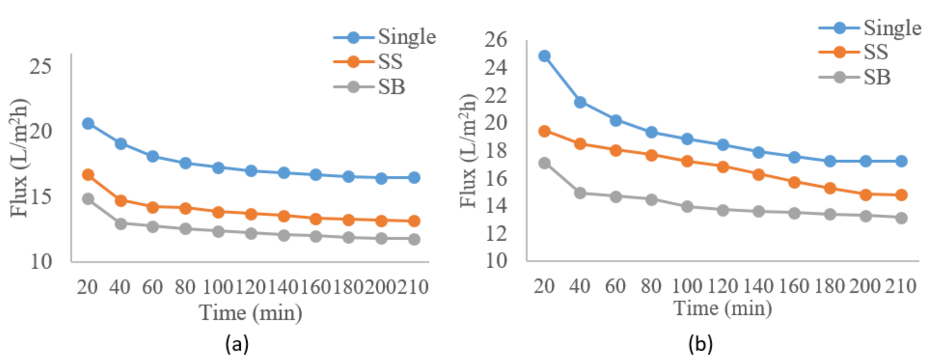

Fig. 2. Permeate flux of different sandwich configurations (a) PES 5kDa (b) RC 5kDa

Meanwhile, the SB-sandwich configuration results in lower permeate flux than SS-sandwich membrane. This due to reverse direction of bottom membrane caused internal concentration polarization to occur [6]. The solid particle that build up inside the pores of membrane caused internal intermediate blocking resulted in low permeate flux [3].

3.2 1 Effect of sandwich configurations on fouling

As can be seen from Figure 3, when membrane was arranged to SB-sandwich configuration, the cake resistance of upper membrane is higher than bottom membrane. Pore blocking resistance of bottom membrane was higher than top membrane. This is because of the internal concentration polarization most likely to occur when bottom membrane was in reverse direction. Besides, when the support layers with larger pores were arranged towards feed solution, there were more opportunities for the solid particles to enter through these pores [6]. This will caused solid particles which able to pass through the top membrane to build-up inside the pores of the second membrane which resulted in intermediate pore blocking fouling.

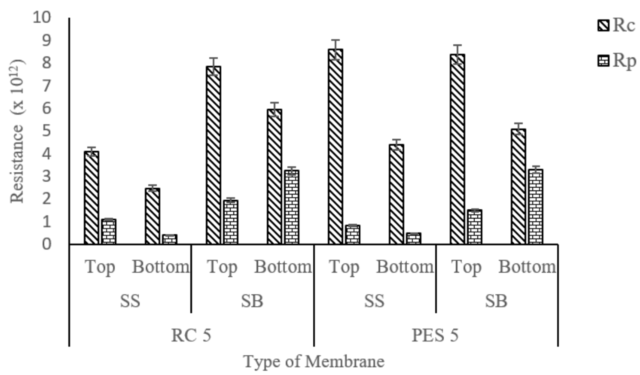

Fig. 3. Fouling resistance of sandwich SS-configuration and SB-configuration of top and bottom membrane

Meanwhile, for SS-sandwich configuration, fouling resistance of both R_c and R_p of top membrane was higher than bottom membrane. Both membrane were facing the feed. The particles tend to accumulate on the membrane surface with this arrangement. Since resistances of bottom was reduced, it indicate that the fouling also reduced. There might be some solid particles that able to pass through the membrane was accumulated on the bottom membrane, while most of them was deposited on the top membrane. This proves that the role of second membrane that acts as second barrier suppress the fouling and improve quality of permeate.

3.2.3 Effect of sandwich configurations on permeate quality

Figure 4 (a) above showed that PES membrane consistently showed lowest dissolved solid for all configurations due to hydrophobic characteristics of polyethersulfone typically shows significant surface adsorption (Saha et al., 2006). Dissolved solids tend to adsorp on membrane surface or inside the pores rather than passing through. Membrane with SS-configuration showed lowest dissolved solid concentration compared to SB-configuration. As previously discussed, some dissolved solid particles accumulate on the upper membrane surfaces, some might pass through the first membrane and will accumulate on surface of second membrane. Thus, reduced the possibilities of dissolved solid from passing through the membrane. Besides, dissolved solid concentration at the bottom membrane surface will be less than at the upper membrane surface.

