

# Evaluation of Fouling Mechanism of Ceramic Membrane for Oil-Water System

Saugata Roy<sup>1</sup>, Avik Denra<sup>2</sup>, Avirup Saha<sup>3</sup>, Mekhala Mitra<sup>4</sup>, Sayantan Adak<sup>5</sup>, Rupayan Mallick<sup>6</sup>,  
Angira Sengupta<sup>7</sup>, Dr. Monal Dutta<sup>8</sup>

U.G. Student, Department of Chemical Engineering, Calcutta Institute of Technology, Howrah, W.B., India<sup>1,2,3,4,5,6,7</sup>

Assistant Professor, Department of Chemical Engineering, Calcutta Institute of Technology, Howrah, W.B., India<sup>8</sup>

**ABSTRACT:** This research evaluates the fouling mechanism of a microfiltration membrane for an oil-water system. The effect of applied pressure drop on the collected permeate volume was determined through different pore blocking models. The degree of membrane fouling was characterized by volume concentration factor and fouling percentage and the degree of membrane fouling was found to decrease with increase in applied pressure due to enhancement in the driving force. Various theoretical models such as complete pore blocking, standard pore blocking and intermediate pore blocking were analysed and it was found that the fouling mechanism was best described by intermediate pore blocking model with a higher value of regression coefficient ( $R^2 = 0.96$ ).

**KEYWORDS:** Fouling, Pore blocking, Volume concentration factor, Membrane, Permeate volume

## I. INTRODUCTION

In the present decade, the treatment of oily wastewater through various membrane based separation processes such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) have been taken into consideration to reduce the rest-oil concentrations in the discharge water [1]. Significant attentions have been paid to remove the residual oil from wastewater by using various membranes [2]. Among all these membranes ceramic membranes are most widely used due to their good chemical stability, mechanical strength, and long service life [3]. In spite of having so many potential advantages, one major problem associated with ceramic membrane is membrane fouling which adversely affects the membrane performance [4]. Fouling of membrane is generally caused due to hydrophobicity of the membrane surface which results into deposition of suspended or dissolved particles either inside the membrane pores or on the external surface of membrane. This subsequent deposition of suspended or dissolved particles leads to decline in permeates flux and membrane efficiency [5]. Unfortunately membrane fouling is inevitable during the course of continuous filtration process which severely reduce the permeate volume [6]. Therefore, cleaning of membrane is necessary in order to maintain a constant permeate flux. But sometimes, the cleaning has become difficult due to irreversible fouling which is caused due to partial blocking of membrane pores. As a result a fraction of the permeate flux is permanently lost [7]. It is therefore very necessary to evaluate different fouling mechanisms in order to study the permeate flux profile [8]. For this purpose, three basic pores blocking models such as pore narrowing model, internal fouling model and complete pore blocking model. In the present study, the performance of a ceramic membrane for filtration of an oily wastewater system is investigated through studying various pore blocking models.

## II. EXPERIMENTAL

### The fouling experiment

The fouling experiments was carried out by using a lab scale experimental set up comprises of a vertical feed reservoir, a membrane, a membrane holder, a high-pressure pump, a flowmeter and a permeate collection unit. The preparation of similar type of ceramic membrane was described in a previous study [9]. The applied pressure was varied from 196 to 392 kPa whereas the cross flow velocity was maintained as  $2.4 \times 10^{-6} \text{ m}^3/\text{s}$ . The velocity and the operating pressure

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 6, June 2018

were maintained by using a flow meter and a bypass valve. The effective surface area of membrane available for cross flow filtration was calculated as 0.0043 m<sup>2</sup>. The feed comprises of an emulsion of oil-water system is introduced from the top and filtrate was collected from the permeate side at predetermined time intervals. The residual oil concentration in the filtrate solution after the cross flow filtration experiment was determined by using a UV-Vis spectrophotometer (Chemito, Spectrascan 2600) at 211 nm.

