Modeling Cross Flow Microfiltration of Oil from Effluent using Multi-channel Ceramic Membrane

Y.H.D. Alanezi . College of Technological Studies (CTS), (PAAET), Kuwait, alqahs1970@yahoo.com

Abstract

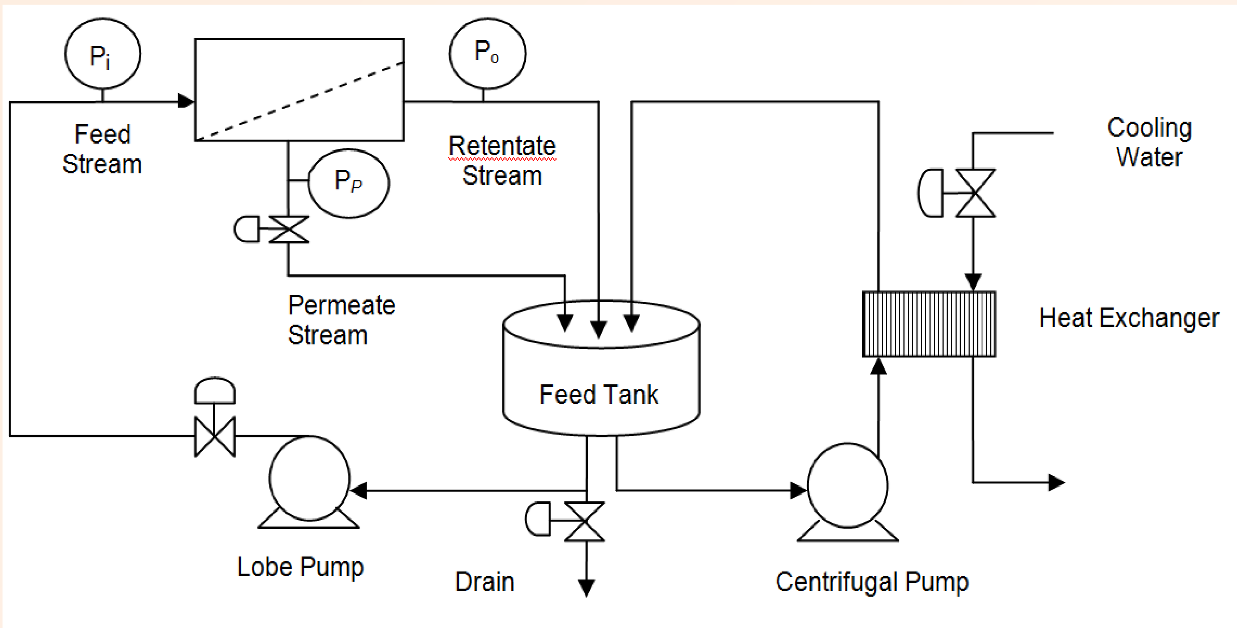
Microfiltration of oil from water was studied under various operating conditions using a multi-channel ceramic membrane. Cross flow velocities, oil concentrations, and ionic strength effects on critical flux were investigated. For the modelling of experimental results in this research work, the unique applications of the back transport models (such as torque balance, inertial lift, and shear-induced models) and deposition rate models such as SEM model in the area of liquid-liquid. For the experimental critical flux results, shear-induced model showed a better prediction in comparison with the other back transport models. Particle size was used as a parameter to fit the shear-induced diffusion model to the experimental results. From the particle size distribution analysis, the number frequency of these fine droplets was less than 5 % in the poly disperse emulsions. Hence, the smaller particles are causing fouling, which in agreement with the findings of previous studies.

Introduction

Produced water re-injection (PWRI) needs a modified treatment such as separation units to eliminate oil and suspended solids before re-injection for pressure build up. De-oiling treatment normally consists of API, American Petroleum Institute, gravity or corrugated plate separator and a gas flotation unit. However, gravity separation is not successful with emulsified oil droplets smaller than 20 µm. The reason is that as the oil droplets size reduces, the essential retention time to obtain acceptable separator efficiency increases considerably. A promising membrane technology is cross flow microfiltration (MF) for removal of suspended particles and emulsified oil droplets in the size range of 0.1-20 µm from their feed suspensions

Experimental Procedure

Prior to the start of a filtration experiment, the oil-in-water emulsions were prepared by mixing n-dodecane (model oil) and sorbitan monooleate (surfactant) with deionised water for half an hour by using a high shear laboratory mixer at a speed of 4000 rpm. J_{crit} is the critical flux, measured by successive increments/decrements of TMP using a step by step Method

