Elaboration of Different Pore Blocking Model for Phenol Removal using Disk Shaped Ceramic Membrane

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Abstract: ***Membrane fouling is mainly associated with the deposition of solute molecules on the membrane surface. The performance of a given membrane is found to be degraded due to membrane fouling and hence it results into a significant decline in the permeate flux. Therefore it is very necessary to interpret the fouling mechanism in order to predict the profile of permeate flux. The present study illustrates the mechanism of membrane fouling through describing four pore blocking models such as complete pore blocking, standard pore blocking, intemediate pore blocking and cake filtration. The model parameters were also evaluated at varying trans-membrane pressures ranging from 196 to 392 kPa. The accuracy of the fitted model was further judged in terms of higher value of regression coefficient (R^2) and here also it is confirmed from Table 1 that cake filtration model exhibits higher values of R^2 ($\approx$ 0.98). The degree of membrane fouling was indicated by model parameter k. The values of permeate fluxes calculated from different models are found to be less than the experimental values of the permeate flux indicating the under prediction of flux profile.***

Index Terms: ***Concentration Polarization, Fouling, Membrane, Permeate Flux, Pore Blocking.***

I. INTRODUCTION

The phenomenon membrane fouling can be defined as the possible deposition of solute molecules on the membrane surface during the course of various filtration processes namely reverse osmosis, forward osmosis, membrane distillation, ultra filtration, microfiltration, or nano filtration etc [1]. The depositions of solute molecule leads to significant decline in permeate flux which degrades the membrane rejection percentage [2]. As the separation efficiency of a membrane gets affected by membrane fouling, the quality of treated water produced is also degraded in case of water purification. On the other hand, membrane fouling also increases the operating cost of the process [3]. Therefore, periodic cleaning of membrane surface is required in order to maintain a constant permeate flux [4]. The membrane fouling can be categorized as reversible and irreversible fouling depending on the type of attachment of solute molecules to the membrane surface [5]. In case of reversible fouling a layer of solute molecules of constant thickness is developed during a continuous filtration process which is gradually transformed to a viscous layer with the passage of time resulting irreversible fouling [6]. The attachment of solute particles in case of irreversible fouling is much more intense in compare to reversible fouling and hence cannot be removed through physical cleaning [7]. Because of this strong, attachment of solute molecules a certain percentage of the permeate flux is permanently lost in irreversible fouling whereas, the deposited molecules can be removed by a strong shear force or backwashing in case of reversible fouling [8]. So it is very important to study the actual profile of permeate flux in case of membrane separation processes. Therefore in the present study, the permeate flux profile through a developed ceramic membrane is studied by analyzing various pore blocking models for phenol removal through microfiltration study.

II. EXPERIMENTAL

A. Preparation of Membrane

The disk shaped ceramic membrane of 75 mm diameter was prepared by mixing various raw materials such as river clay, sodium nitrate, commercial activated carbon and oxalic acid in a predetermined proportion through paste casting technique followed by a heat treatment step in a muffle furnace at 970 °C.

B. Filtration Experiment

In order to study the permeation flux of phenol molecules, the filtration experiment was carried out at room temperature by using a simple microfiltration set up. For this purpose, the applied pressure was varied from 196 – 392 kPa, feed concentrations from 20 – 100 mg/L and cross flow rates from 0.08 × 10-7 - 2.4 × 10-6 m3/s.

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The aliquots of the permeate samples were collected at regular time intervals and the samples were analyzed by using a UV-Vis spectrophotometer (Chemito, Spectrascan 2600) at a wave length of 270 nm.

