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Palm oil mill effluent (POME) treatment and bioresources recovery using ultrafiltration membrane: Effect of pressure on membrane fouling

T.Y. Wu [a], A.W. Mohammad [a,b,*], J. Md. Jahim [a], N. Anuar [a]

[a] Department of Chemical and Process Engineering, Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Malaysia

[b] Advanced Engineering Centre, Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Malaysia

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Abstract

An attempt was made to examine the effect of applied pressure on membrane fouling that might influence the potential use of ultrafiltration (UF) membrane in treating as well as recovering the bioresources, namely protein and carbohydrate from complex feed like palm oil mill effluent (POME). POME was first subjected to physical pretreatment processes, consisting of depth and surface filtration in order to remove the total suspended solids (TSS). The pretreatment processes enabled the reduction of TSS, turbidity, total dissolved solid (TDS) and chemical oxygen demand (COD) up to 97.3%, 88.2%, 3.1% and 46.9%, respectively. Protein (45.3%) and carbohydrate (41.5%) that retained as insoluble matters together with suspended solids might be used as fertilizer or animal feed by-products. Then, polysulphone UF membrane of 20 kDa was used in the UF membrane study. This study indicated that the applied pressure imposed a direct effect on fouling, permeate flux, protein and carbohydrate recovery as well as wastewater treatment. In total, the permeate flux decreased with filtration time until it reached steady-state values. Beyond a certain applied pressure between 0.6 and 0.8 MPa, the increase in permeate flux with pressure was negligible and insignificance. The highest applied pressure (0.8 MPa) encouraged the formation of fouling up to 85.8% but at the same time enabled the recovery of protein and carbohydrate up to 61.4% and 76.4%, respectively. The highest reduction of TSS, turbidity, TDS and COD also occurred at 0.8 MPa up to 97.7%, 88.5%, 6.5% and 57.0%. The study revealed that it is possible to have appropriate control of applied pressure in order to favor fouling that would, in turn, lead to better rejection of other solutes present in the feed.

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1. Introduction

The Malaysian palm oil industry is growing rapidly and becomes a very important agriculture-based industry, where the country today is the world's leading producer and exporter of palm oil, replacing Nigeria as the chief producer since 1971 [1]. However, wet process of palm oil milling consumes a large amount of process water. It is estimated that for 1 tonne of crude palm oil produced, 5–7.5 tonnes of water are required, and more than 50% of the water will end up as palm oil mill effluent (POME) [2].

Raw POME is a colloidal suspension containing 95–96% water, 0.6–0.7% oil and 4–5% total solids including 2–4% suspended solids that are mainly consisted of debris from palm fruit mesocarp generated from three main sources, namely sterilizer condensate, separator sludge and hydrocyclone wastewater [3,4]. For a well-controlled conventional mill, about 0.9, 1.5 and 0.1 m^3 wastewater are generated from sterilizer condensate, separator sludge and hydrocyclone wastewater, respectively, for each tonne of crude palm oil produced [5]. In the year 2004, more than 40 million tonnes of POME was generated from 372 mills in Malaysia [6]. If the effluent is discharged untreated, it can certainly cause considerable environmental problems [7] due to its high biochemical oxygen demand (25,000 mg/l), chemical oxygen demand (53,630 mg/l), oil and grease (8370 mg/l), total solids (43,635 mg/l) as well as suspended solids (19,020 mg/l) [8]. Therefore, the palm oil mill industry in Malaysia is identified as the one that produces the largest pollution load into the rivers throughout the country [9].

The discharge of untreated POME though creates adverse impact to the environment, the notion of nurturing POME and its derivatives as valuable resources should not be dismissed.

* Corresponding author at: Advanced Engineering Centre, Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Malaysia.
Tel.: +603 89216453; fax: +603 89202314.
E-mail address: wahabm@eng.ukm.my (A.W. Mohammad).

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This is because POME contains high concentrations of protein, carbohydrate, nitrogenous compounds, lipids and minerals [9–11] that may be converted into useful materials using microbial processes [12]. Several studies have been reported on the exploitation of POME and its derivative as fermentation media to produce antibiotic and bioinsecticide [13], solvents [14–16], polyhydroxyalkanoates [17–19], organic acids [20–22] as well as enzymes [23,24].

There is an urgent need to find a compromising way that will enable the balance between the environmental protection and sustainable reuse of the nutrient sources found in the POME. The current treatment system, which is based mainly on biological treatments of anaerobic and aerobic systems, is quite inefficient and this unfortunately leads to the environmental pollution issues [25]. Moreover, the nutrient sources available in the POME cannot be effectively reused as a substrate in the fermentation after the conventional treatment process has been adopted.

