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Research paper

Effect of Polysulfone Content on Forward Osmosis Membrane Performance.

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Abstract

Desalination is the process to separate salt content from saline water. This study observes the effect of different polysulfone (psf) content on forward osmosis (FO) membrane towards its water flux and salt rejection performance. The loading percentages of psf used in the membrane are 15%, 15.5% and 16%. Theoretically, the higher the psf content, the lower the water flux passes through membrane. The membranes were prepared using interfacial polymerization technique and tested through reverse osmosis (RO) process and FO setup. From the reverse osmosis (RO) experiment, the results showed that the salt rejection of 15% psf, 15.5% psf, 16% psf, are 92.94%, 93.71%, 95.98% respectively. In the FO experiment, the water flux results recorded for 15% psf, 15.5% psf, 16% psf, content are 1.21 L/m2h, 0.43 L/m2h, 0.21 L/m2h, respectively. Based on these two parameters, it would seem that by increasing the psf content the salt rejection value had increased but the water flux had decreased accordingly. These trends may due to when the psf content was increased; the support layer became denser and less porous which would lead to a higher solute rejection and lower water flux through the membrane. In conclusion, increasing of psf content will give forward osmosis membrane with higher salt rejection but lower water flux.

Keywords: *Forward Osmosis Membrane; Salt Rejection; Polysulfone.*

1. Introduction

Water cover 70% of the earth and the rest 30% is land (Cara, 2014). Seawater has accounted for 58.9% of the global desalination source water with the fact that 97% of earth's water is in the ocean (L. Zhao & Ho, 2014). As the population growth increase, the needs of reliable clean water sources also increase. Based on the research by (S. Zhao, Zou, Tang, & Mulcahy, 2012), there are more than 1.2 billion people that have lack access to safe and clean drinking water in this world. It is because, the amount of water that is safe for drinking is only 0.8% and the rest 99.2% is consider non-potable water (S. Zhao et al., 2012). Ocean water does not considered as safe drinking water as it contain huge amount of salt (US Department of Commerce, n.d.). In order to increase percentage of potable water, Reverse Osmosis (RO) and Forward Osmosis (FO) method were used as both of the process has gained a significant research due to high potential of application in water desalination (Phuntsho, Hong, Elimelech, & Shon, 2014). RO and FO are an osmotically driven membrane process using thin film composite membrane (TFC) for water desalination (Choi et al., 2017). The membrane is fabricated using layered interfacial polymerization (LIP) to achieve high sodium chloride (NaCl) rejection for water desalination purpose (Choi et al., 2017).

Desalination is the process of removing salt from the water. Nowadays, it is a process that is considered as the most viable solution for providing fresh water to many areas around the globe (Blanco-Marigorta, Lozano-Medina, & Marcos, 2017). It also can contribute to the lowering the water treatment energy footprint (Blanco-Marigorta et al., 2017; Choi et al., 2017). Desalination can be categorized into two methods. The first method is by using thermal energy (thermodynamic) and the second method is by using osmotic pressure. In the osmosis pressure method, there are several known process that can be used to attain desalination operation, for examples RO and FO (Choi et al., 2017).

These days, RO is currently the most used method for water desalination and the process is using a thin film composite membrane (Choi et al., 2017). RO is basically a water purification technology that can remove ions and larger molecules using semipermeable membranes. It can be done by forcing water under pressure through a membrane. RO also has reach it rapid growth for desalination process because of the ability to produce desalinate water with a relatively low cost (Ali et al., 2017). The widely used RO membrane in current market is the polyamide (PA) TFC membrane most commonly synthesized via interfacial polymerization (IP) of m-phenylenediamine (MPD) and trimesoyl chloride (TMC) on nanoporous polysulfone (*psf*) (Lee, Arnot, & Mattia, 2011; Li & Wang, 2010; Pang & Zhang, 2018). The membrane that is used in RO has a dense layer of TFC membrane where only the water can passes through it and do not allow solute such as salt to pass through it. However, since the process required high pressure, RO is deemed as energy intensive operation. In contrast, forward osmosis is favorable as it only need low energy requirement (Le & Nunes, 2016). Thermodynamically, FO would be more energy needed than RO when recovery of draw solution needed. Therefore, FO process may find applications mainly in special areas where either RO is not suitable due to high salinity (Zhang et al., 2016)

