Computational Research Progress in Applied Science & Engineering
©PEARL publication, 2015
ISSN 2423-4591
CRPASE Vol. 01(02), 67-74, May 2015

Mini Review of the Membrane Fouling Mechanism and It's Affecting Parameters

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Keywords:

Membrane,
Fouling Mechanism,
Concentration
Polarization,
Transmembrane
Pressure.

Abstract

One of the main problems of membrane separation processes is the occurrence of the fouling and concentration polarization that cause by sedimentation on membrane surface and adsorption into the pores of the membrane particles. Membrane fouling during separation process reduced the efficiency and caused an increase in the operation cost and in the other hand the occurrence of the membrane fouling is inevitable in the membrane process, so various methods were used for the membrane recovery. On the other hand the costs related to washing such as cleaning chemicals, frequent stops of the separation operation for cleaning and etc. should be considered. All these factors cuased reduction in the production time and finnaly create the economic problems. So, understanding and knowing the effective factors that affect the fouling mechanism in order to increase the efficiency of separation and reduce the cost of washing and cleaning is necessary.

1. Introduction

Membrane process had beed considered in recent decades because of low energy consumption, high selectivity, easy installation, being controllable, less space occupation, high biocompatibility and none use of chemical compounds [1]. But the main issue in the membrane seperation processes that limit the membrane usage in the industries is the occurrence of the fouling and concentration polarization [2].

These factors have economic aspects that cuase the increase in the costs of operation and maintanance such as increase in the energy costs related to fouling reduction or fouling elimination, costs for membrane cleaning and washing using chemical cleaning agent, the reduction of the useful time for production, frequent stops of the separating operation, reduction in the membrane lifetime and the cost of membrane replacing [3-6]. For such the reasons, the elimination or reduction of the

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Received: 12 March 2015 ; Accepted: 11 April 2015

membrane foaling is very important. Therefore many experimental, mathematical and numerical studies were done by researcher for better understanding of the fouling mechanism in the membrane processes [7].

Ng et al in 2014 [8] surveyed foaling mechanism and the factors affecting on membrane performance such as trans-membrane pressure, operational tempreture and exclusion limit or "cut-off" of the membrane in the separating process of the milk. In mentioned research Hermia’s Model is used for prediction and analysis of the foaling mechanism during seperating operation.Gao et al in 2014 [9] examined characterization of internal and external concentration polarizations during forward osmosis processes (FO). Boussu et al (2007) [10] survey the effect of varius characteristics of the membrane and colloidal material like size and electrical load on fouling of nanofiltration membranes. James et al (2003) [11] evaluated the membrane fouling during filtration of milk. Peter-Varbanets et al (2011) [12] investigated the membrane fouling mechanisms during ultra-low pressure ultrafiltration to treat water. Ma et al (2013) [13] and Arévalo et al (2014) [14] tested the effect of various temperatures on membrane performance and it’s fouling. Huang et al (2014) [15] evaluated the influence of feed concentration and transmembrane pressure on membrane fouling and the obtained results showed that these two factors has more influence on the membrane foaling. Yazdanshenas et al (2010) [16] modeled the effluent from ultrafiltration membrane in the apple juice squeezing process using concentration polarization and fouling models. Results shows that the main factor that cause fouling is the amount of feed concentration.

2. Concentration Polarization and Fouling

Concentration polarization named as the first factor of flux reduction.When the transmission of excreted components from the surface of the membrane to the feed mass slowly done because of it’s low turbulence, it caused accumulation and concentration gradient on the membrane surface and then a boundary layer is formed on the surface of the membrane that shows concentration polarization [17]. Then, over the time, gradually the adsorbtion and sedimentation on the membrane surface increase that cuase closure of the pores and formation of the gel layer on the membrane surface because of density of the excreted compounds.In this state, fouling occurred. Transition state from concentration polariztion to fouling when occurre that van der waals forces between membrane and the particles are more than electrostatic repulsion forces. In the concentration polarization and fouling, the increase in the osmotic pressure cause reduction in the effect of the driving force of the Transmembrane Pressure (TMP) which according to Darcy equation, membrane filtration flow rate decreases [3].

$$J=(\Delta p-\pi)/(\mu\sum R) \quad (1)$$

Concentration polarization is the reversible phenomenon and caused no changes in membrane structure and by washing the membrane easyly disappeare. Fouling based on its relative strength versus washing and cleaning methods, classified in the two classes of reversible and irreversible. Reversible fouling according to cleansing article categorized in two class of backwashable and non-backwashable. Backwashable and non-backwashable fouling disappeared by washing with water and chemical compounds respectively [18]. In the state of irreversible fouling which cuase by three factors of clogging of the pores, chemical reactions and chemisorption, the fouling is not disappeared by washing by water and chemical compounds, therefor the membrane must displaced. Dissolve organic matters exist in the input feed is the main factor of this type of fouling [19].These maters is adsorbed to the membrane and changed its structure irreversibly. Generally, pores clogging, forming the gel layer on the membrane surface, adsorbtion and biological clogging were named as the main factors of the fouling [20].

