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Tertiary Treatment of Biologically Treated Palm Oil Mill Effluent (POME) Using UF Membrane System: Effect of MWCO and Transmembrane Pressure

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Abstract
This study evaluate the performance of ultrafiltration UF membrane system in the treatment of biologically treated palm oil mill effluent (POME) by varying the effects of transmembrane pressure and using different molecular weight cut-off (MWCO). Flat sheet polyethersulfone (PES) ultrafiltration membrane of molecular weight cut-off (MWCO) 1 kDa and 5 kDa were used in this study. Biologically treated POME was subjected to physical pretreatment processes, consisting of coagulation and adsorption to remove total suspended solids. Transmembrane pressure was varied between 0.5 bar to 1.5 bar and the performance of these membrane systems were assessed in terms of reduction of chemical oxygen demand (COD), color and turbidity in POME. Pretreatment processes which consist of coagulation and adsorption showed remarkable results in reducing COD, color and turbidity up to 92.8 %, 99.3 % and 99.9 % respectively. At transmembrane pressure 0.5 bar, more reduction in COD, colour and turbidity were observed. The smallest MWCO of the membrane at transmembrane pressure 0.5 bar gave a better reduction of pollutants from the pretreated POME. The increasing transmembrane pressure leads to a corresponding increase in permeate flux which starts to level off at higher transmembrane pressures. The application of membrane separation technology to treat biologically treated POME has improved the quality of the final effluent discharged. The UF membrane plays very important role in reducing pollutants present in biologically treated POME.

Keywords: POME, polyethersulphone, COD, MWCO, turbidity

1. Introduction

The production of palm oil generates wastes that are of great concern to the environment. The process of palm oil mill production consumes large amount of water and 50 % of it ends up as palm oil mill effluent (POME). POME is a highly colloidal suspension of 95-96 % water, 0.6-0.7 % oil and 4-5 % total solids including 2-4 % suspended solids originating from the mixture of a sterilizer condensate, separator sludge and hydrocyclone wastewater [1]. POME is a highly voluminous liquid waste which has an unpleasant smell and very polluting. Therefore, it is an urgent need to find a compromising way that will enable the balance between the environmental protection and sustainable reuse of the water in the POME. Majority of palm oil mill uses conventional biological treatment of aerobic, anaerobic or facultative ponds which needs large area and long treatment periods [2]. This conventional treatment system is quite inefficient and this unfortunately leads to the environmental pollution issues [3]. Thus, the discharge of inefficiently treated POME creates adverse impact to the environment.Membrane technology has become a recognized separation method that is well suited for the recycling and reuse of wastewater. The main advantages of membrane technology is constant production of high quality water, non toxic and fully automated process [3]. Recently, ultrafiltration UF has been successfully used as a separation method in various industrial process especially in the production of pure water, food and pharmaceutical industries. However, major drawbacks of using membrane includes fouling, and decline in permeate flux. This flux decline leads to an increase in the membrane cleaning and replacement costs [1].

A number of studies have been carried out to overcome the problem of decline in flux and fouling. The introduction of pretreatment units for modifications of feed water by removing suspended solids that may bring about pore clogging leading to membrane fouling is an effective way of improving the performane of membrane filtration system. Many studies have incorporated pretreatement units such as depth fitration, coagulation, flocculation, adsorption etc to pretreat feeds before using the membrane filtration system [2,10]. Wong et al,[9] used coagulation as a pretreatment process for the treatment of POME and which showed 50 % improvement in the filtration performance of the membrane. In this study, the pretreatment unit used is the combination of coagulation process with adsorption using granular activated carbon as adsorbent with UF process. The objective of this study is to study the effects of transmembrane pressure and molecular weight cut-of (MWCO) of UF membrane system on biologically treated POME.

2. Materials and Methods

2. 1. Pretreatment of POME

Biologically treated POME was obtained from a local mill factory (Sime Darby Labu in Seremban, Negeri Sembilan, Malaysia) and the typical characteristics are shown in Table 1. The effluent was subjected to coagulation using ferric chloride and polyacrylamide as the flocculant aid in concentration of 100 mg/l for both. The effluent from coagulation became the influent for the adsorption process where different mass of adsorbents were used in further pretreatment process. The total filtrate collected from the combination of the pretreatment stages was analyzed for color, turbidity and chemical oxygen demand (COD).

