Membrane Performances and Cost Analysis of Integrated Moving Bed Biofilm Reactor-Membrane System for Palm Oil Mill Effluent (POME) Treatment at UKM-YSD Pilot Plant.

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***Abstract*—Reclamation and reuse of water from palm oil mill effluent (POME) becomes an alternative towards achieving sustainability compared to present conventional ponding system in mills. Therefore, a pilot plant study using membrane filtration coupled with pre-treatment conducted at Tennamaram palm oil mill presents a viable technique in POME treatment which requires less energy, maintenance cost and space. Acclimatization of moving bed biofilm reactor (MBBR) was conducted prior to membrane filtration to reduce chemical oxygen demand (COD) concentrations in pre-treated POME which stabilized to 550 mg/L to minimize chances of membrane fouling in reverse osmosis (RO) unit. However, final COD concentration did not achieve below 500 mg/l as required. Certain units were bypassed to create four different configurations in analyzing RO flux behavior as basis of membrane performance. Configuration I which bypassed MBBR showed the least flux decline of about 14% and greater flux recovery between physical cleanings. Configuration II bypassed MBBR and RO 2 had 24% flux decline. Configuration III which bypassed MBBR and ultrafiltration (UF) unit while Configuration IV bypassed MBBR, UF unit and RO 2 both presented higher flux decline with 30% and 59% respectively. Configuration I and II were concluded the most cost-effective systems through cost analysis of each configuration whereby both configurations yielded the highest permeate flux with good flux recovery with the same amount of physical cleaning for all configurations with high stable operating pressure.**

Keywords— Palm Oil Mill Effluent (POME), Moving Bed Biofilm Reactor (MBBR), Membrane flux, Cost analysis.

I. INTRODUCTION

Treatment of industrial effluents has emerged as a trending role in water resources management in providing efficient water reclamation and reuse as environmental legislations have become increasingly stringent. The palm oil mill industry in Malaysia has been recognized as producing the largest pollution load into the rivers throughout the country [1]. The wastewater produced known as palm oil mill effluent (POME) mainly comes from a combination of water and sludge separation in palm oil extraction processes. Generation of this effluent in huge quantities presents an opportunity for water reuse in mill operations hence reducing the amount of effluent discharge. Membrane filtration technique emerged as one of the most significant methods in POME treatment [2]. The membrane technology coupled with pretreatment of POME would lower the concentration of the colloidal particles before entering the membrane system which could reduce damage and fouling thus reducing the maintenance cost of the membrane modules. It is estimated that more than 85% of palm oil mills in Malaysia have preferred the use of the conventional ponding system and the rest have taken on using open digesting tank. Although the ponding system has proven to be a low-cost method in treating POME, large area of land however is needed for these ponds and long retention time of around 20-200 days before considered safe to discharge into nearby rivers is time-consuming [2] as well as escaping greenhouse gases (GHGs) such as methane generated from the anaerobic ponding system which is corrosive in nature [3].

Integration of membrane technology with moving bed biofilm reactor (MBBR) as pre-treatment provides a suitable alternative in POME treatment methods. The MBBR's simple and efficient technology has been adopted in many industrial wastewater treatment systems such as pulp and paper industry, refineries, and poultry processing wastewater to minimize chances of membrane fouling. Biofilms are adapted widely in biological wastewater treatment due to its high removal efficiency for organic pollutants and ammonia nitrogen from the feed wastewater as well as low sludge yield [4]. According to a pharmaceutical application of MBBR, acclimatization of MBBR was performed prior to primary treatment to reduce COD concentration to 500 mg/L and 1000 mg/L [5]. Preliminary studies of lab scale of MBBR with POME was conducted and found to reach below 500 mg/L which fulfills the requirement of MBBR application for POME treatment. Ultrafiltration functions to remove macromolecules and high-molecular-mass compounds including bacteria and viruses, however, metal ions, aqueous slats, sugars and nonprotein nitrogen can pass through the membrane into the permeate [6].

Membrane separation has become a significant technology in wastewater treatment due to its excellent efficiency of particulate removal, less area requirement and less human intervention needed thus resulting in low labor cost. Reverse osmosis (RO) is a water purification process of which solvent and solute are separated through pressure difference removing fine water pollutants such as phosphorus and organic matter [7][8]. According to Colla et. al [7], RO has been proven to remove metal ions such as phosphate and chloride in the effluent discharge in the electroplating industry. However, short life expectancy due to fouling is a major disadvantage for application in industrial scale hence integrating the method with other methods such as pre-treatment helps to increase the overall system efficiency [9]. Fouling occurs due to accumulation of substances on the surface of the membrane which then reduces membrane permeability [10]. Permeate flux has been a parameter of membrane performance where percentage of flux decline is observed. Based on Ahmad et. al [6], flux decline for membrane performance in POME treatment proved to be 50% of the initial flux after 23h.