3. Fouling Affected Parameters

Varius factors like material and membrane properties (eletrical charge exist in the membrane surface, membrane thickness, size of the pores), dissolved compounds and solvent characteristics (pH, ionic strength, particle eletrical charge), operational parameters (tempreture, transmembrane pressure), the hydrodynamic conditions of the process (feeding velocity and initial flow leakage) affect the membrane fouling [19, 21].

3.1. Membrane Charecteristic

Choosing the appropriate membrane to reduce the fouling rate is very important. In the filtration process, the first studing step is for surveying and understanding the varius membrane to choose the best membrane. Many experiment or teorical studies were done to identify a best membrane according to feed property, to reduce the fouling rate and increasing the performance of filtration process Mechanical strength, thermal stability and resistance versus disintegration by chemical compounds is related to structure and membrane property. Various types of common membrane with their property followed in Table 1 [3].

Table 1. Polymer and ceramic membranes feature [3]

	CA	PAN	PES	PS	PVDF	Ceramic
Mechanical strength	Good	Good	Good	Good	Good	Excellent
Thermal Limit (^{o}C)	30	40	80	75	40	High
pH	4–8	2–10	2–12	1–13	2–10.5	Superior
Oxidant tolerance	Moderate	Moderate	Good	Good	Excellent	Superior
Ultrasonic irradiation	Moderate	Moderate	Poor	Good	Good	Excellent

3.2. Molecular Weight Cut-off (MWCO) of the Membrane

Effluent flux rate in the membrane by high cut-off is more than membrane with low cut-off.Futhermore, in the membrane with high cut-off, reduction of the discharging flux from the membrane in a certain period has lower slope compared by the membrane with lower cut-off. This subject shows that fouling rate is more affected in the membrane with low cut-off [22].

3.3.Tempreture

Tempreture of the process has high effect on fouling rate and the flux rate of the leakage flow. In the base of Arrhenius equation the flux rate of the leakage flow increased by increasing tempreture. In the below equation A_p is the activation coefficient and E_p is activtion energy [23].

$$J=Ap.\exp(-Ep/RT) \quad (2)$$

By increasing tempreture, viscosity of the input feed decrease and its infiltration coefficient increase and also the membrane pores are expanded. Totally these factors caused the increase in the effluent flux from membrane and reduction in fouling rate [24]. In another hand, Van't Hoff equation shows that the osmotic pressure increased by increasing tempreture which with regard to Darcy equation, the rate of discharging flux reduced in the constant pressure condition [24, 25]. Also by excessive increase in temperature, infiltration coefficient increased more than ever and then pollutants disposal are reduced. For this porpuse, indicating the optimal tempreture is important for improving performance of the membrane process [26].

3.4. Trans-membrane Pressure

As regards, separating operation in the UF and MF membrane basically occurred by pressure driving force so with regard to Darcy equation, the flux rate increased by increasing pressure but concentration polarization and fouling occurred quickly afterward [27]. flow flux due to rapid clogging of the pores and compression of sediment or gel layer on the surface of the membrane is reduced within a few seconds and does not change with further increase of the pressure, therefore the effect of the increasing in pressure easily neutralize, so for this reason the effect of pressure increasing is temporary. Flux increasing is done by increasing the pressure to the specefic pressure named critical pressure and after that point, by increasing of the pressure, leakage flux remains constant [28].

3.5. Input Feed Velocity

Increasing in influent velocity caused turbulence and shear stress in the membrane and these factors cuased displacement of the parts of the gel layer that settled on membrane surface and quick transfer of the excreted compounds to the liquid mass and finnaly prevent the gel layer from getting thicker [23]. Increasing in influent velocity also caused reduction in turbidity and suspended particle in membrane effluent [27]. Simultaneously by increasing in feed influent velocity, trans-membrane pressure increases.If flow velocity on the membrane surface was zero, trans-membrane pressure reached its limit in far less time than high membrane surface velocity and therefore the maximum obstruction occur In high velocity, trans-membrane pressure increases with much milder slope and therefore in the longer time reached the critical pressure [25].