C. Model Development

The transport mechanism through membrane pores is largely affected by the development of concentration boundary layer which is generally caused due to membrane fouling where partial blocking of membrane pores may take place. It is therefore has become very necessary to study the decline in the permeate flux during the filtration process. In this study, in order to determine the decrease in permeation flux of phenol containing wastewater four theoretical models for membrane fouling such as, complete, standard, intermediate pore blocking and cake filtration were investigated [9]. The complete pore blocking model generally encounters the blocking of membrane pores on the surface and it doesn't generally include the blocking of pore interior. It is generally found to occur when the diameter of solute molecules are bigger than the diameter of membrane pores [10]. This model can be presented by the following expression

$$\ln J^{-1} = \ln J_0^{-1} + k_b t \quad (1)$$

If the non-uniformity in the pore channel exists then standard pore blocking may take place. It generally happens when the diameters of solute molecules are lower than the diameter of the membrane surface and as a result the solute molecules penetrate inside the pores resulting into pore blocking. Therefore, the decrease in permeate flux is directly proportional to decrease in pore volume [11]. This model can be represented

$$J^{-0.5} = J_0^{-0.5} + k_s t \quad (2)$$

On the other hand, intermediate pore blocking happens when the size of solute molecules and the membrane pores are of same dimension [12]. In this pore blocking partial blocking of the membrane pores may occur due to settling of solute particles over one another.

$$J^{-1} = J_0^{-1} + k_i t \quad (3)$$

In cake filtration model, when large solute particles accumulate on membrane surface give rise to a constant layer of cake. This solute deposition on the membrane surface offers extra resistance to flow and reduce the permeate flux with time.

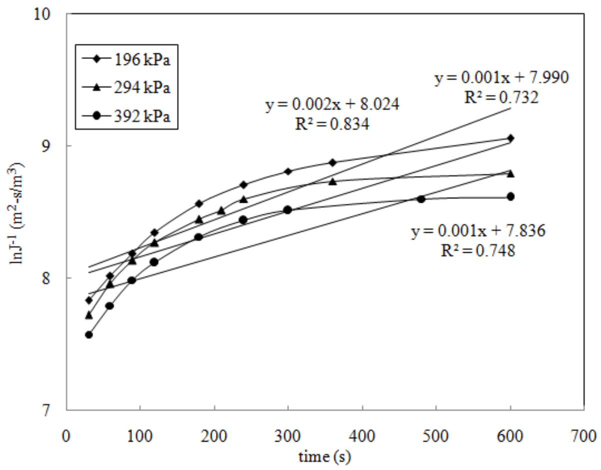
$$J^{-2} = J_0^{-2} + k_c t \quad (4)$$

Where, J denotes the permeate flux in m^3/m^2-s, t in time in s and kb, ks, ki and kc are the model constants. These are the linearized forms of the pore blocking models and the values of various constants such as and kb, ks, ki and kc can be evaluated from the slope of the graph. The adequacy of the above mentioned models can be judged in terms of the value of regression coefficient (R^2) [13].

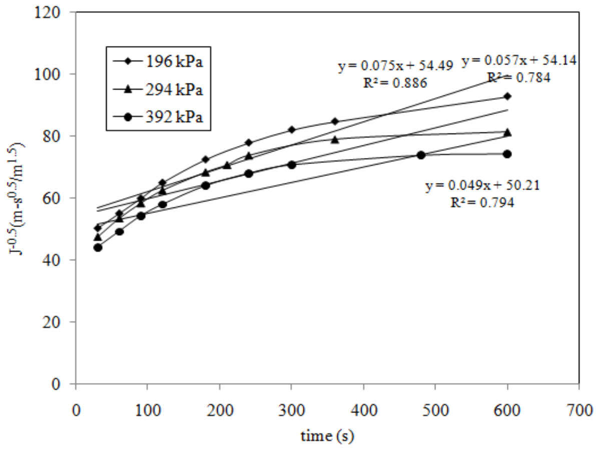
III. RESULTS AND DISCUSSION

A. Fouling Analysis

In case of membrane transport mechanism it is very much pertinent to investigate the fouling characteristics of the used membranes [14]. The gradual decrease in permeate flux gives us a brief idea about the pore blocking models as discussed in the preceding sections. In the present study four types of pore blocking models were investigated at varying experimental conditions (Fig. 1a to Fig. 1d). It can be seen from the figures that the cake filtration model exhibits better fit with the experimental data.