The permeate flux J_v, is taken as permeate flowrate Q_p (L/h), over the effective filtration area A (m^2) of the membrane [6].

$$J_v = \frac{Q_p}{A} \quad \text{(Eq.1)}$$

Only few economic studies have been conducted regarding POME treatment in areas of membrane technology application, one of which was conducted by Ahmad et. al [11]. Cost comparison analysis becomes a necessity in determining which provides both equally a cost-effective system as well as economically attractive for application. The exact cost-effectiveness of the assessment of two or more alternatives require a comparative analysis in terms of their cost and treatment efficiency [12]. A comparative study by Ahmad et. al [11] on a membrane-based palm oil mill effluent (POME) treatment plant of three different designs, Design A used ultrafiltration (UF) ceramic membranes and reverse osmosis (RO) polymeric membranes; Design B applied UF polymeric membranes and RO polymeric membranes; Design C used a two-pass RO polymeric membrane system which were all examined of both performance and cost. All three designs used similar pre-treatment methods (equalization, cationic and anionic polymer flocculation) with the recovered water all met the effluent discharge standards imposed by the Department of Environment (DOE). The study concluded that Design C which operated at high pressure with low membrane unit cost is preferable based on estimated total cost per cubic meter at optimum conditions.

II. Materials and Methods

A. *POME Collection and Chemical Oxygen Demand (COD) Analysis*

Approximately 900 L of POME was collected manually using a 1 m^3 container from the last pond of the existing ponding system of Tennamaram Palm Oil Mill. COD analysis of the POME was conducted to determine the amount of dilution needed before feeding into the treatment system. This was to ensure system efficiency as well as reducing risk of equipment damage (i.e. clogging, fouling) during system run. The optimum COD level before feeding into the system is about 150 mg/l. The dilution with water was conducted manually following the equation,

$$M_1V_1 = M_2V_2 \qquad \text{(Eq.2)}$$

where M_1 (mg/l) is the molar concentration of the current fluid, and V_1 (l) is the volume of the fluid. The right side of the equation represents the molar concentration, M_2 and volume, V_2 required for the process feed.

B. *Acclimatization of MBBR*

POME was pumped into the MBBR of about 500 L twice a week to undergo acclimatization. Samples were taken and tested for COD, ammonia, hardness, colour, turbidity, chlorine, total suspended solids and conductivity. Acclimatization was considered achieved if the COD values are stable for three consecutive analysis. However, the COD concentration did not reach the required range for membrane treatment which was supposedly below 500 mg/L. Therefore, the alternative method was by dilution using the formula as stated in II(*A*) (Eq. 2) to a COD level of 150 mg/L in a prepared mixing tank. The POME was then pumped into a 2000 L clarifier to be clarified by removing sedimentation from the raw POME. This was to avoid plugging throughout the system due to clumped solids therefore reducing potential of fouling in the following membranes.

C. *Configurations of Integrated Pretreatment Membrane system.*

The POME was pumped through the pre-treatment filtration units; polypropylene (PP) filter bag, activated carbon filter, 5µn pre-filter, sand filter and polyvinyl chloride (PVC) ultrafiltration (UF) unit. The treated POME was then pumped through three subsequent RO units (Filmtec BW30-4040 Spiral Wound 4040) which were labeled as RO 1, RO 2 and RO 3 (Fig. 1). Average flowrate through the RO membranes was 0.5 m^3/hr with a permeate recovery of 50-60% with operating temperature of 1-45ºC and pressure 1-41 bar.

Configurations were constructed based in the order from pretreatment to membrane filtration with variations by bypassing certain units including MBBR, UF and RO 3 in order to observe changes in membrane performance (permeate flux) at RO 3 of the end product of treated POME. Each configuration was repeated six times of 30 minutes each for better observation (Fig. 2).

- *Configuration I:* Bag filter + sand filter + activated carbon+ pre-filter + UF filter + RO1 + RO2 + RO3 (bypass MBBR).
- *Configuration II:* Bag filter + sand filter + activated carbon+ pre-filter + UF filter + RO1 + RO3 (bypass RO2 and MBBR).
- *Configuration III:* Bag filter + sand filter + activated carbon + pre-filter + RO1 + RO2 + RO3 (bypass UF filter and MBBR).
- *Configuration IV:* Bag filter + sand filter + activated carbon + pre-filter + RO1 + RO3 (bypass UF filter, RO2 and MBBR).

D. *Analysis*

Permeate flowrate was recorded for each configuration and stored in the system data. The flowrate was then analyzed by dividing with active surface of the membrane to obtain permeate flux (L/m^2.h). The permeate flux of the four configurations were compared using graphical method. Flux consistency and recovery were observed as key points in determining the optimum configuration in producing standard quality treated water. The quality of the treated water at sampling point of RO 3 after each configuration was analyzed based on parameters such as COD, ammonia (NH_3-N), hardness (Mg), hardness (Ca), colour, turbidity, chlorine, total suspended solids, TSS (NTU) and conductivity.

