The Influence of Operating Parameters on Membrane Performance in Used Lube Oil Processing

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Abstract. Membrane process is an attractive technology for used lube oil treatment due to the advantages, i.e. relatively low energy consumption, intensive process, higher separation efficiency, and the improvement of final product quality. The performances of membrane processes depend on several factors such as feed characteristic, membrane properties, and operating parameter. In this work, the influences of solute concentration and applied pressure on the performance of hollow fiber polypropylene membrane during used lube oil filtration are investigated. The osmotic pressure model is used to simulate the influence of operating parameter on membrane performances and it results in good agreement with experimental data. By using the osmotic pressure model, the intrinsic properties of the membrane, namely membrane resistance \(R_m\) and mass transfer coefficient \(k\) are 5x10⁶ atm.s/m and 5x10⁻⁹ m/s, respectively. Generally, the flux increases with applied pressure and decreases with solute concentration. However, when the osmotic pressure builds up, the flux decreases gradually reaching a limiting value. At this condition, increasing an applied pressure gives an insignificant effect and the flux is in the limiting flux region. When the permeate flux reaches a limiting flux, the flux will be 5% of or less than the pure solvent permeability.

1. Introduction
Membrane-based process is an attractive technology because of their features such as lower energy consumption, more intensive process, higher separation efficiency, and higher product quality [1-5]. With those advantages, membrane has been widely used in various applications. Membrane applications include food processing and biotechnology, chemical processing [6-10], energy conversion [11], gas separation [12, 13], water treatment [14-22], and wastewater treatment [23-26]. In addition, membrane can also be used to treat and recover valuable component such as base oils from used lube oils, which will result in a waste minimization and an environmental protection.

Generally, used lube oils contain sludge, soot, carbonaceous particles, unburned fuel, tar, polycyclic aromatic hydrocarbons (PAHs), chlorinated paraffin and poly-chlorinated biphenyls (PCBs), metal-additives and wear metal of engines parts [27-29]. Several membranes were used and studied for used oils processing, e.g. polyethersulphone (PES), polyvinylidenefluoride (PVDF), polyacrylonitrile (PAN) [27], polyimide [30], and ceramic membranes [31-34]. Results showed that the membrane exhibited a better removal of ash content (55–75%) than the conventional method [35].

The performances of membrane processes depend on various factors including the characteristic of feed, the properties of the membrane, and the operating parameters [36]. For example, in the used oil
filtration, the solute concentration significantly affect the performance of a membrane [37]. In this work, the influence of solute concentration and applied pressure on the performance of hollow fiber polypropylene membrane during used lube oil filtration is investigated. A simulation is conducted by the osmotic pressure model to observe the influence of those operating parameter on membrane performances. The model is evaluated by comparing with the experimental data.

2. Material and methods
Used lube oil was obtained from automotive crankcase engine in certain concentrations of impurities. The hollow-fibre polypropylene membrane module was supplied by GDP Filter, and the schematic and experimental set-up of membrane apparatus are shown in Figure 1. The samples of used oils with various concentrations of impurities were placed in a feed tank and was subjected to screen filter prior to the membrane module for minimizing module blocking from relatively bigger particles. The flux was calculated using equation 1.

\[ J = \frac{Q}{A} \]  

(1)

where, \( J \) is the flux of permeate (L.m\(^{-2}\).h\(^{-1}\)), \( Q \) is volumetric rate of permeate (L), and \( A \) is the membrane surface area (m\(^2\)).

The rejection of impurities was analyzed based on the concentration of the impurities in the feed and permeate, and was calculated using equation 2.

\[ R_i = \frac{C_{if} - C_{ip}}{C_{if}} \times 100\% \]  

(2)

where, \( R_i \) is the rejection of component \( i \) (%), \( C_{if} \) is concentration of component \( i \) in feed stream (wt%), and \( C_{ip} \) is the concentration of component \( i \) in permeate (%-wt.).

![Figure 1. Experimental set-up.](image)

3. Result and Discussion
3.1. The effect of operating parameter on membrane performance.

Generally, flux tends to increase with increasing applied pressure and decreases with increasing solute concentration. Figure 2 shows the flux and rejection as a function of applied pressure and feed concentration. The impurities concentration highly affects the viscosity of used lube oil as described in the viscosity of permeate which was lower after membrane separation due to the removal of sludge,
carbonaceous particles, etc. [27]. Lai and Smith [33] reported that the permeate flux increased with the decrease of asphaltene contents in heavy oil filtration. The dependences of flux on impurities contents were related to the changes of viscosity [38].

A higher concentration of impurities leads to a higher tendency of concentration polarization and fouling. The concentration polarization and gel formation on membrane surface result in the additional mass transfer resistance of membrane filtration leading to a lower flux. In addition, this deposition of impurities onto the membrane surfaces results in a higher osmotic pressure, gel layer formation, solute adsorption, and pore blocking [36, 39].