2. 2. UF of Pretreated POME

Ultrafiltration membrane of 1 kDa and 5 kDa flat sheets were used and the characteristic of these membranes are shown in Table 2. Before starting the experiment, the membranes were soaked overnight in distilled water to remove impurities left from manufacturing processes. Then the membranes were wetted out by circulating distilled water at 2.0 bar for 30-60 min the next day. 2 liters of pretreated POME was subjected to UF processes at transmembrane pressures of 0.5 bar, 1.0 bar and 1.5 bar. The duration for each experimental run was 60 minutes. The total permeate collected was analyzed for turbidity, color and COD.

Table 1: Characteristics of biologically treated POME obtained from a local palm oil mill

Parameters	Mean
pH	9.08
Color	2579 units PtCo
Turbidity	1275
COD	2420mg/l

Table 2: Characteristics of Polyethersulphone UF flat sheet membrane

Designation	MWCO	Effective Filtration Area (m^2)	Pressure (bar)
3051460901E—SG	1 kDa	0.1 m^2	< 4 bar
3051463901E—SG	5 kDa	0.1 m^2	< 4 bar

2. 3. Analytical Methods

The effluent from the pretreatment stage and permeate from the pretreatment steps and UF processes were collected and analyzed. Turbidity was measured using the nephelometric method with a 2100P HACH portable turbidimeter. The COD was analyzed using the reactor digestion method and color was analyzed using Platinum-Cobalt Standard Method (HACH methods). The reductions for color, turbidity and COD in the pretreatment processes were calculated by using the following equation:

$$R_{pretreatment}(\%) = \left(1 - \frac{C_p}{C_r}\right) \times 100 \qquad (1)$$

Where R pretreatment is the percentage reduction for the pretreatment stage, Cp is the concentration obtained after pretreatment and Cr is the initial concentration of the biologically treated POME.

To justify the efficiency of the UF membrane process alone in reducing color, turbidity and COD for the various pressures, Eq. (1) with similar expression would be used:

$$R_{UF}(\%) = \left(1 - \frac{C_{UF}}{C_p}\right) \times 100 \qquad (2)$$

Where RUF (%) is the percentage reduction of the UF process, CUF is the concentration obtained after UF process and CP is the concentration of the pretreated POME.

3. Results and Discussion

3. 1. Quality of pretreated POME

Turbidity, color and COD were analyzed after coagulation and adsorption pretreatment process of POME was carried out and the results are illustrated in Fig. 1. The values are average percentage reductions from reproducibility data of three tests. Pretreatment process which consisted of coagulation and adsorption played significant role in reducing COD, color and turbidity by 97.9 %, 99.3 % and 99.9 % respectively. The organic reduction efficiency observed in this study is comparable to previous studies that used coagulation and adsorption as pretreatment steps. In previous study carried out by Tan et al.,[7] coagulation process reduces turbidity by 97 % and COD removal 64 %. Also in another study carried out by Wong et al., (2002) Coagulation was able to reduce turbidity and color as much as an average of 68 %. Thus, the result obtained in this study is better than those of previous studies.

3. 2. UF of pretreated POME

3. 2. 1. Effect of transmembrane pressure on quality of permeate

In general, the Chemical Oxygen Demand (COD), color and turbidity of the pretreated POME were further reduced irrespective of the transmembrane pressure applied. Table 3 shows the effect of transmembrane pressure on percentage reduction of COD, color and turbidity for molecular weight cut-off (MWCO) of 1 kDa at different transmembrane pressure. The color of the pretreated POME changed from light yellow to colorless regardless of the pressure applied which corresponded to values obtained from the turbidity. The reduction of COD, color and turbidity of the pretreated sample increased as the transmembrane pressure decreased from 0.5 bar to 1.5 bar. 64 %, 84 %, 66 % reduction of COD, color and turbidity values were observed respectively at 0.5 bar transmembrane pressure. The highest reductions of COD, color and turbidity values were observed at transmembrane pressure of 0.5 bar. This phenomenon might be influenced by the existence of a fouling area which acted as another filter layer that increased the resistance for organic materials to pass through. The adsorption of organic matter on the fouling layer on the surface of the membrane led to lower COD, color and turbidity values [1]. According to a study carried out by Ratanatamskul and Kaweenantawong [4], UF membrane system was used in reclaimimg wastewater from texile industry and the highest performance in times of COD and total organic carbon (TOC) occurred at the lowest applied transmembrane pressure of 2.0 bar. Also, in another study where UF was applied to remove heavy metal from electroplating industry, the highest reduction of the metals were observed from the lowest applied transmembrane pressure of 0.5bar [5]. However, Wu et al., [10] and Muhammed et al., [8] in their research found out that the increase in transmembrane pressure would lead to more reductions of COD, colour and turbidity values which is in contrary to the findings of this study. This could be as a result of quality of the POME used. In their study, raw POME was used as the feed using depth filtration in the pretreatment step which can only remove few suspended matter while in this study, coagulation and adsorption was used in the pretreatment stages in which the quality of feed was close to that of tap water with no suspended matter observed.