E. *Cost analysis*

Costs of equipment and installation was gathered from supplier quotation of the pilot plant which then was compared from previous works on similar membrane application including by Ahmad et. al [11]. Capital costs of each configuration was calculated and tabulated and then compared on each total capital cost which were then analysed for the most cost-effective configuration with consideration of their respective permeate flux performances.

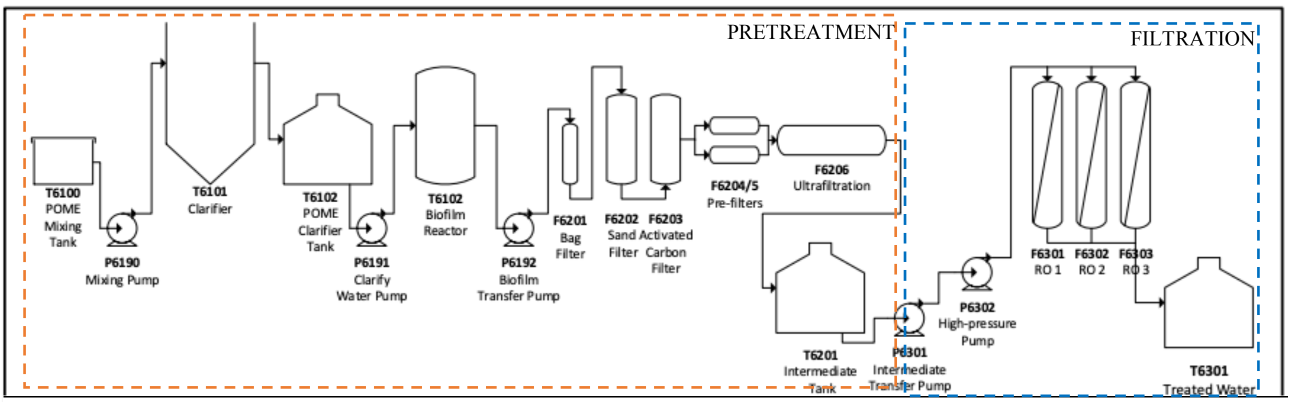

Fig. 1: Diagram of Integrated Moving Bed Biofilm Reactor-Membrane System

III. RESULTS AND DISCUSSION

A. *Acclimatization of MBBR.*

Declination of COD levels from initial feed COD of approximately 2600 mg/L was observed over 36 days of acclimatization with a reduction of 79%. The COD reading was then seen stable around 550 mg/L after the 20th day (Fig. 2). This result did not achieve the expected performance of reaching below 500 mg/L after acclimatization, therefore the alternative was to result to manual dilution of POME before entering the subsequent systems.

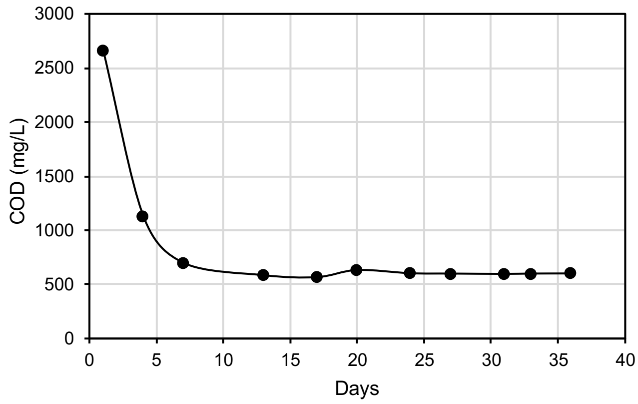

Fig. 2: COD Concentration of POME in MBBR.

According to Leyva-Diaz et. al. [13], which analyses industrial wastewater, the COD removal efficiency of a MBBR can be achieved up to 90-95% of the feed. In consideration of the higher organic load of POME compared to standard industrial wastewater, the COD removal can be justified to be lower than that of the latter effluent. The expected performance of the MBBR was not achieved in this study whereby approximately only 79% COD reduction occurred in the acclimatization process therefore the expected performance of the MBBR was considered not achieved. According to a previous study involving POME treatment, the MBBR performance for POME treatment is highly dependent on the quality of POME which can be affected by fluctuations in organic loading [1]. Quality of harvested fruits, climate and treatment techniques used become major factors in affecting the quality of POME [14]. A former full-scale MBBR application was conducted for de-nitrification however the expected performance was not achieved due to carrier flotation, settling, fouling and operational problems. Developments have been made since on improving carrier type and mixing method [15]. It has been reported that the material of carriers can have a considerable effect in COD removal efficiency. Polyethylene carriers can achieve up to 94.97% COD removal due to existing pores on the outside surface of the carrier to protect from biofilm loss [16]. While according to Zhang et. al [17], it is claimed that polyurethane sponge can achieve better COD removal efficiency of approximately 97.52% (± 1.63%).