3.6. pH

The seperation operation using membrane process is mainly based on particle size (Assuming that particles have no eleterical charge) but the other factors that have significant effects on separation are the repulsive force between charged membrane surface and ionic particles and also repulsive force between distributed ionic particles [10]. The level of pH has important role on aggregating particles. In low pH level because of the deprotonation reduction of the acidic groups in macromolecule such as proteins and humic acids, the electrostatic repulsion forces between particles are decreases and due to the van der Waals attractive force between particles, colloidal particles are connected to each other and lumping together that consequently caused clogging of the membrane pores and also gel layer on the membrane surface will be extended [3].Connection of the colloidal materials can be justified based on the DLVO theory [28, 29]. Membrane electrical charge by affecting on the repulsion forces between membrane and ionic particles, is significantly affected the membrane performance such as amount of clogging and the amount of impermeable material reluption [13]. By increasing of the pH, minus electrical charge in membrane surface increases and if the large number of particles have negative charge, consequently electroestatic reluption force between minus electrical charge exist on the membrane surface and minus electrical charge exist in the effluent increases which reduces the adhesion of the gel layer on the membrane surface and this factor keep the flux in the high level and prevents membrane fouling [28].

3.7. Feed Concentration

Increase in the input feed concentration cause the accelerated increase in the thickness of the cake layer and the amount of fouling. In the condition that transmembrane pressure is fixed, increase in the feed concentration increases the osmotic pressure and therefore the membrane output flux reduces and the fouling rate increases [16, 25].

4. Conclusions

With regard to problems caused by the membrane fouling such as costs of operation, maintenance and costs related to washing the membrane, optimization of the operationg condition is necessary. So the main affecting factors accordingly choosen that mentioned below.

- By increase of the nominal molecular weight cut-off (MWC), trans-membrane flow (flux) increased.
- By increase in the operation tempreture, the flux rate increased.
- By increasing in the operation tempreture, the pollutants concentration in the effluent increased.

Therefor with regard to above mentioned choosing the best combination of these three factors is so important.

References

[1] Ghidossi R., Veyret D., Moulin P.,: Computational fluid dynamics applied to membranes: State of the art and opportunities, Chemical Engineering and Processing: Process Intensification, **45**, 437-454 (2006).

[2] Bauser H., Chmiel H., Stroh N., Walitza E.,: Control of concentration polarization and fouling of membranes in medical, food and biotechnical applications, Journal of Membrane Science, **27**, 195-202 (1986).

[3] Shi X., Tal G., Hankins N.P., Gitis V.,: Fouling and cleaning of ultrafiltration membranes: A review, in: Journal of Water Process Engineering, 121-138 (2014).

[4] Miller D.J., Kasemset S., Paul D.R., Freeman B.D.,: Comparison of membrane fouling at constant flux and constant transmembrane pressure conditions, Journal of Membrane Science, **454**, 505-515 (2014).

[5] Sablani S.S., Goosen M.F.A., Al-Belushi R., Wilf M.,: Concentration polarization in ultrafiltration and reverse osmosis: a critical review, Desalination, **141**, 269-289 (2001).

[6] Salahi A., Abbasi M., Mohammadi T.: Permeate flux decline during UF of oily wastewater: Experimental and modeling, Desalination, **251**, 153-160 (2010).

[7] Zare M., Zokaee Ashtiani F., Fouladitajar A.,: CFD modeling and simulation of concentration polarization in microfiltration of oil–water emulsions; Application of an Eulerian multiphase model, Desalination, **324**, 37-47 (2013).

[8] Ng C.Y., Mohammad A.W., Ng L.Y., Jahim J.M.,: Membrane fouling mechanisms during ultrafiltration of skimmed coconut milk, Journal of Food Engineering, **142,** 190-200 (2014).

[9] Gao Y., Wang Y. N., Li W., Tang C.Y.,: Characterization of internal and external concentration polarizations during forward osmosis processes, Desalination, **338**, 65-73 (2014).

[10] Boussu K., Belpaire A., Volodin A., Van Haesendonck C., Van der Meeren P., Vandecasteele C., Van der Bruggen B.,: Influence of membrane and colloid characteristics on fouling of nanofiltration membranes, Journal of Membrane Science, **289**, 220-230 (2007).