Figure 4 (b) 20 shows only the difference in turbidity between single and sandwich membrane. Generally, all the configurations reduced the turbidity lower than 3 NTU. SS-configurations achieved highest rejection among single membrane and SB-sandwich configuration. From graph above, it can be seen that the lowest turbidity rejection was PES 5kDa membrane by using SS-sandwich configuration. Permeate from this configuration is much clearer if seen by naked eyes. This suggested that SS-configuration was more effective in term of rejecting suspended solid with skin-side-up orientation membrane. Even though this configuration will decreased the permeate flux, the rejection of suspended particles was improved due to the bottom membrane acts as second barrier reduced the possibility of suspended solid to pass through the membrane thus improved the quality of the permeate.

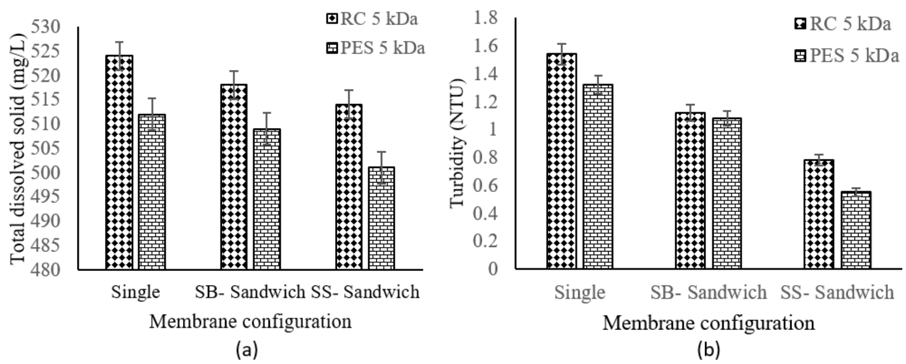

Fig. 4. Comparison of (a) dissolved solid and (b) turbidity in permeate of different membrane configuration

As for SB-configuration, the rejection of particles is lower than SS-configuration. For example the turbidity of PES 5kDa using SB-sandwich turbidity was 1.12 NTU while for SS-configuration was 0.55 NTU. This is due to the fouling which will reduced the flux but improved rejection. For SB-configuration, the bottom membrane in reversed direction, the particles that pass through the upper membrane were clogged throughout the support might be able to penetrate throughout the bottom membrane with the help of transmembrane pressure.

Table 1 represents the comparison of the quality final discharged before ultrafiltration, after ultrafiltration with final discharged limit from department of environment and water reuse standard. From the result above, sandwich membrane were effective in improving final discharged compared to single membrane. For example, PES 5kDa membrane, the percentage difference of BOD_5 for permeate after SS-sandwich and SB-sandwich compare to single membrane were 24.9% and 14.08% , for RC 5kDa 30% and 14.7%, Meanwhile, COD value also reduced significantly when compared with single membrane, for instance, PES 5kDa and RC 5kDa using SS-sandwich and SB-sandwich were 23.57%, 12.4%, 39.58% and 35.4% respectively. Dissolved solid concentration which consists of natural organic matter will affected on the BOD_5 and COD values (Wu et al., 2007). The lowest BOD_5 and COD were 21.8 mg/L of permeate was obtained using PES 5kDa with configuration SS-sandwich.

Table 1
Comparison of permeate quality of single membrane, sandwich membrane and water reuse guideline

Parameter	Final discharged	5 kDa RC (Single)	5 kDa PES (Single)	5 kDa RC (SS)	5 kDa RC (SB)	PES 5 kDa (SS)	PES 5 kDa (SB)	Final Discharged Limit Standard B	EPA Guideline for water reuse standard
Dissolved solid (mg/L)	890	541	538	535	536	530	533	Not stated	Not stated
Suspended solid (mg/L)	43	<25	<25	<25	<25	<25	<25	≤ 50	≤ 30
BOD_5 (mg/L)	97	33.3	27.7	23.3	28.4	21.8	23.8	50	≤30
COD (mg/L)	170.8	96	62.8	58	62	48	55	100	Null
Turbidity (NTU)	17.6	1.44	1.02	0.88	0.92	0.72	0.58	-	-

4. Conclusion

The purpose of this research was to study the performance of sandwich membrane with SS and SB configuration in treating final discharged of POME. The effectiveness of these configurations were evaluated in terms of permeate quality such as dissolved solid, turbidity, COD and BOD_5. From the results it is evident that sandwich membrane treatment process with SS-configuration of PES 5kDa showed the best permeate quality as it able improve permeate quality such as as dissolved solid, turbidity, COD and BOD_5 up to 39.2%, 91.8%, 71.89%, and 77.52% respectively. As a conclusion, the sandwich membrane configuration has shown great potential in reducing some pollutant elements in final discharged compared to single membrane. Besides, the quality of permeate achieved water reused standard thus, can it be reused for many purpose in the mill. Therefore, water security can be sustained and conserved by reclaiming water from final discharge.

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