B. *Integrated Pretreatment Membrane System.*

Permeate flux inevitably decreases over time due to any or a combination of several factors of which are increased osmotic pressure, compaction of the membrane, membrane fouling or concentration polarization [18]. Fluctuations are common in operations due to the above factors and may take a period of time to acquire stabilization.

Configuration I which bypassed the MBBR shows a promising constant flow rate of solution throughout several run times. Minimal fluctuations are observed as the permeate flux maintains in the range of 59-69 L/m^{3}h (Fig. 3). On the other hand, Configuration II bypassed the MBBR and RO 2 resulted in a slightly lower fluid flow rate which reaches between the range of 45.7-60.5 L/m^{3}h (Fig. 4). This larger range however shows slightly similar fluctuations where stabilization of fluid flow can be seen around the 20th minute into operation. The permeate flux becomes unstable in Configuration III which bypassed the MBBR and ultrafiltration unit hence resulted in a larger range of fluctuation between 51.6–67.8 L/m^{3}h shown in Fig. 5. Larger fluctuations occurred in Configuration IV in which the permeate flux range decreased dramatically and apparent flux decline was observed throughout each run where the system bypassed the MBBR, ultrafiltration unit and RO 2 unit (Fig. 6).

A similar method of integration of pre-treatment with membrane filtration conducted by Ahmad et. al. [6] in drinking water reclamation from POME showed an almost similar result where continuous flux decline occurred after a period of time into operation

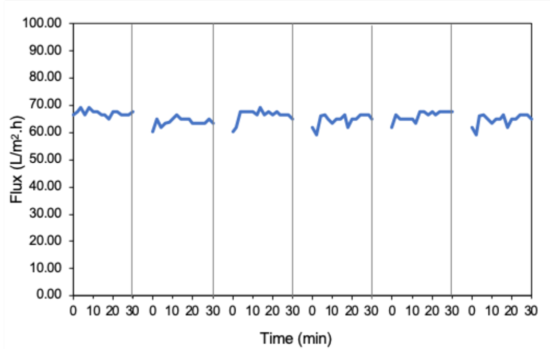

Fig. 3: Flux Behavior Configuration I

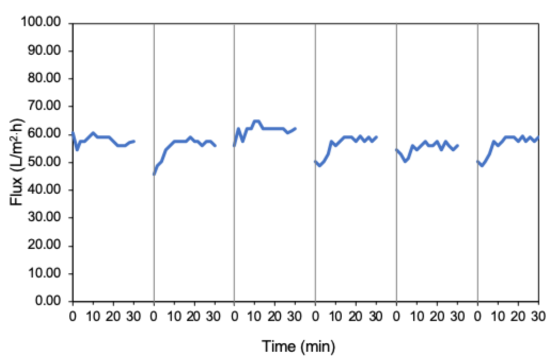

Fig. 4: Flux Behavior Configuration II

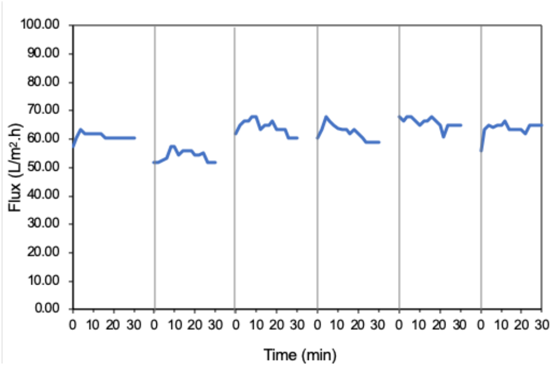

Fig. 5: Flux Behavior Configuration III

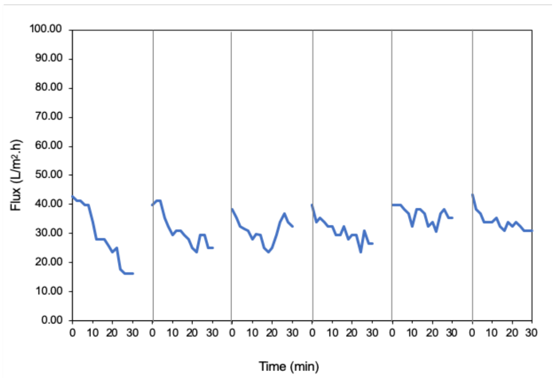

Fig. 6: Flux Behavior Configuration IV

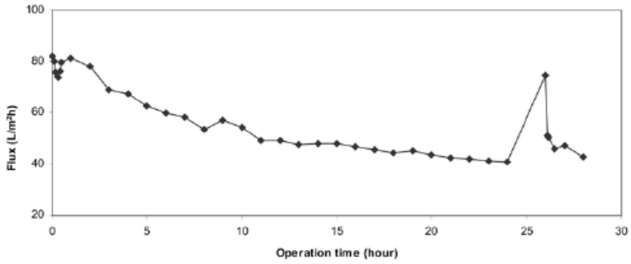

Fig. 7: Drinking water reclamation from POME using coagulation, flocculation, ultrafiltration and RO [6].

