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Experimental and Simulation Study of Cross-Flow Microfiltration Process of Oil-in-Water Emulsion Using Cellulose Acetate Membrane

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INTRODUCTION

Over the past few decades, membrane filtration has played an important role in the industrial separation processes. Moreover, hydrocarbon sewage is an important environmental concern which needs urgent attention. In addition, cross-flow microfiltration is an economical energy storage process to separate oil from the oil-in-water emulsion emulsion [1].

Recent experimental and computational studies have been carried out on the use of different membranes to increase the separation efficiency in these processes [2]. Various parameters such as cross-flow velocity (CFV), Trans-membrane pressure (TMP), initial feed concentration, membrane type, the diameter of membrane pores and fluid hydrodynamics on membrane surface function [3]. In these processes, various models, which include the Hermia model, have been developed to predict permeate flux [4]. In the recent years, the law of Darcy has been used to describe the permeate flux through the membrane surface, which is a function of TMP, resistance (summation of cake and internal membrane resistances), and fluid viscosity [5].

EXPERIMENTAL PROCEDURE

EMULSION PREPARATION

In order to prepare emulsion, two non-ionic surfactants have been used with commercial names for the Twin 80 and Span 80. Moreover, the required amount of surfactant should also be evaluated to choose the preparing method for stable emulsion. For this purpose, three emulsions with a concentration of 1000 mg/L (mg/L) from kerosene were prepared using three amounts of surfactant, i.e. 0.5, 1 and 1.5% by weight of the oil phase. Moreover, all emulsions were circulated in the microfiltration setup using a centrifuge pump for an hour. Then, the emulsions were sampled at different times of mixing. The examination of samples by microscope showed that the number of oil droplets remained almost constant after about 30 minutes. The final emulsion was sampled after sufficient mixing time using zeta sizer to measure the droplet size distribution (DSD). Based on the droplet size distribution given in Fig. 1, the average droplet size can be considered as 2 microns, which is also used in the simulation.

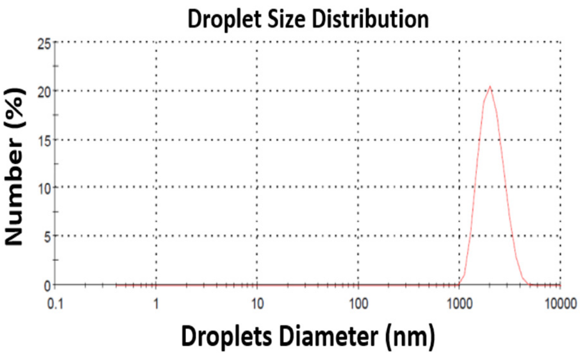

Figure 1: Droplet size distribution.

MICROFILTRATION SETUP

This device is equipped with a calibrated rotameter a thermometer and two digital barometers. A heat exchanger is placed in the setup and two coils inside the feed tank to control the changes in feed temperature and reduce its viscosity changes during the microfiltration process. In which case, it is possible to simulate the process with the assumption at the isothermal condition and eliminate energy equations in the simulation. It should be noted that a small stirrer was used to completely mix the temperature and concentration in the feed tank. The schematic view of the microfiltration setup is shown in Fig. 2.

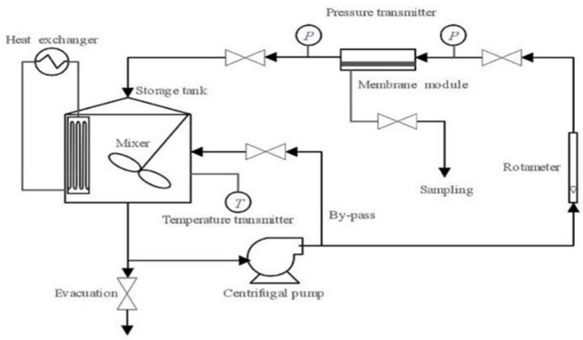

Figure 2: Microfiltration setup

RESULTS AND DISCUSSION PERMEATE FLUX

The equation below has been used to calculate the permeate flux through the membrane:

$$J = \frac{m}{A \times \Delta t} \qquad (1)$$

where m is the water volume pass through the membrane (L^3), A is the membrane area (m^2), and t is process time with the unit of h.

The experimental permeate fluxes are shown for pure water and oil-in-water emulsion in Fig. 3 (a) and Fig. 3 (b) respectively.

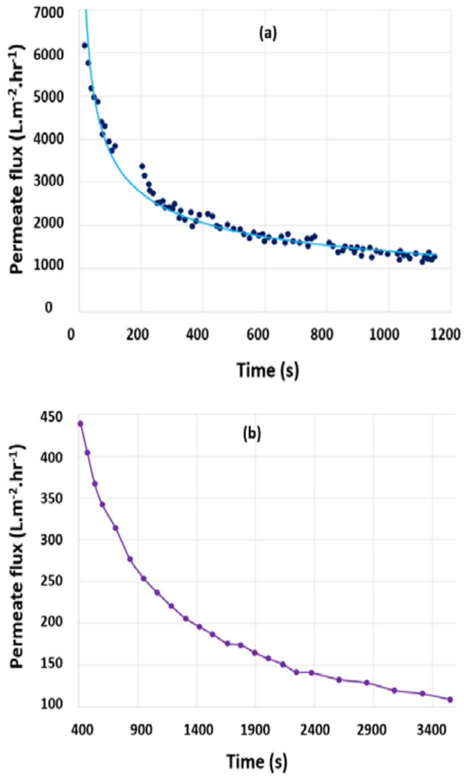

Figure 3: Variation of permeate flux vs. time for (a) pure water (b) oil-in-water emulsion at TMP of 1 bar, CFV of 0.8 m/s and temperature of 293 K.