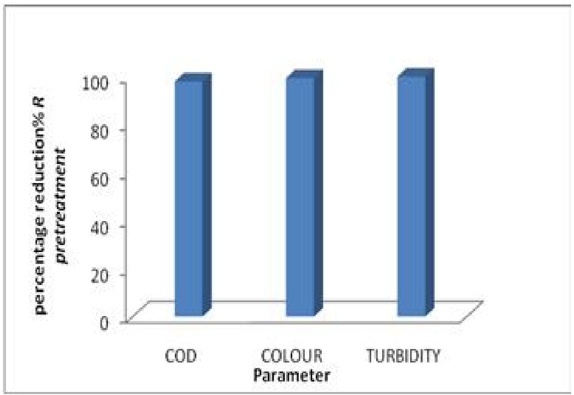

Fig. 1: Percentage reduction of COD, Color and Turbidity after pretreatment process

Also, Table 3 shows the effect of transmembrane pressure on percentage reductions of COD, color and turbidity for molecular weight cut-off 5 kDa. Similar findings were observed when compared with that of 1 kDa. Increase in reductions of COD and turbidity values were obtained at the lowest applied transmembrane pressure of 0.5 bar. This phenomenon may be as a result of existence of fouling layer and pore plugging which increased the resistance for organic matter to pass through. In general, the smallest MWCO of the membrane at the lowest applied transmembrane pressure would have better reduction of pollutants from POME [6,8]. From this research, it is concluded that the best permeate quality was obtained at transmembrane pressure of 0.5 bar using MWCO of 1kDa which can be used for process water applications in the palm oil mill processing.

Table 3: Percentage reduction of COD, color and turbidity after UF process of 0.5 bar, 1.0 bar and 1.5 bar respectively of MWCO 5 kDa and 1 kDa

PARAMETERS	Percentage rejection R (%)					
	MWCO 5KDa			MWCO 1KDa		
	TMP (bars)			TMP (bars)		
	0.5	1.0	1.5	0.5	1.0	1.5
COD (mg/l)	60	30	36	64	48	24
TURBIDITY (NTU)	56.6	50	16.7	66.7	50	21.3
COLOUR (PtCo)	94.7	84.2	73.7	100	84.2	78.9
TDS (mg/l)	30	28.7	16	37.1	30.3	23.1

3.2.2. Effect of transmembrane pressure and MWCO on permeate flux

Fig. 2 shows the effect of transmembrane pressure and MWCO on permeate flux of the pretreated POME. Generally, it is observed that the permeate flux increased with increasing applied transmembrane pressure for both MWCO of 1 kDa and 5 kDa. However, the permeate flux started to level off at higher transmembrane of 1.5 bar. This could be as a result of gradual build up of a cake layer on the membrane surface [8,11]. As a result, the permeate flux could not form a linear relationship with applied transmembrane pressure. As expected MWCO of 5 kDa showed the highest permeate flux for all transmembrane pressures as compared with MWCO of 1 kDa and this was also observed in previous studies carried out by [6,10,11].