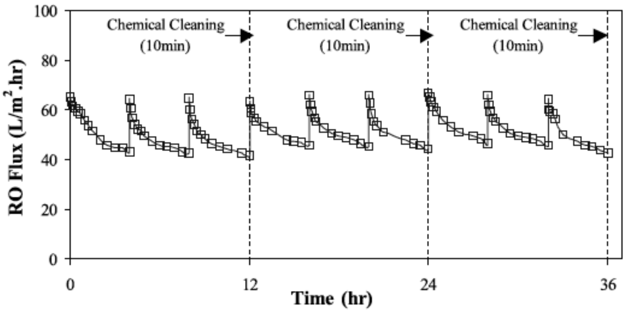

Fig. 8: RO flux of ultrafiltration and reverse osmosis system in POME treatment [19]**.**

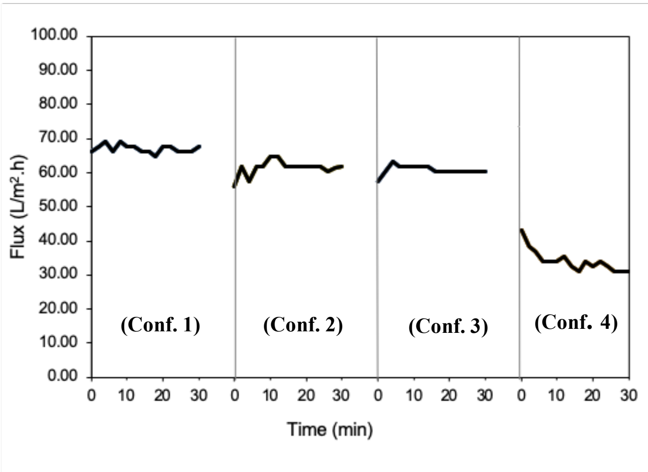

Fig. 9: Comparison of Average Permeate Flux for Different Configurations

as seen in Fig. 7. The method used include coagulation and flocculation as pre-treatment followed by ultrafiltration and reverse osmosis at flow velocity of 0.1 m/s and temperature of 25°C. Fig. 7 shows the RO membrane flux decreased to about 50% of the initial flux after 23 h. Kim et. al [19] conducted pre-treatment of POME using ultrafiltration then fed into RO modules which consisted of three batch runs of 12 h each. The UF and RO membranes were physically cleaned every 4 h for a duration of 5 min followed by chemical cleaning which then performed for every 12 h after completion of each batch run. The RO flux decline can be seen between 22– 35% between each physical cleaning. Almost no fluctuations can be seen throughout each batch run (Fig. 8).

The flux decline in Fig. 7 was observed to be smaller in range compared to Fig. 8 in a 4 h period context. Pre-treatment which included coagulation, flocculation and ultrafiltration prior to reverse osmosis presented minimal flux decline due to removal of a major part of suspended solids and solutes in the pre-treated POME. Therefore, resulting in longer operation time without frequent fouling interference. However, the same cannot be said for Figure 5 where a faster decline in flux trend can be seen after 4 h of operation. Fouling occurs more frequent therefore resulting in regular maintenance to ensure efficient flux recovery in each batch run. Fig. 8 shows 40% more flux decline compared to Fig. 7 which concludes that proper pre-treatments of POME before membrane filtration play a significant impact in maintaining optimum flux trends in RO operation runs.

In the study of integrated moving bed biofilm reactor-membrane system, the configuration that showed the least RO flux decline was Configuration I as seen in Fig. 9 where the flux trend declines gradually with minimal fluctuations. The flux decline range in Configuration I deviates slightly lower of about 14% than that of the study conducted by Ahmad et. al [6]. Configuration II showed slightly similar result where the deviation 25%. The deviation can be justified by different methods of pre-treatment used where pre-filtration (using bag filter, sand filter, pre-filters and ultrafiltration) is used in the current study while coagulation and flocculation became the pre-treatment of choice of the former study [6].

Increased concentration of solutes in the membrane leads to increase of osmotic pressure which requires higher feed pressure as compensation. Compaction of the membrane occurs when physical compression exists and deforms the membrane which decreases the permeate flux. A situation of solution concentration near the surface of the membrane exceeds the concentration in the bulk liquid is known as concentration polarization.