[11] James B.J., Jing Y., Dong Chen X.,: Membrane fouling during filtration of milk—a microstructural study, Journal of Food Engineering, **60**, 431-437 (2003).

[12] Peter-Varbanets M., Margot J., Traber J., Pronk W.: Mechanisms of membrane fouling during ultra-low pressure ultrafiltration, Journal of Membrane Science, **377**, 42-53 (2011).

[13] Ma C., Yu S., Shi W., Heijman S.G.J., Rietveld L.C.: Effect of different temperatures on performance and membrane fouling in high concentration PAC–MBR system treating micro-polluted surface water, Bioresource Technology, **141**, 19-24 (2013).

[14] Arévalo J., Ruiz L.M., Pérez J., Gómez M.A.,: Effect of temperature on membrane bioreactor performance working with high hydraulic and sludge retention time, Biochemical Engineering Journal, **88**, 42-49 (2014).

[15] Huang J., Liu L., Zeng G., Li X., Peng L., Li F., Jiang Y., Zhao Y., Huang X.,: Influence of feed concentration and transmembrane pressure on membrane fouling and effect of hydraulic flushing on the performance of ultrafiltration, Desalination, **335**, 1-8 (2014).

[16] Yazdanshenas M., Tabatabaee-Nezhad S.A.R., Soltanieh M., Roostaazad R., Khoshfetrat A.B.,: Contribution of fouling and gel polarization during ultrafiltration of raw apple juice at industrial scale, Desalination, **258,** 194-200 (2010).

[17] Matthiasson E., Sivik B.,: Concentration polarization and fouling, Desalination, **35**, 59-103 (1980).

[18] Rayess Y. El, Albasi C., Bacchin P., Taillandier P., Mietton-Peuchot M., Devatine A.,: Analysis of membrane fouling during cross-flow microfiltration of wine, Innovative Food Science & Emerging Technologies, **16**, 398-408 (2012).

[19] Guo W., Ngo H.-H., Li J.,: A mini-review on membrane fouling, Bioresource Technology, **122**, 27-34 (2012).

[20] Goosen M.F.A., Sablani S.S., Al-Hinai H., Al-Obeidani S., Al-Belushi R., Jackson D.: Fouling of Reverse Osmosis and Ultrafiltration Membranes: A Critical Review, Separation Science and Technology, **39**, 2261-2297 (2005).

[21] Al-Amoudi A., Lovitt R.W.,: Fouling strategies and the cleaning system of NF membranes and factors affecting cleaning efficiency, Journal of Membrane Science, **303**, 4-28 (2007).

[22] Grenier A., Meireles M., Aimar P., Carvin P.: Analysing flux decline in dead-end filtration, Chemical Engineering Research and Design, **86**, 1281-1293 (2008).

[23] Mohammadi T., Esmaeelifar A.,: Wastewater treatment of a vegetable oil factory by a hybrid ultrafiltration-activated carbon process, Journal of Membrane Science, **254**, 129-137 (2005).

[24] Mohammadi T., Esmaeelifar A.,: Wastewater treatment using ultrafiltration at a vegetable oil factory, Desalination, **166**, 329-337 (2004).

[25] Wang L., Wang X., Fukushi K.-i.: Effects of operational conditions on ultrafiltration membrane fouling, Desalination, **229**,181-191 (2008).

[26] Beril Gönder Z., Arayici S., Barlas H.,: Advanced treatment of pulp and paper mill wastewater by nanofiltration process: Effects of operating conditions on membrane fouling, Separation and Purification Technology, **76**, 292-302 (2011).

[27] Alpatova A., Kim E.-S., Dong S., Sun N., Chelme-Ayala P., Gamal El-Din M.,: Treatment of oil sands process-affected water with ceramic ultrafiltration membrane: Effects of operating conditions on membrane performance, Separation and Purification Technology, **122**, 170-182 (2014).

[28] Gönder Z.B., Arayici S., Barlas H.,: Treatment of Pulp and Paper Mill Wastewater Using Utrafiltration Process: Optimization of the Fouling and Rejections, Industrial & Engineering Chemistry Research, **51**, 6184-6195 (2012).

[29] Ma Z., Wang M., Gao X., Gao C.,: Charge and separation characteristics of nanofiltration membrane embracing dissociated functional groups, Frontiers of Environmental Science & Engineering, **8**, 650-658 (2014).