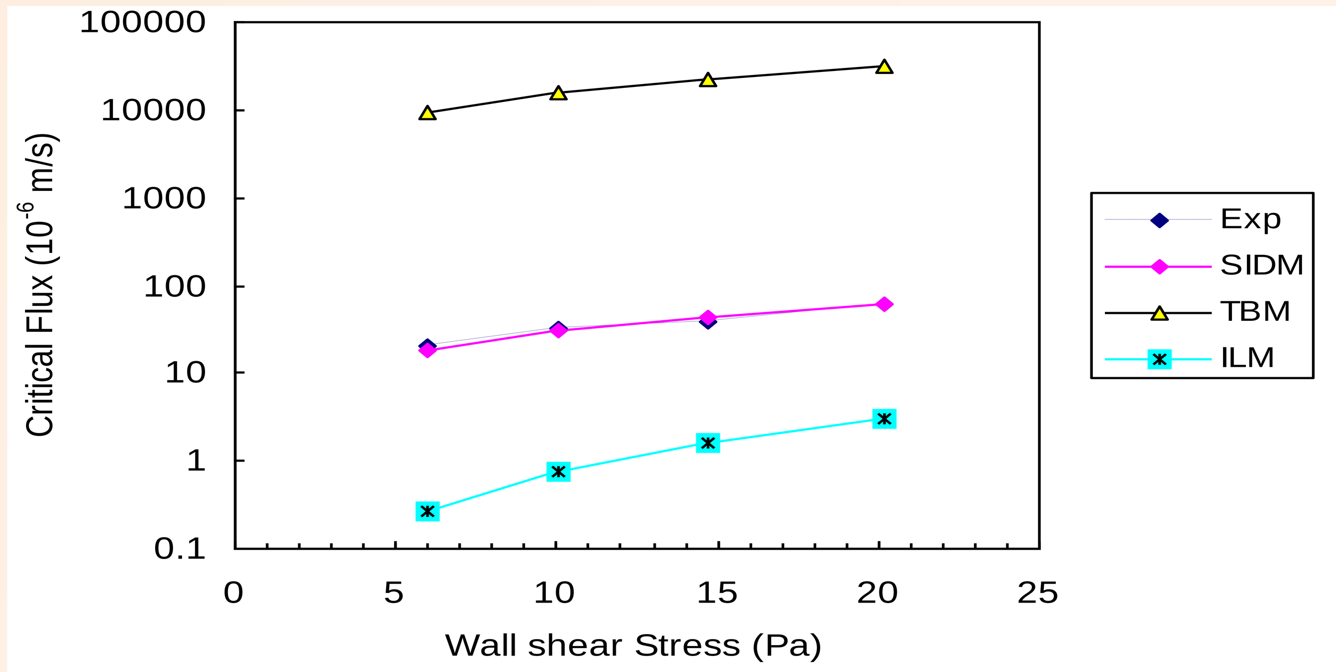


Comparisons Experimental Results and Models

Various mechanisms have been proposed to be accountable for this back transport such as shear-induced diffusion, Brownian diffusion, axial transport (particle rolling), inertial lift forces, and particle-particle interaction forces (Huisman, 1999). Presuming Brownian diffusion back transport is the dominant mechanism, predicted fluxes for micron-sized particles were found to be one or more of orders of magnitude less than those observed experimentally (Belfort, 1994). This has been referred to as the 'flux paradox' for colloidal suspensions. Axial transport models are derived from solving fully-developed laminar flow equations and the flow in this work the turbulent regions. Summary of prominent back-transport and lift models is shown in the table below (Baruah and Belfort, 2003).

Flux model	approaches	Flux equation	Eq. no.	Applicable range
Brownian diffusion	Use Leveque solution for laminar flow in a solid wall tube and Stokes-Einstein diffusion	$J = 0.114\left(\frac{\gamma \kappa^2 T^2}{\mu_0^2 a^2 L}\right)^{1/3} \ln\left(\frac{\phi_w}{\phi_b}\right)$	4	Applicable for very small diameter particles (< 1µm); under predicts flux by 1-2 orders of magnitude for large particles
Inertial lift	Include the inertial terms in solving the force balance around a single particle	$J = \left(\frac{0.036\rho\, a^3 \gamma^2}{\mu_0}\right)$	5	Applicable for large diameter particles (>20µm) and consider only single particles