Pressure at RO outlet (permeate) of each configuration was observed and found Configuration I had the highest pressure outlet in the range of 12.8-13.5 bar (Fig. 10). Configuration II showed slightly lower pressure outlet, 12.1-12.7 bar (Fig. 11). Configuration III and IV resulted in a significant low pressure outlet compared to the previous two, where 8.3-8.7 bar and 7.1-7.4 bar respectively (Fig. 12, 13). Pressure at RO outlet signifies the flow condition of the final product whether it be in a slow or rapid production. In this case, Configuration I had better production of the treated POME where with minimal pressure drop of the initial feed pressure. Lower pressure outlet in the subsequent configurations showed slower RO permeate production hence the rejection rate of concentrate is higher in these configurations.

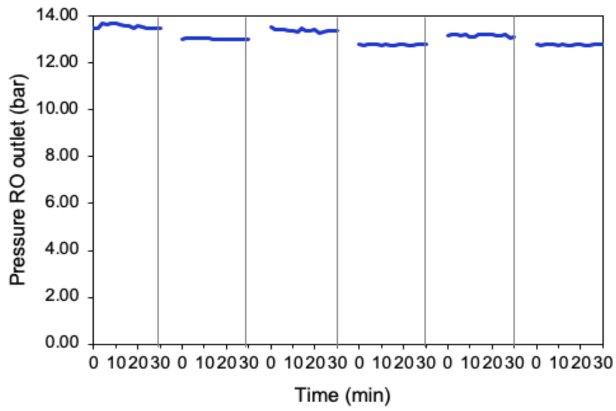

Fig. 10: Pressure RO Outlet Configuration I

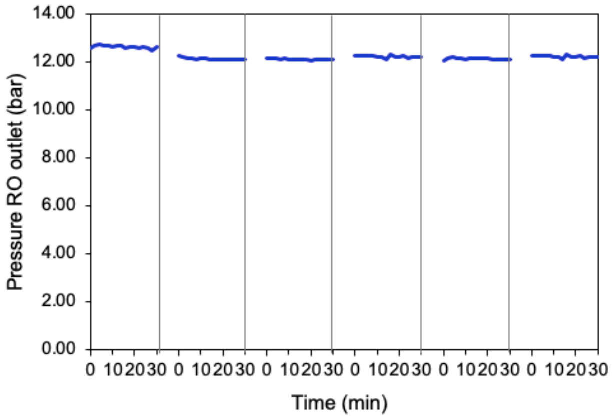

Fig. 11: Pressure RO Outlet Configuration II

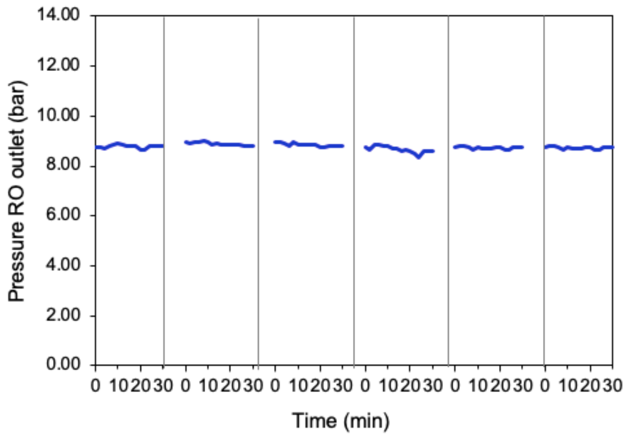

Fig. 12: Pressure RO Outlet Configuration III

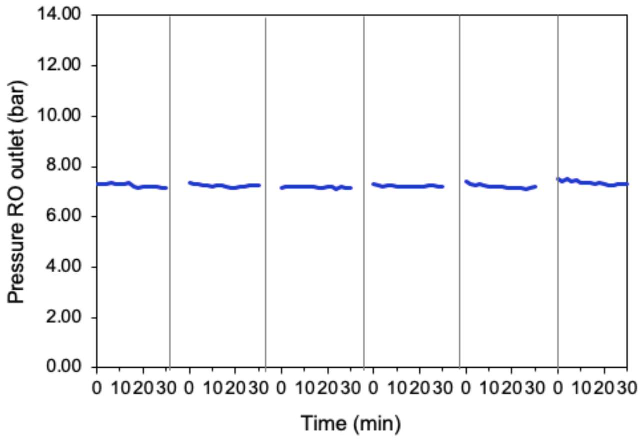

Fig. 13: Pressure RO Outlet Configuration IV

Existence of a layer on top of the membrane which acts as a filter hence reducing the permeability of dissolved solid through the membrane could be justification for the low pressure RO outlet for Configuration III and IV [20]. The effect of bypassing prior filtration membranes such as the UF unit and RO 3 membrane led to rapid flux decline as a consequence of fouling on the membrane surface. This is in agreement with Wu. Et al [21], where rapid flux decline would occur a few seconds or minutes into the start of the operation once certain (sorptive) membrane was fouled by protein. As the layer formation increases on the membrane surface, pressure drop becomes significant. Due to the resulting lower pressure, this pressure would not be enough to pressurize a part of the deposition of the cake layer to the permeate side [3]. Therefore, the resulting physical plugging of the membrane which had led to higher pressure drop thus causing serious impediment on the efficiency of the membrane filtration performance.