## Determination of filtration parameters

Different model parameters associated with cross flow filtration experiment were determined in order to characterize the filtration process and degree of membrane fouling. One of such parameter is cross flow filtration volume which gives a fair idea about mass transfer during the filtration process and it can be calculated by dividing the filtrate volume by cross sectional area of membrane at unit time as.

$$v = \frac{F}{A} \quad (1)$$

Where, v is the cross flow rate in m/s, F is the volumetric flowrate of filtrate in m<sup>3</sup>/s and A is the membrane area in m<sup>2</sup>.

The degree of permeation during the course of filtration process was characterized by volume concentration factor (VCF) which was calculated as follows:

$$VCF = 1 + \frac{V_P}{V_R} \quad (2)$$

Where, V<sub>P</sub> is the permeate volume or filtration volume in m<sup>3</sup> produced at any time t (s) and V<sub>R</sub> is the retentate volume in m<sup>3</sup>.

## Measurement of degree of fouling

The degree of membrane fouling was evaluated through flux decay coefficient of the prepared membrane (FD) and it was determined as:

$$F_D = \frac{J_0 - J_1}{J_0} \times 100 \quad (3)$$

Where, J<sub>0</sub> is the initial flux at the beginning of the filtration process (m<sup>3</sup>/m<sup>2</sup> s), and J<sub>1</sub> is the permeate flux (m<sup>3</sup>/m<sup>2</sup> s) of the fouled membrane at various times

## III. RESULTS AND DISCUSSION

### Filtration parameters at various experimental conditions

Various filtration parameters such as volume concentration factor and degree of fouling were evaluated by varying the applied pressure from 196 to 392 kPa for a feed concentration of 100 mg/L and a cross flowrate of 2.4 × 10<sup>-6</sup> m<sup>3</sup>/s as shown in Table 1.

Table 1: The values of various filtration parameters

Applied pressure (kPa)	VCF	FD (%)
196	1.0757	26.6064
294	1.1144	16.8605
392	1.1814	12.1016

The values of volume concentration factor (VCF) are found to be increased from 1.07 to 1.18 with the increase in applied pressure from 196 to 392 kPa. This behavior may be attributed to the enhancement of driving force with

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 6, June 2018

increase in applied pressure which helps to produce comparatively larger permeate volume ( $V_p, m^3$ ) and hence increase the VCF value [10]. It is further evident from Table 1 that the degree of fouling decreases from 26.60 to 12.10% as the applied pressure is increased from 196 to 392 kPa. Generally the fouling of a membrane causes due to deposition of solute molecules on the membrane surface which offers an extra resistance to flow of permeate. On the other hand, with increase in applied pressure, helps to overcome the additional resistance offered by the deposited layer of solute molecules and hence increase the permeate flowrate by a small degree [11].

### Evaluation of fouling mechanism

The fouling mechanism was investigated through studying various fouling models at varying applied pressures. The models were fitted with the experimental data generated at various pressures for oil-water system. Four basic conventional fouling models such as, complete pore blocking, standard pore narrowing model and intermediate pore blocking models were investigated to study the fouling mechanism. In case of complete pore blocking models, pores on the membrane surface are choked by the solute molecules and it results from irreversible fouling. The model can be described as follows [12]:

$$\ln J^{-1} = \ln J_0^{-1} + k_b t \quad (4)$$

In case of standard pore blocking, pores present in the internal membrane surface have become partially blocked due to tortuicity of the pore walls and this model can be described in the following way [13]:

$$J^{-0.5} = J_0^{-0.5} + k_s t \quad (5)$$

On the other hand, when solute molecules start settle one over another during the continuous filtration process resulting into partial pore blocking is called intermediate pore [14]

$$J^{-1} = J_0^{-1} + k_i t \quad (6)$$

In this study, three above mentioned pore blocking models were evaluated at varying applied pressures from 196 – 392 kPa and the corresponding models parameters were also determined at these conditions as shown in Table 1. In order to find out the best fitted model, a linear regression was carried out and the best fitted model was identified based on the value of linear regression coefficients ( $R^2$ ). The values of permeate flux ( $J_0$ ) evaluated at various experimental condition are also shown in Table 2 and it is evident from Table 2 that the value of permeate flux increases from 0.0002 to 0.0006  $m^3/m^2-s$  with increase in applied pressure from 196 to 392 kPa.