The back transport mechanism is more likely to govern the flux behaviour, bearing in mind the range of the measured particle sizes is the shear induced diffusion. Howell (1995) claimed that the shear-induced diffusion would be the main back transport mechanism for particle within the micron size range. Hence, the shear-induced diffusion model is fitted to the experimental data by using the particle size as the curve fitting parameter, providing physical illustrations of the particle sizes at critical flux value for different cross flow velocities. The shear-induced model (SIDM) makes use of the shear-induced hydrodynamic diffusivity rather than the Brownian diffusivity, determined by using Stokes-Einstein correlation. The model employed here has been obtained from prior researchers (Belfort, 1994, Huisman *et al.*, 1999) where detailed description of the model was provided. Comparisons with other models are shown in Figures below ; the SID model showed a better prediction of experimental results of critical fluxes at different oil feed concentrations and various cross flow.

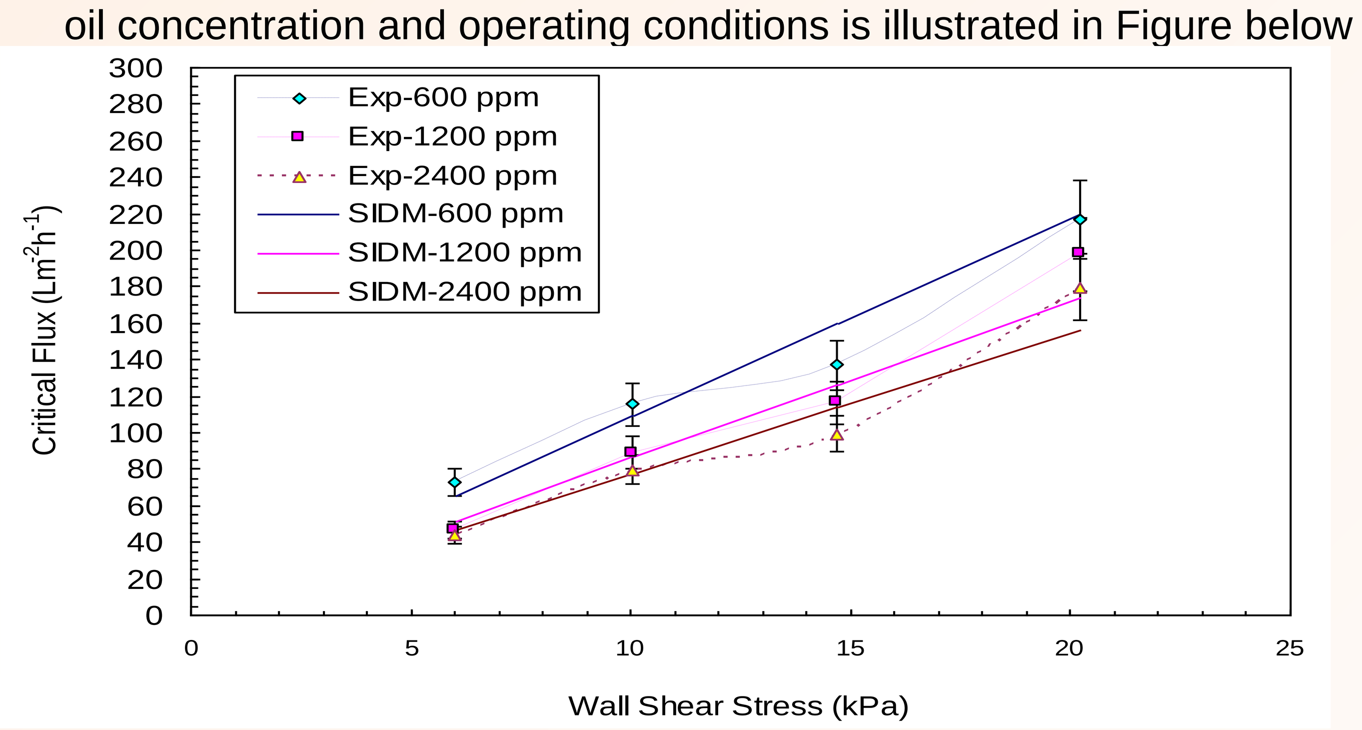


Shear-Induced Diffusion Model (SIDM)

SIDM has been fitted to experimental data by calculating the average critical particle size for the four cross flow velocities by rearranging the following shear induced model equation

$$J_{crit} = \frac{\tau_w}{\mu_p}\left(\frac{1\times10^{-4} a^4}{\phi_b X}\right)^{1/3}$$