C. Analysis of Treated POME

Parameters of analysis as seen in Table 2 for all four different configurations was compared with the drinking water standards set by the US Environmental Protection Agency (USEPA) in Table 1. This resulted in Configuration I having the best quality of treated water with zero COD concentration and all parameters were well below the standards set by. However, further analysis of more parameters is required such as pH, oil and grease and other heavy metals such as aluminium, iron, copper and zinc in order to fully comply with standards for use as boiler water and other mill operations. The drinking water standard according to USEPA was used as basis for comparison which can be deemed as the best quality water for usage in palm oil mill operations. Conductivity became a significant parameter as it differs largely between each configuration with a maximum of 75% especially when the system bypassed RO 2. This is also due to reverse osmosis membrane operates in removing fine water pollutants such as phosphorus, organic matter including removing Na^- and Cl^- in desalination processes which deals mainly in ionic particles therefore contributes largely in decreasing the conductivity level of the permeate [8].

Table 2 shows the effluent characteristics after membrane treatment which include the parameters measured from the RO 3 permeate sample of each configuration. From the initial feed COD of 150 mg/L through dilution directly into the pre-filtration system, it was observed that COD reduction of all configurations is between 97%-100% with Configuration I carrying the highest COD reduction. This result is contrary to the findings obtained by Latif et. al [22], whom conducted a study in water recycling from POME using similar technique through UF and RO membrane treatment where a 96% reduction in COD concentration was achieved in the effluent. Only Configuration IV exceeded one parameter which was colour with slightly higher deviation of about 11%. Other parameters measured in Configuration I, II and III was seen to be in compliance with the USEPA standards hence the water quality of the permeate was considered sufficient to be able to use the RO permeate as boiler feed water as stated by Salma et. al [23].

Table 1: Drinking Water Standards (USEPA) [24]

Sample	Description
COD (mg/L)	NR
Ammonia (NH3-N) (mg/L)	NR
Hardness Mg (mg/L)	150
Hardness Ca (mg/L)	NR
Colour (units)	15
Turbidity (NTU)	<0.5
Chlorine(mg/L)	250
Total dissolved solids (mg/L)	500
Conductivity (µS/cm)	2500

*NR: not required

Table 2: Effluent characteristics after membrane treatment

Sample	Configuration I	Configuration II	Configuration III	Configuration IV
COD (mg/L)	0.00	0.75	1.50	4.00
Ammonia (NH3-N) (mg/L)	0.01	0.07	0.36	0.50
Hardness Mg (mg/L)	0.28	0.30	0.40	1.37
Hardness Ca (mg/L)	1.14	1.19	1.89	2.39
Colour (mg/L)	1.33	2.00	5.33	18.00
Turbidity (mg/L)	0.13	0.25	0.38	0.50
Chlorine(mg/L)	0.01	0.01	0.01	0.02
TSS (NTU)	2.30	3.40	2.90	3.20
Conductivity (µS/cm)	9.00	31.00	13.00	49.00

D. Cost Analysis

Cost of equipment was obtained from Ikhlas Resmi (M) Sdn. Bhd. quotation for the construction of the UKM-YSD pilot plant. Cost of every configuration was evaluated by comparison on which was the most cost-effective configuration in respective of their flux behaviors. As seen in Table 4, the equipment price and installation costs are stated for the whole integrated moving bed biofilm reactor-membrane system. The list includes as well the storage tanks, pumps, piping and instrumentation costs that are needed for the system.

Cost analysis of all four configurations presented in Table 5 that Configuration I had the highest total capital cost for construction (with GST included) of approximately RM142,835. A 20% decrease in capital cost was seen in Configuration 2 with a difference of bypassing the RO 2 membrane. Meanwhile, Configuration III showed only 2% decrease from Configuration I by bypassing the ultrafiltration unit. Configuration IV was the least expensive with RM111,342.4 as the system bypassed the ultrafiltration unit and RO 2 membrane. All configurations bypassed the MBBR due to the explained reasons in II(*B*).

Table 3: Capital Costs of Design A, B and C for POME Treatment by Ahmad et. al [11].

