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New Approach for Estimating Hydraulic Permeability Coefficient and the Removal Rate Capacity of the Membrane

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Abstract

In this paper, a new approach for estimating the hydraulic permeability coefficient of Spiegler-Kedem model has been proposed and verified. Using this new method, estimated flux errors have been decreased in comparison to other laboratory methods. In addition to that, by using the estimated parameter, an imaginary rejection coefficient for a perfect membrane has been estimated which is beneficial to increase insights of membrane makers to make a higher quality membrane.

Keywords: Spiegler-Kedem model, Decreasing estimated fluxes errors, Estimating rejection coefficient of perfect membranes

List of Abbreviations

v: Van Hoff Factor; R_0: Observed Rejection coefficient; K: Mass Transfer Coefficient; c_p: Product Concentration; c_f: Feed Concentration; T: Absolute Temperature; R: Gas Universal Constant; Δp: Applied Pressure; $\Delta\pi$: Osmotic Pressure; J_v: Total Flux; J_{va}: Flux of the Perfect; σ_2: Solute and Solution Coupling Coefficient; σ_1: Reflection Coefficient; L_p: Hydraulic Permeability of the Membrane; L_p: Hydraulic Permeability of the Perfect; L_p^B: Hydraulic Permeability of the Imperfect

Introduction

The reverse osmosis (RO) and Nanofiltration (NF) processes have remained interesting ways to remove nitrate and other salts. Nanofiltration membranes are being used for many applications of desalination [1,2], food, and pharmaceutical processes [3,4]. Many models have been introduced to describe the reverse osmosis process and mass transfer through membranes. these models by modeling such processes successfully not only help increase our knowledge to make high-quality membranes but can also assist in selecting good input variables such as applied pressure, and temperature in order to get more desired results. In our opinion, in attempting to modification of membrane technologies to get better efficiency, we should use various existing models like Spiegler-Kedem [5], which has given accurate estimations of volumetric flux and try to modify and renew them according to recent needs. Our attempts should be directed toward ways that lead us to use the model parameters in applied purposes so that using the modified models derived from more relevant concepts of mass transfer with real observation leads us to design optimized membranes. Spiegler-Kedem model, for example, has two equations that should be considered simultaneously.

$$J_v = L_p(\Delta p - \sigma_1 \Delta\pi) \quad (1)$$

$$\frac{R_0}{1-R_0} = \frac{\sigma_2}{1-\sigma_2}\left(1 - exp\left(\frac{-(1-\sigma_2)J_v}{P_s = \frac{P_m}{\Delta x}}\right)\right) exp\left(\frac{-J_v}{k}\right) \quad (2)$$

where J_v is total permeate flux; p and π are applied and osmosis pressure; σ_1 and σ_2 are reflection coefficient and solute - solution coupling coefficient respectively; R_0 is observed rejection coefficient; P_m is local solute permeability in the membrane; L_p is hydraulic permeability of the membrane; k is mass transfer coefficient. In the modified SK model (Mohammad's model) [6], the membrane has been divided into two black boxes which one is perfect and another is imperfect, and according to that equations of the model have been rewritten, and correlated together used to estimate the parameters. L_p can be estimated either by laboratory methods or the model itself. In some papers [7], L_p was estimated using the first

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equation of the model. This method seems to be not a good idea because it misses out the other equation of the model. On the other hand, in some researches L_p has just been determined using laboratory methods [6] so that by using that, other parameters of the model have been estimated. Laboratory methods are not conclusive, hence in this paper after estimating all model parameters using determined L_p from laboratory methods, L_p is again estimated using the first equation of the model. in addition to that, using estimated parameters, the product concentration of the boundary layer of the perfect black box is obtained which gives a good insight into the membrane performances.

Theory

Various laboratory methods have been proposed to estimate a reliable L_p [8-10]. For estimating L_p, L_p^A, L_p^B, the hydraulic permeability of total, perfect, and imperfect sections respectively, using just equation 3 which is similar to the first equation of solution-diffusion model [11], are not obtained good results in terms of fitting data to a carve with a high regression. For obtaining reliable ones a new method is introduced, using modified SK model introduced in the paper [6] σ_1 is estimated (by correlating between the two model equations, at first σ_2 is estimated then σ_1 is obtained) then by replacing it into equation 3 L_p is obtained, then by replacing it into equation 5 L_p^A and L_p^B are obtained. Using the hydraulic permeability coefficients allow us to estimate the rejection coefficient of the perfect section of the membrane using equations 6 and 7.