**Table 2: Values of different pore blocking model parameters**

Complete pore blocking model	Pressure (kPa)		
	196	294	392
$J_0 (m^3/m^2-s)$	0.0002	0.0004	0.0006
$k_b (s^{-1})$	0.0003	0.0005	0.0004
$R^2$	0.9212	0.9449	0.9218
<b>Standard pore blocking model</b>			
$J_0 (m^3/m^2-s)$	0.0002	0.0004	0.0006
$k_s (s^{0.5} m^{-0.5})$	0.0085	0.0139	0.0081
$R^2$	0.9273	0.9545	0.9311
<b>Intermediate pore blocking model</b>			
$J_0 (m^3/m^2-s)$	0.0002	0.0004	0.0006
$k_i (m^{-1})$	1.1623	1.5621	0.7191
$R^2$	0.9331	0.9623	0.9397

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 6, June 2018

The possible reason may be during the filtration process, an additional layer of solute molecules get deposited on the membrane surface which will offer an extra resistance to the permeate flow and as a result a significant decline in the permeate flux may be observe. On the other hand, when the applied pressure is increased the driving force of mass transfer is also increased which enables to enhance the permeate flux. The similar behavior was also observed in a previous study [15]. It is further concluded from Table 1 that the intermediate pore blocking model is best fitted with the existing experimental data with higher value of regression coefficient ( $R^2 = 0.9623$ ). The fitting of different pore blocking models are also shown in Fig.1a to Fig. 1c for an initial solute concentration of 100 mg/L and for a filtration period of 600 second. Here also it can be seen that the intermediate pore blocking model offers a better fit in compare to other pore blocking models. The similar behavior was also observed in the previous literature [16].