In the last decade, ultrafiltration (UF) has been successfully developed from a useful laboratory tool to an industrial process. The application areas of UF include the production of pure water, fractionation or concentration steps in the food, pharmaceutical and biotechnological industries as well as treatment of wastewater [26–28]. Therefore, UF may work as a reliable tool for treatment [25] and recovery of protein and carbohydrate found in the POME.

It is well known that feed sample containing considerable amount of protein will eventually lead to membrane fouling [29–35]. This fouling resistance may be due to several mechanisms including gel layer formation, adsorption and pore plugging, which are difficult to differentiate although adsorption-related pore plugging is important in larger pore membranes [31]. The membrane fouling causes an increase in the membrane cleaning cost, process down time and also membrane damage due to the frequency and harshness of cleaning condition [36]. On the contrary, membrane fouling may be used advantageously in the simultaneous concentration and purification of a deposit-forming solute, which was observed by some scholars [37–40].

The effect of hydrophobicity of the membrane material on UF of protein has also been the subject of many studies and hydrophilic membranes are preferentially used because of their low-binding properties. Nevertheless, Hanemaaijer et al. [41] reported a higher increase in retention values for polysulphone membranes (hydrophobic membranes) after contact with protein compared to the case with regenerated cellulose membranes (hydrophilic membranes). Mohammad et al. [42] as well as Qi and Lu [43] also found that polysulphone UF membranes were able to treat and reclaim the protein from POME and soy protein wastewater, respectively, with significant efficiency.

Without any specific pretreatment, the membrane unit should withstand fairly high concentration of suspended solids found in the agro-industrial wastewater like POME. Coagulation–flocculation, latex adsorption and activated carbon treatment have been introduced [2,25,35] as the pretreatment processes for POME but the potential bioresources in the POME might be greatly depleted along with chemical and adsorption processes. For promoting the use of "environmentally friendly" processes, depth and surface filtration were introduced [24,42] as pretreatment steps for membrane filtration. Depth filtration involves the removal of particulate material suspended in a liquid by passing the liquid through a filter bed comprised of a granular or compressible filter medium, whereas surface filtration involves the removal of particulate material by passing the liquid through a thin septum (i.e. filter material) [44].

Before conducting the comprehensive experiments presented in this paper, no specific literature existed on how protein and carbohydrate would behave, along with membrane fouling, in a range of applied pressure during UF by application of a complex feed like POME. In this study, polysulphone membrane of 20,000 MWCO would be used rather than the other hydrophobic membranes with lower MWCO because the former was able to treat and retain protein efficiently from the POME [42]. Thus, the main aim of the present study was to investigate the effect of applied pressure (0.2–0.8 MPa) on membrane fouling in relationship to the potential use of polysulphone UF membrane of 20,000 MWCO in treating and recovering both protein and carbohydrate in the POME, in which case the recovered bioresources has been proven to be a usable fermentation substrate [24].

2. Materials and methods

2.1. Pretreatment of POME

Raw POME was obtained from a local palm oil mill factory (Seri Ulu Langat Palm Oil Mill Dengkil, Kajang, Selangor) and the typical characteristics of raw POME were shown in Table 1. The effluent was pre-filtered by means of simple depth filtration to remove the coarse solids found in the suspension. The raw POME was initially passed through a filter bed, which was consisted of minor stones with average size of 0.7 cm. Then, the collected filtrate was passed through another filter bed that was consisted of mixture of minor stones and sand (average diameter size of 300–600 μm) in the ratio of 1:2. Later, the filtrate from the second filter bed was subjected to simple surface filtration, under vacuum through a Whatman No. 41 filter paper (20–25 μm) and finally a Whatman No. 40 filter paper (8 μm) before proceeding to the UF process. The filtrate after undergoing the surface filtration was named as pretreated POME.

The total filtrate collected from each step of the pretreatment processes would be analyzed accordingly for total suspended solids (TSS), turbidity, total dissolved solids (TDS), chemical

Table 1
The characteristics of the raw POME obtained from a local palm oil mill factory

Parameter	Mean
pH	4.52 ± 0.05
TSS (mg/l)	25,800 ± 1510
Turbidity (NTU)	22,667 ± 1242
TDS (mg/l)	17,033 ± 252
COD (mg/l)	70,900 ± 4431
Protein (g/l)	12.9 ± 2.97
Carbohydrate (g/l)	28.9 ± 1.60

Note: Values represent means of triplicate determination ± standard deviations.

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