$$J_v = L_p(\Delta p - \sigma_1 \Delta\pi) = L_p^A(\Delta p - \Delta\pi) + L_p^B \Delta p \quad (3)$$

$$L_p = L_p^A + L_p^B \quad (4)$$

$$\sigma_1 = \frac{L_p^A}{L_p^A + L_p^B} \quad (5)$$

$$\sigma_2 = \frac{L_p^A(\Delta p - \Delta\pi)}{J_v} \quad (6)$$

$$\Delta\pi = vRT(C_f - C_p)\exp\left(\frac{J_v a}{k}\right) \quad (7)$$

Verification and Discussion

This method allows us to have a reliable way to obtain the results with low errors. Figure 1 is results of experimental fluxes derived from Ahmad's thesis [12], and estimated fluxes of 0/23M, 0/6M, 0/82M feed concentration of NaCl with various applied pressures that shows the errors of our estimation often are smaller than errors of models which obtain L_p with laboratory methods especially at low concentrations (Figures 1a and 1b). at higher concentrations (Figure 1c) better results have been obtained at higher pressures.

Figure 2 shows the differences between the actual rejection coefficient obtained from laboratory tests and the rejection coefficient of the perfect section of the membrane obtained from our presented method.

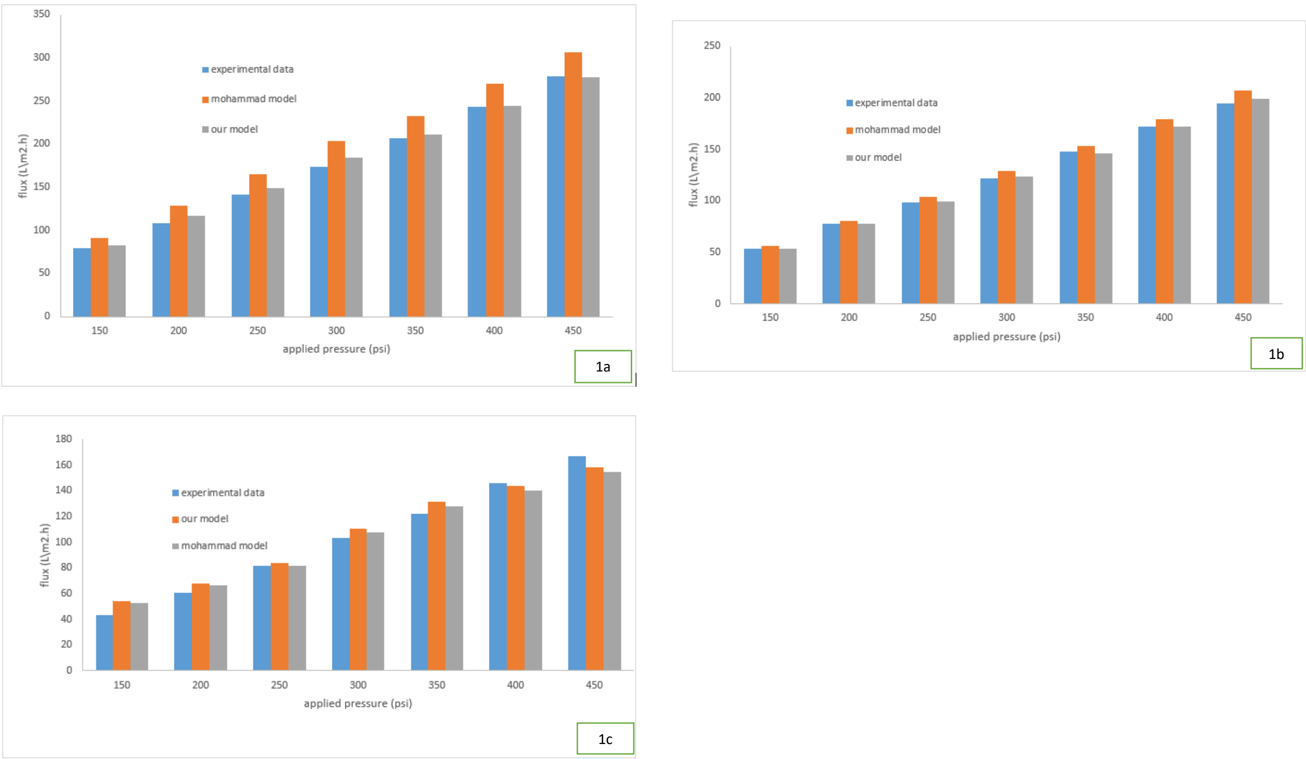

Figure 1: The comparison between estimated fluxes of our model and Mohammad's model based on Ahmed's data [12] for NF270 a) 0/23M b) 0/6M c) 0/82M NaCl.