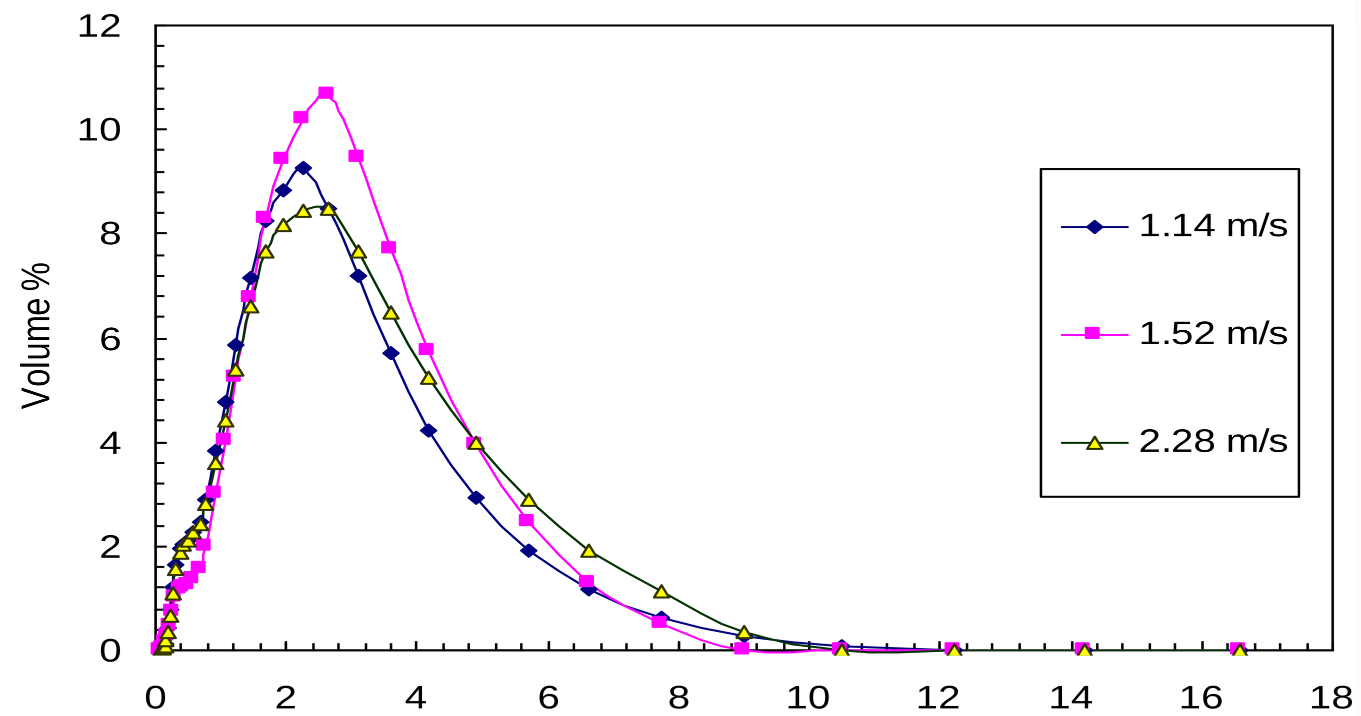
Where ϕ_b is the volume fraction of particles in the bulk, and *X* is the length of membrane. The comparison between critical fluxes measured experimentally and those estimated using above equation at different oil concentration and operating conditions is illustrated in Figure below