However, due to the fact that performing compaction testing at higher pressures may cause a change in the membrane structure and reduce its thickness. In this study, by taking into account the industrial conditions, the test was carried out at TMP of 1 bar for pure water as feed. As shown in Fig. 3 (a), the permeate flux for pure water will decrease until the 20th minute from the beginning of the process, but almost the intensity of this drop will reduce from the fifth minute. Therefore, in order to apply the effects of cellulose acetate membrane compacting, all the experimental data are reported after the sixth minute.

TMP EFFECTS ON PERMEATE FLUX

The experiments were carried out at two different TMPs to investigate the effects of TMP on flux. As expected, by increasing pressure from 1 to 2 bar, the values of permeate fluxes have increased about 120%. According to Darcy's law, the permeate flux has a direct relation with TMP. Here, the effects of TMP on experimental permeate flux for oil-in-water emulsion is reported in Fig. 4.

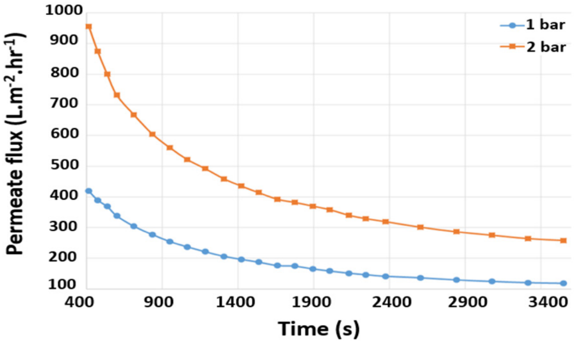

Figure 4: The effects of TMP on permeate flux vs. time for oil-in-water emulsion at CFV of 0.8 m/s and temperature of 293 K.

VELOCITY PROFILE

The effects of CFV and TMP on the output velocity profile of the concentrate and permeate channels are investigated as shown in Fig. 5 (a) and Fig. 5 (b) respectively. As expected, by increasing CFV, the outlet velocity of concentrate channel increases, and also by increasing TMP, the outlet velocity of the permeate channel increases due to Darcy's law equation.

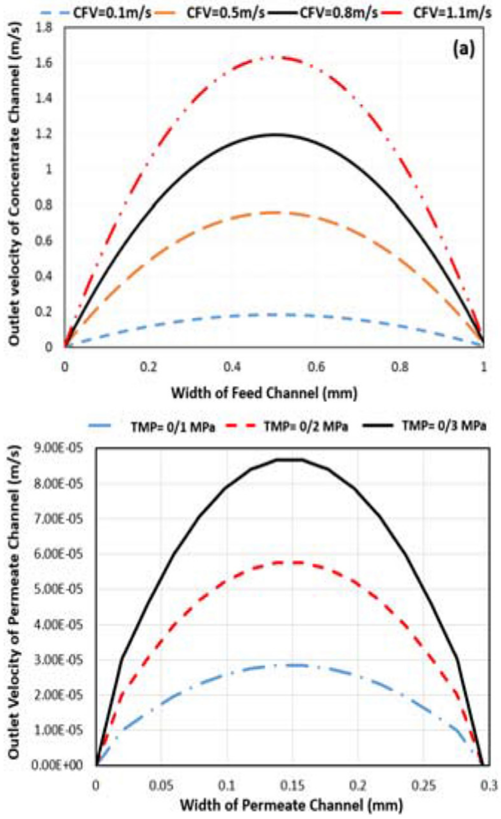

Figure 5: Effects of CFV and TMP on velocity profile at outlet (a) concentrate channel (b) permeate channel.

CONCLUSIONS

Time variation of permeate flux has been obtained for both pure water and oil-in-water emulsion as feeds. The effect of TMP increasing on the permeated flux was also investigated. Darcy's law equation has been used to simulate membrane permeate flux which is a function of local pressure in membrane module, resistance to flow (resistance of cake formation and membrane) and fluid viscosity. The results showed that the errors for steady-state fluxes are 5% and 35% for pure water and oil-in-water emulsion at 1 and 2 bars respectively. Due to simplifying assumptions and previous studies, the errors are acceptable. Also, by solving the Navier-Stokes equations, mass balance and Darcy's law, the effects of various parameters such as CFV and TMP on the output velocity of the concentrate and permeate channels and the thickness of the CP layer were investigated. Finally, the results showed that by increasing feed speed from 1.0 to 1.1 m/s, the CP thickness decreases 52% and by increasing TMP from 1 to 2 bars, the outlet velocity of permeate channel increases by about 190%. However, due to the constant pressure condition over the feed channel, the increase in TMP does not affect the outlet velocity of the concentrate channel.

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