As it can be seen in figure 2 the perfect rejection coefficient R_0 is higher than the actual one, because the capacity of the membrane to remove salts is always higher than its actual performances. At higher pressures the differences between the perfect and the actual R_0 increase (Figures 2a,2b and 2c). It indicates that at higher pressures the membrane doesn't show good performances so that from this, researchers can redesign membrane structures to improve performances of the membrane at higher pressures. In addition to that, it allows researchers to know the capacity of a perfect membrane to remove salts, in the other word, if we succeed to make a 100% well-performed membrane without any imperfection, the capacity of the membrane to remove salts (ignoring the imperfect black box) using various applied pressures and feed concentrations can be estimated, and it can be considered as a factor to make membranes with higher qualities.

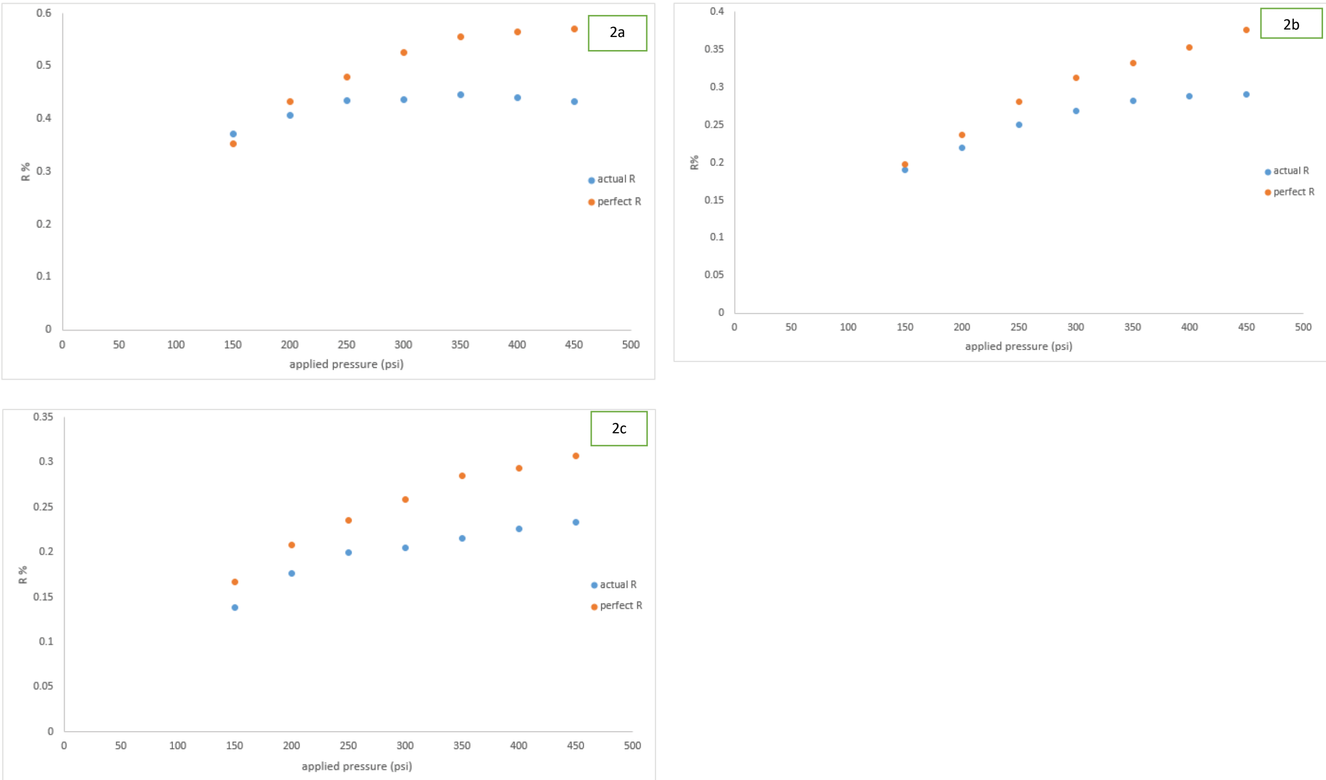

Figure 2: The comparison between experimental rejection coefficient and estimated rejection coefficient for the perfect section according to Ahmed's data [12] a) 0/23 M b) 0/6 M c) 0/82 M NaCl.

Conclusion

This method allows us to have deeper information about the application of the parameters of SK model. By estimating L_p using the new method in many tests, better results for estimated volumetric fluxes have been obtained especially at lower concentrations in comparison to laboratory methods which confirm the authenticity of the new method. In addition to that, it allows researchers to develop their knowledge about membranes in terms of mass removal. This knowledge allows them to make such membranes that have not only a small portion of the imperfection section but also have a well-designed structure in perfect section to increase the capacity of the perfect section of the membrane which is required to develop membrane making technologies.

Conflict of Interest

The authors declare no conflict of interest.

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