(a)



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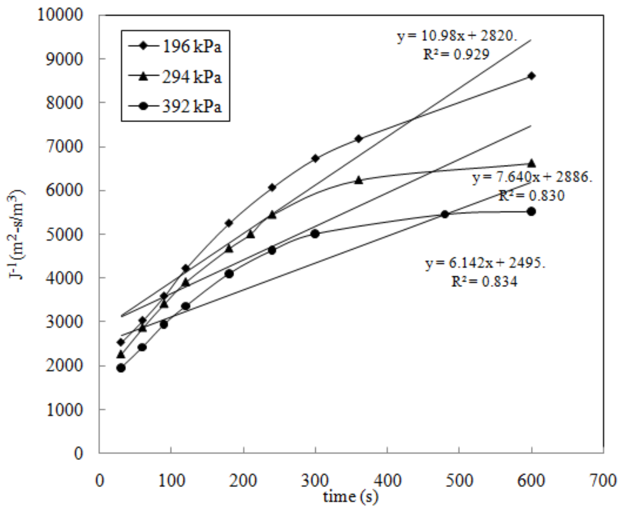

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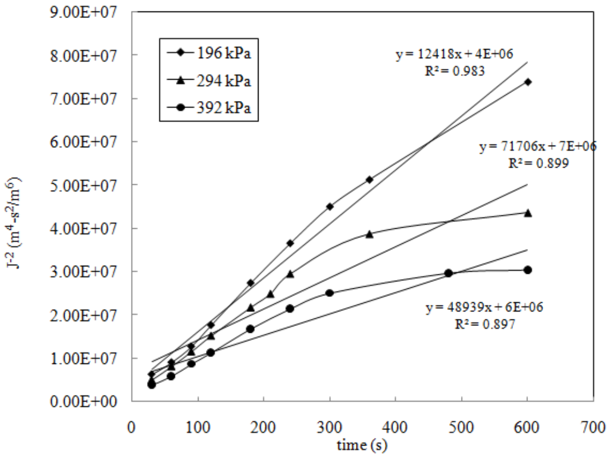

(d)

Fig. 1: Fitting of Different Pore Blocking Models (a) Complete Pore Blocking (b) Standard Pore Blocking (c) Intermediate Pore Blocking (d) Cake Filtration Model

B. Comparison of Various Models

Different model parameters values for four different models are summarized in Table 1.

Table 1: Pore Blocking Models at Various Conditions

Complete pore blocking model	Pressure (kPa)		
	196	294	392
J_0 (m^3/m^2-s)	0.00033	0.00034	0.0004
k_b (s^{-1})	0.0021	0.0017	0.0016
R^2	0.834	0.732	0.748
Standard pore blocking model			
J_0 (m^3/m^2-s)	0.00033	0.00034	0.0004
k_s ($s^{0.5}m^{-0.5}$)	0.075	0.057	0.049
R^2	0.886	0.784	0.794
Intermediate pore blocking model			
J_0 (m^3/m^2-s)	0.00035	0.00035	0.0004
k_i (m^{-1})	10.98	7.64	6.14
R^2	0.929	0.831	0.834
Cake filtration model			
J_0 (m^3/m^2-s)	0.0005	0.00038	0.0004
k_s (s-m^{-2})	124181	71706	48939
R^2	0.983	0.889	0.897

The adequacy of the fitted model was further judged in terms of higher value of regression coefficient (R2) and here also it is confirmed from Table 1 that cake filtration model exhibits higher values of R2 (≈ 0.98). The other model parameter k signifies the degree of membrane fouling as described by Hermia's model parameters. It can be further seen from Table 1 that the initial values of permeate fluxes calculated through plotting the linearized forms of pore blocking models are comparatively less than the flux obtained experimentally which signifies the under prediction of permeate flux. Therefore the fouling analysis of the used membranes is directly proportional to the life of the membranes [15].

IV. CONCLUSIONS

Use In the present study, the transport mechanism of phenol molecules through the pores of developed ceramic membrane was investigated by analyzing the phenomenon membrane fouling. The fouling process is characterized through four pore blocking model such as, complete, standard, intermediate and cake filtration model. In order to find out the suitability of the given models, the existing experimental data taken at various experimental conditions were fitted to these models and the adequacy of the most suitable model was judged through linear regression analysis. Various model parameters were also evaluated and it was found that cake filtration model exhibited better fit with the experimental data with a reasonably high value of regression coefficient (R2 ≈ 0.98).

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