	Design A UF Ceramic RO Polymeric	**Design B** UF Polymeric RO Polymeric	**Design C** RO Polymeric RO Polymeric
Total Capital Cost (10^6 RM)	56.98	9.06	3.95

In comparison with a cost comparison study by Ahmad et. al, which conducted on three designs; Design A, B and C, the capital costs are significantly higher as the capacity for the membrane-based POME treatment can withstand an inlet flowrate of 27 m^3/h (Table 3). The present study has only a capacity of up to 500 L per batch of POME. A similar membrane type for comparison would be Design B and C as both studies used polymeric membranes. Therefore, the resulting cost of the present study can be justified to be higher than Design C as the addition of a UF unit along with a three-pass RO membrane system and cheaper than Design C as the capacity of each unit was smaller in accordance with the pilot plant

Table 4: Cost of Equipment

Sample	Description	Unit Price (RM)
Wastewater Storage Tank (PE)	2 m^3	3,450
Clarifier (FRP)	2 m^3	3,900
Clarify Water Pump	3PH/4150V/50Hz motor	2,400
Filter Bag (PP)	7” Ø x17” L	3,100
Activated Carbon Filter	80 L	2,100
Pre-filter	65mmØ x 20” L x 5μn	600
Sand filter	80 L	1,900
Ultrafiltration membrane (PGV&-8040)	200mm (D) x 1350mm (L)	3,390
Backwash Pump	3PH/4150V/50Hz motor	2,400
Intermediate Tank (PE)	2 m^3	3,450
Circulation Pump	3PH/4150V/50Hz	2,400
Reverse Osmosis System	Filmtec BW30-4040 Spiral Wound 4040	78,960
Instrumentation - Control system, wiring, turbidimeter, total dissolved solid meter, etc.		18950
Piping		2750
Mobilization and Installation		5000
MBBR & Instrumentation		64710

*All prices are in RM and of 2018

Table 5: Capital cost of configurations.

Sample	Configuration I	Configuration II	Configuration III	Configuration IV
Wastewater Storage Tank	3,450	3,450	3,450	3,450
Clarifier	3,900	3,900	3,900	3,900
Clarify Water Pump	2,400	2,400	2,400	2,400
Filter Bag	3,100	3,100	3,100	3,100
Activated Carbon Filter	2,100	2,100	2,100	2,100
Pre-filter	600	600	600	600
Sand filter	1,900	1,900	1,900	1,900
Ultrafiltration membrane	3,390	3,390	-	-
Backwash Pump	2,400	2,400	2,400	2,400
Intermediate Tank	3,450	3,450	3,450	3,450
Circulation Pump	2,400	2,400	2,400	2,400
Reverse Osmosis System (Polymeric) • RO 1 • RO 2 • RO 3	26,320 26,320 26,320	26,320 - 26,320	26,320 26,320 26,320	26,320 - 26,320
Instrumentation	18,950	18,950	18,950	18,950
Piping	2750	2750	2750	2750
Mobilization and Installation	5000	5000	5000	5000
MBBR & Instrumentation	-	-	-	-
Total Cost (including 6% GST RM)	142,835	114,935.8	139,241.6	111,342.4
Total Cost (10^6 RM) *	7.71	6.21	7.52	6.01

*Cost multiplied by 54 for comparison with Ahmad et. al [11] scale of the present study. Ahmad et. al [11] concluded that Design C was the optimal design for application of membrane based POME treatment due to the reason of high operating pressure with low membrane unit cost was preferable as maintaining a high supply is less costly than increasing the membrane area to achieve higher yield of permeate flux. Therefore, Configuration I and II were observed to be the most cost-effective systems with similar reason of producing high permeate flux and operating pressure performance.

IV. CONCLUSION

Acclimatization of MBBR was considered achievable as the COD concentration reduced to about 65% of the initial feed POME. However, the expected performance in reducing the COD to below 500 mg/L was not achieved which due to probable reasons such as carrier floatation, fouling, settling and operational problems. As a result, the MBBR was bypassed for the configurations. Optimization of the MBBR should be conducted on improvement of carrier type and mixing method of the MBBR for pilot plant scale. Configuration I which bypassed only the MBBR yielded the highest flux trend in a range of 59-69 L/m^{3}h with minimal flux decline of about 14%. Configuration II bypassed the MBBR and RO 2 resulted in a rate which reaches between the range of 45.7-60.5 L/m^{3}h of 24% flux decline. Configuration III and IV showed larger flux decline of an average of 30% and 59% in the same observed period of time of 30 mins each run. Higher flux decline is not preferable in membrane system since this represents fouling occurrence in the membrane system. Faster flux decline shows faster fouling occurrence. Good flux recovery after cleaning was observed for Configuration I and Configuration II. Therefore, Configuration I and Configuration II were accepted as being suitable configurations for the application of integrated system for POME treatment. Cost analysis of all four configurations showed Configuration I had the highest total capital cost for construction (with GST included) of approximately RM142,835 and Configuration II with RM114,935.8. As good flux recovery can be obtained in these two configurations therefore maintenance cost would be reduced as it had lower fouling frequency. Therefore, Configuration I and II would be the better option for the integrated moving bed biofilm reactor-membrane system for POME treatment.

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