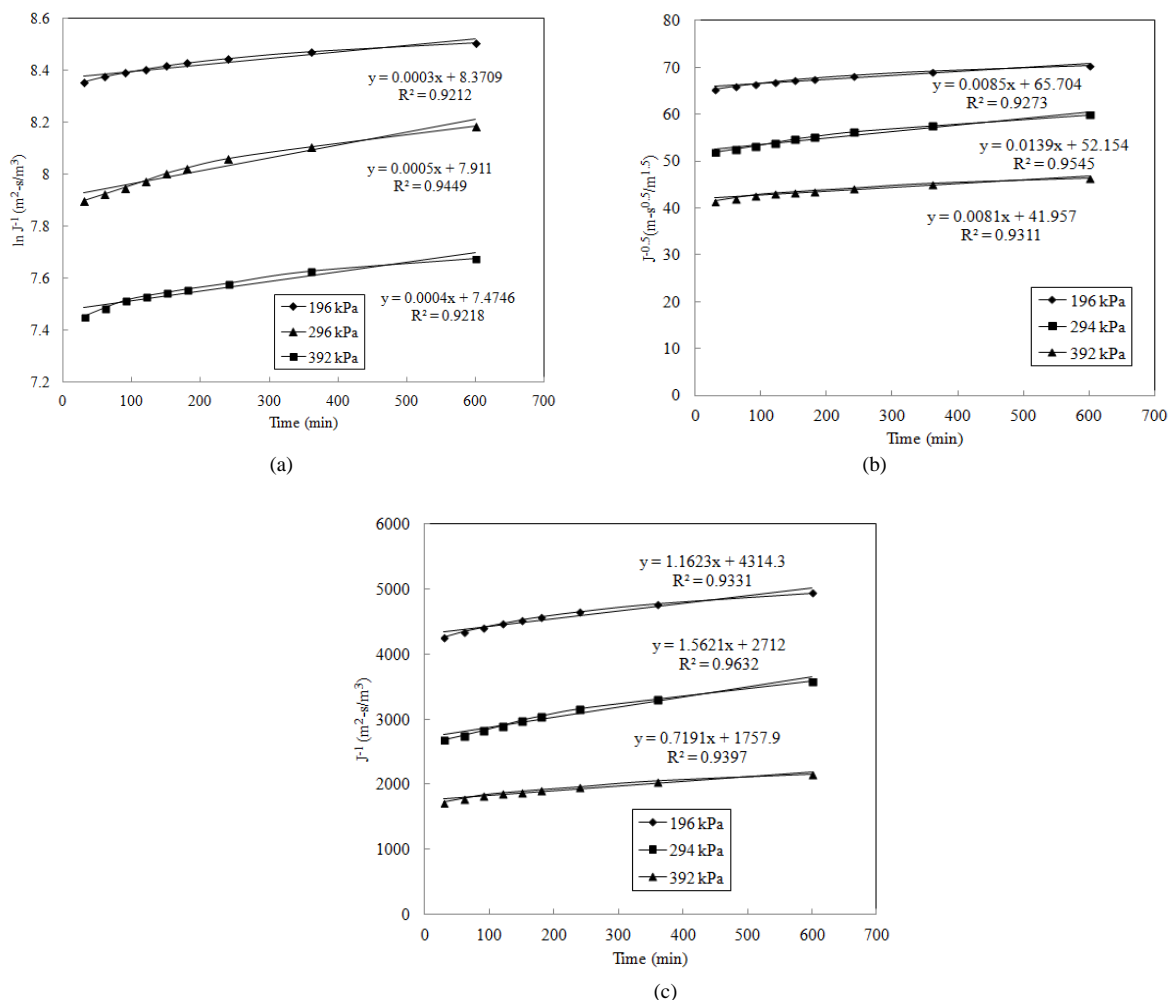


Fig. 1: The fitting of various pore blocking models with the experimental data (a) complete pore blocking model (b) standard pore blocking model (c) intermediate pore blocking model

# International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 6, June 2018

## IV. CONCLUSION

In this investigation, the fouling of the ceramic membrane has been studied through complete pore blocking, standard pore blocking and intermediate pore blocking model. The fouled membrane was characterized through a significant decline in the permeate flux which was partially recovered by increasing the applied pressure. Here, the phenomenon of membrane fouling was mainly characterized by two parameters namely volume concentration factor (VCF) and degree of fouling (FD). These parameters were evaluated at varying applied pressure and it was found that with increase in applied pressure from 196 to 392 kPa, the VCF value was increased from 1.07 to 1.18 due to enhancement in the driving force. On the other hand, degree of membrane fouling was found to be decreased from 26.60 to 12.10% with increase in applied pressure from 196 to 392 kPa. Three fouling models such as, complete pore blocking, standard pore blocking and intermediate pore blocking were fitted to experimental data and it was found that intermediate pore blocking model exhibited a better fit with a higher value of regression coefficient ( $R^2 = 0.96$ ).