![Figure 2](image)

**Figure 2.** The Influence of applied pressure (a) and feed concentration (b) to membrane performance.

The flux increased with the applied pressure until reach the maximum value (limiting flux), where the increasing pressure will not effectively increase the flux [36]. The value of limiting flux highly depends on the solute concentration in the feed [40]. However, according to the experimental results, the fluxes are not significantly affected by concentration in the range of this study. This may be due to the narrow concentration range used.

### 3.2. Simulation of the membrane performance.

The in fluences of feed concentration and applied pressure were simulated using osmotic pressure model [40]. In the osmotic pressure model, concentration of impurities in membrane wall \( c_m \) is higher than the bulk \( c_b \), therefore the osmotic pressure of feed influences the flux of permeate, as described in equation 3.

\[
J = \frac{\Delta P - \Delta \pi}{R_m}
\]

where, \( \Delta P \) is hydraulic pressure difference, \( \Delta \pi \) is the osmotic pressure difference, and \( R_m \) is the membrane resistance. In a 100% rejection of solute, the concentration of solute on membrane surface \( c_m \) determines the difference of osmotic pressure. The difference of osmotic pressure shows non-linear correlation like pure solvent, as explained in equation 4.

\[
\Delta \pi = a \cdot c^n
\]

where \( a \) constant \( >1 \), \( n = 2 \) in dilute solution [41].

The flux of membrane as a function of Hydraulic pressure, osmotic pressure, feed concentration, and membrane resistance is expressed in equation 5.

\[
J = \frac{\Delta P - a \cdot c_b^n \cdot \exp\left(\frac{nL}{K}\right)}{R_m}
\]
Figure 3. The performance of filtration. (a) the correlation of flux \( J \) and applied pressure (TMP) at various feed concentration \( c_b \), 0.05 – 0.3, \( R_m \), 5x10^6 atm.s/m, \( n : 2 \), \( a \): 100 atm, and \( k : 5 \times 10^{-9} \) m/s; (b) the plot of experimental data with the model.

In this work, the characteristic of flux at various operating condition (concentration, applied pressure) was simulated. The intrinsic parameters, such as membrane resistance \( (R_m) \), coefficient activity \( (a) \), mass transfer coefficient \( (k) \), and the exponent value \( (n) \) were derived using experimental data. The membrane resistance was defined as the resistance value of membrane, which was derived from measurement of steady-state flux of pure solvents through the membrane at various values of trans-membrane pressure [42]. An activity coefficient \( (a) \) is a factor used in thermodynamics to account for deviations from ideal behaviour in a mixture of chemical substances [43]. In engineering, the mass transfer coefficient is a diffusion rate constant that relates the mass transfer rate, mass transfer area, and concentration change as driving force [44]. The exponent value \( (n) \) represents the dilution of macromolecule in solution, where in semi-dilute macromolecular solutions it will have a
value of about two [41], while in more concentrated solutions the exponent is even larger than two [45]. Simulation of membrane filtration was conducted using differentiation of equation 6.

\[
d\frac{J}{dP} = \left[ R_m + a \frac{c_b}{k} \exp \left( \frac{nJ}{k} \right) \right]^{-1}
\]  \hspace{1cm} (6)

The results show that the intrinsic properties of membrane filtration as stated in weight fraction value, \(c_b\), result in the parameter of membrane resistance, \(R_m = 5 \times 10^6\ \text{atm.s/m}\), the exponent value of solution, \(n = 2\); \(a = 100\ \text{atm}\); mass transfer coefficient, \(k = 5 \times 10^9\ \text{m/s}\). According to those values, the simulation of membrane process to investigate the effect of concentration and applied pressure was conducted.

Figure 3 shows the influence of concentration and applied pressure to the performance of membrane filtration. The increasing of feed concentration decreases the flux of permeate, while the flux increases with applied pressure (Figure 3.a). The limiting flux is obtained at the applied pressure higher than 2.5 atm and varies with the feed concentration. The osmotic pressure builds up gradually reaching a limiting flux. At this condition, the increase in applied pressure becomes less effective or insignificant and one can define more or less arbitrarily a “limiting flux region”. When the permeate flux reaches a limiting flux, the flux will be 5% of or less than the pure solvent permeability. The simulation shows a relatively good agreement with experimental data as illustrated in Figure 3.b in the range of applied pressure of 2.5 – 4.5 atm and concentration of 0.16 – 0.2 weight fraction.

4. Conclusion
In this work, the influences of solute concentration and applied pressure on the performance of hollow fiber polypropylene membrane during used lube oil filtration are investigated. Generally, the flux increases with applied pressure and decreases with concentration. By using the osmotic pressure model the intrinsic properties of the membrane, i.e. membrane resistance \((R_m)\) and mass transfer coefficient \((k)\) are \(5 \times 10^6\ \text{atm.s/m}\) and \(5 \times 10^9\ \text{m/s}\), respectively. The osmotic pressure model used to simulate the influence of operating parameter on membrane performances results in good agreement with experimental data.

5. References

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