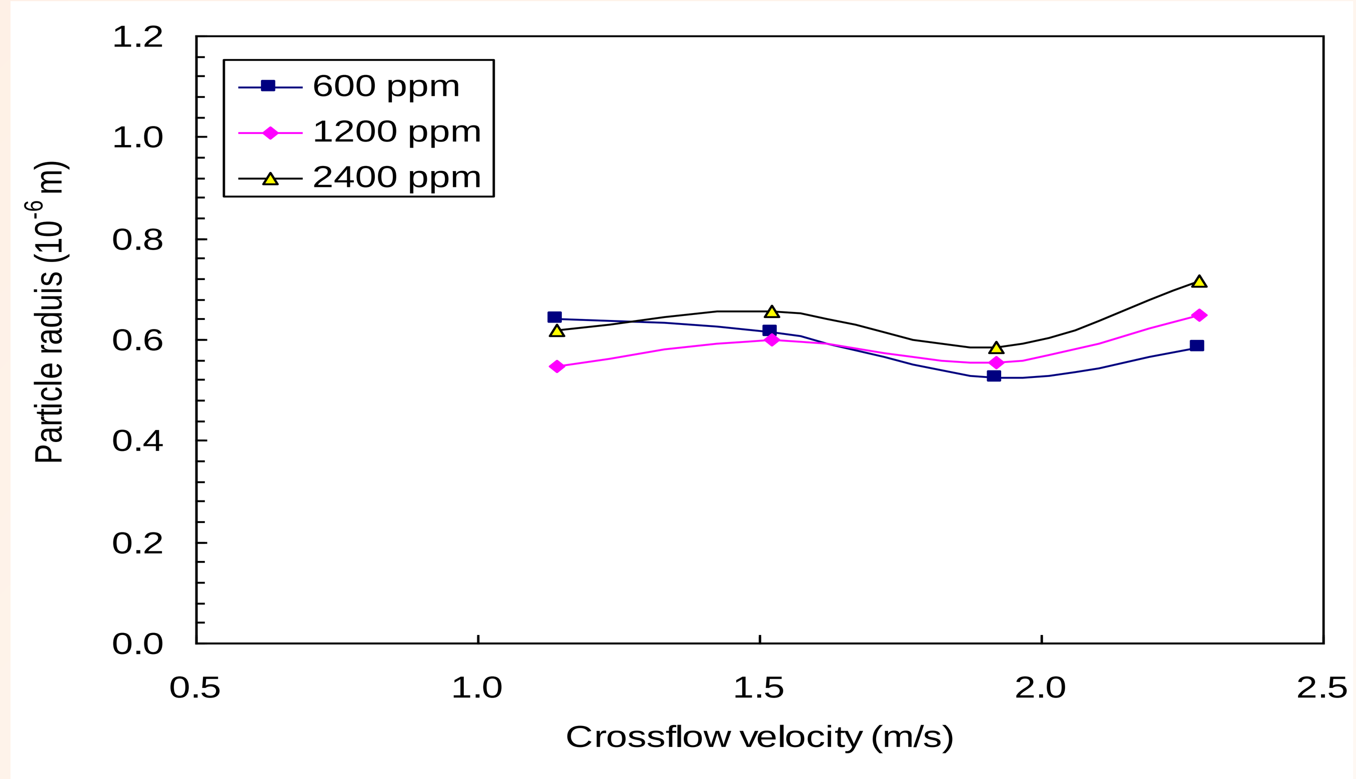
The experimental critical flux values were inserted and the equation was rearranged to

$$a_{crit} = \left(\frac{J_{crit}\,\mu_p}{\tau_w}\right)^{3/4}\left(\frac{\phi_b X}{1\times10^{-4}}\right)^{1/4}$$

Then was calculated using equation above and compared with the measured



Hence is considered be a fitting parameter to give relatively smooth curves that would to give 'best' fit the experimental data points. The particle sizes used in the SIDM to fit the model to experimental data at the four cross flow velocities are plotted against cross flow velocity in Figure below.



The 'fitted' mean particle size for the emulsion with 1200 mg L^{-1} n-dodecane was lower than the others (Figure 11), where its mean particle size was about 0.588 µm. While for each individual cross flow velocity the particle radii were approximately 0.548 at the cross flow velocity of 1.14 m s^{-1}, 0.601 µm at the cross flow velocity of 1.52 m s^{-1} , 0.554 µm at the cross flow velocity of 1.92 m s^{-1}, and 0.648 µm at the cross flow velocity of 2.28 m s^{-1}. The other 'fitted' mean particle sizes were 0.592 µm for the emulsion with 600 mg L^{-1} n-dodecane and 0.645 µm at the for the emulsion with 2400 mg L^{-1} n-dodecane.

Conclusion

Particle back transport models such as torque balance model, inertial lift model, and shear-induced diffusion model, were compared to experimental data where particle size was used as a fitting parameter at different oil feed concentration and wall shear stresses. The torque balance over predicted by three orders of magnitude of the experimental fluxes, while the inertial lift model under predicted by one order of magnitude. However, the shear-induced model showed a better prediction for the experimental data. The 'fitted' particle sizes were in the lower ranges of the measured feed particle size distributions, suggesting that these smaller particles were responsible for the initial permanent particle fouling on the membrane surface at J_{crit}. It is difficult to provide proof directly by experiment because of the lack of ability to visualise and size particles resting on the membrane in situ in the filter. In particular for oily wastewater streams, where the measured particle size distribution of feed emulsions was in the range 0.1-10 µm.

References

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