## REFERENCES

- [1] M. Zoubeik, M. Ismail, A. Salama, A. Henni, "New developments in membrane technologies used in the treatment of produced water: A review", *Arabian Journal for Science and Engineering*, vol. 43, no. 5, pp. 2093–2118, 2018.
- [2] A. Motta, C. Borges, K. Esquerre, A. Kiperstok, "Oil produced water treatment for oil removal by an integration of coalesce bed and microfiltration membrane processes", *Journal of Membrane Science*, vol. 469, pp. 371–378, 2014.
- [3] K. Guerra, J. Pellegrino, J.E. Draws, "Impact of operating conditions on permeate flux and process economics for cross flow ceramic membrane ultra filtration of surface water", *Separation and Purification Technology*, vol. 87, no. 5, pp. 47–53, 2012.
- [4] B. Xing, A. L. Sydney, M. Kumar, "Fouling of microfiltration membranes by flow back and produced waters from the Marcellus shale gas play", *Water Research*, vol. 99, pp. 162-170, 2016.
- [5] M. Baghbanzadeh, D. Rana, C.Q. Lan, T. Matsuura, "Effects of hydrophilic silica nanoparticles and backing material in improving the structure and performance of VMD PVDF membranes", *Separation and Purification Technology*, vol. 157, no. 8, pp. 60–71, 2016.
- [6] N.A. Ochoa, M. Masuelli, J. Marchese, "Effect of hydrophilicity on fouling of an emulsified oil wastewater with PVDF/PMMA membranes", *Journal of Membrane Science*, vol. 226, no. 1–2, pp. 203–211, 2003.
- [7] X. Chen, J. Luo, B. Qi, W. Cao, Y. Wan, "NOM fouling behavior during ultrafiltration: effect of membrane hydrophilicity", *Journal of Water Process Engineering*, vol. 7, pp. 1–10, 2015.
- [8] V. Jegatheesan, D.D. Phong, L. Shu, R. Ben-Aim, "Performance of ceramic micro- and ultrafiltration membranes treating limed and partially clarified sugar cane juice", *Journal of Membrane Science*, vol. 327, no.1-2, pp. 69–77, 2009.
- [9] M. Mitra, S. Adak, R. Mallick, S. Roy, A. Sengupta, A. Denra, A. Saha, Dr. M. Dutta, "Development of chalk layered microfiltration ceramic membrane", *International Journal of Advance Research, Ideas and Innovations in Technology*, vol. 4, no. 3, pp. 23-26, 2018.
- [10] A. Zaidi, K. Simms, S. Kok, R. Nelson, "Recent advances in the application of membrane technology for the removal of oil and suspended solids from produced waters, in: J. P. Ray, F. R. Engelhardt (Eds.), *Produced Water: Technological/Environmental Issues and Solutions*", Plenum Publishing Corp., New York, pp. 489–502, 1992.
- [11] B. Xiong, A.L. Zydney, M. Kumar, "Fouling of microfiltration membranes by flow back and produced waters from the Marcellus shale gas play", *Water Research*, vol. 99, PP. 162-170, 2016.
- [12] L. Sim, L. Shu, V. Jegatheesan, D.D. Phong, "Effect of operating parameters and cleaning on the performance of ceramic membranes treating partially clarified sugar cane juice", *Separation Science and Technology*, vol. 44, no. 15, pp. 3506-3537, 2009.
- [13] V. Jegatheesan, L. Shu, D.D. Phong, D. Navaratna, A. Neilly, "Clarification and concentration of sugar cane juice through ultra, nano and reverse osmosis membranes", *Membrane Water Treatment*, vol. 3, no. 2, pp. 99-111, 2012.
- [14] Y. Jin, Y. Ju, H. Lee, S. Hong, "Fouling potential evaluation by cake fouling index: Theoretical development, measurements, and its implications for fouling mechanisms", *Journal of Membrane Science*, vol. 490, pp. 57–64, 2015.
- [15] A. Sengupta, A. Saha, S. Roy, M. Mitra, R. Mallick, A. Denra, S. Adak, M. Dutta, "Elaboration of Different Pore Blocking Model for Phenol Removal using Disk Shaped Ceramic Membrane", *International Journal of Engineering and Advanced Technology*, vol. 7, no. 5, pp. 24-27, 2018.
- [16] S. Mondal, S. De, "A fouling model for steady state crossflow membrane filtration considering sequential intermediate pore blocking and cake formation", *Separation and Purification Technology*, vol. 75, no. 2, pp. 222-228, 2010.