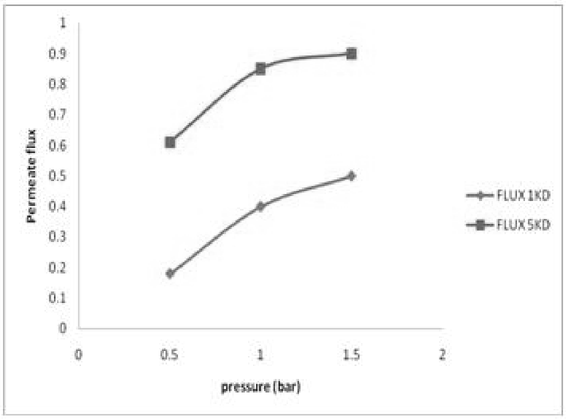

Fig. 2: Effect of transmembrane pressure and MWCO on permeate flux

3.3 Effect of transmembrane pressure on membrane fouling

The rate of fouling for MWCO of 1 kDa at different transmembrane pressures was conducted at this stage. Distilled water flux, J0 was measured before each experiment with a clean membrane at the transmembrane pressures of 0.5-1.5 bar. After the UF with pretreated POME, the cell was emptied, rinsed briefly, and refilled with distilled water, then; the distilled water flux through the fouled membrane Jf was measured. The approach of Wu et al., (2007) was used in calculating the percentage rate of fouling. The percentage fouling was calculated by comparing the distilled water permeability before and after the UF as shown in equation 3.

$$fouling\,(\%) = \left(1 - \frac{DWP_a}{DWP_b}\right) \times 100 \qquad (3)$$

Where DWPa is the distilled water permeability after effluent UF (in L/m2 hbar) and DWPb is the distilled water permeability before effluent UF (in L/m2 hbar).

From the results shown in Fig. 3, it can be seen that the percentage rate of fouling was high at transmembrane pressure of 0.5 bar. This could be as a result of accumulation of particles on the surface of the membrane. The percentage rate of fouling obtained are 44 %, 43 %, 20 %, 9.09 % and 3.23 % at 0.5 bar, 0.75 bar, 1.0 bar, 1.25 bar and 1.5 bar respectively. From the results, little changes were observed for transmembrane pressure of 0.5 bar and 0.75 bar. This could be as a result of little change in the transmembrane pressure of 0.25 bar. Although significant changes is observed when considering the rate of fouling of 0.75 bar and 1 bar which is seen from the graph. This can be as a result of low removal of pollutant at transmembrane pressure of 1 bar. The highest rate of fouling obtained was 44 % which is considerable low compared with earlier studies carried out by Wu et al., 2007. In their result, the percentage degree of fouling obtained was about 85.8 % at applied pressure of 0.8 MPa. Thus, it can be concluded that the membrane fouling is primarily due to cake formation on the surface of the membrane which is reversible and can be easily removed by chemical cleaning.

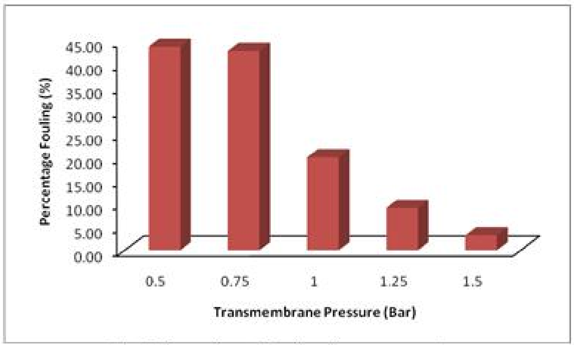

Fig. 3: Intensity of fouling (in percentage)

4.Conclusion

Pretreatment processes which consist of coagulation and adsorption showed remarkable results in reducing COD, color and turbidity up to 92.8 %, 99.3 % and 99.9 % respectively. This study also indicated that at transmembrane pressure 0.5 bar, increase in reduction COD, color and turbidity were observed. Thus, it is concluded that the smallest MWCO of the membrane at transmembrane pressure 0.5 bar gave a better reduction of pollutants from the pretreated POME. Also, it can be concluded that increasing transmembrane pressure leads to a corresponding increase in permeate flux which starts to level off at higher transmembrane pressures. The application of membrane separation technology to treat biologically treated POME has improved the quality of the final effluent discharged. From this study, it is obvious that UF membrane plays very important role in reducing pollutants present in biologically treated POME. Also the rate of formation of fouling was observed at transmembrane pressure of 0.5 bar.

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