FO is characterized by its low fouling tendency, easy operation, and low operational pressure as they used low hydraulic pressure (Darwish, Abdulrahim, Hassan, Mabrouk, & Sharif, 2014). Besides, FO also has high potential to help achieve high water flux and high water recovery due to the high osmotic pressure gradient across the membrane (S. Zhao et al., 2012). The driving force for the desalination for FO is an osmotic pressure gradient between solutions of high concentration (Mukherjee, 2015). In FO, spontaneous water permeation across a semi-permeable membrane occurs, which is driven by a chemical potential difference arising from concentrated draw solution and diluted feed solution (Wang, Goh, Li, Setiawan, & Wang, 2018).The solution with high amount of salt is called draw solution meanwhile the solution with lower concentration is called as feed solution (Ge, Ling, & Chung, 2013). Those two solution can act as the driving force for water permeation through the membrane. The important thing that is critical for high-salinity wastewater is the TFC of FO membranes must have a low degree of internal concentration polarization (ICP) (Chen et al., 2017). One of the way to reduce the ICP is to adjust the *psf* content in the membrane (Chen et al., 2017).

In this research, different amount *psf* content for the TFC membrane were used to observe the effect of various percentage of *psf* content to the water flux and salt rejection towards the semipermeable membrane. Based on the previous RO research, it is shown that *psf* content will effect water flux and salt rejection in the membrane. The higher the *psf* content, the lower the flux of water towards the membrane(Choi et al., 2017). Furthermore, the membrane with high *psf* content is denser and less porous that is why it can give high rejection of salt **.**The percentage of *psf* content that has been used to cast the membrane are 15%, 15.5% and 16%. The permeade selective layer of the TFC of *psf* membrane is designed to selectively reject salt while permitting water (Choi et al., 2017). PA was used as the LIP of the TFC membrane as it has the high ability in water permeability and salt rejection towards the membrane (Tang, Kwon, & Leckie, 2009).

2. Methodology

2.1 Materials

Polyvinylpyrrolidone (PVP), N-methyl-2-pyrrolidone (NMP), *psf* was used to prepare the dope solution. This dope solution will then casted into the membrane support layer. To create PA layer on top of the support layer, MPD-RO water solution will be applied together with TMC solution. To simulate the saline water condition, RO water with 2 Molar NaCl concentrations was prepared (Ding, Yin, & Deng, 2014).

2.2 Dope Preparation

Initially, PVP, NMP and PSF was weighted where PVP 0.5 wt%, NMP /83.5/84/84.5 wt% and *psf* 15/15.5/16 wt%. Then, PVP and NMP were mixed together in a 250ml container for each formulation. The mixture then was stirred for 30 minutes. Afterwards, the first half *psf* was poured and mixed for 20 minutes. After 20 minutes, the remaining *psf* was poured into the mixture and continued stirred. The solution was left to stir for 24 hours. Stirring the dope solutions for 24 hours at room temperature, then degassing under atmospheric pressure for 6 hours and dope solution obtained (L.-B. Zhao, Xu, Liu, & Wei, 2014)

2.3 Membrane Casting

Each dope solutions (15%, 15.5%, and 16 wt% psf) were poured on a glass plane and rolled downwards with a glass rod to cast the support layer. Then, the layer was soaked in a basin filled with tap water. The layer was left for over 24 hours.

2.4 Interfacial Polymerization

A solution of RO water and MPD and another solution containing with n-Hexane and TMC solution were prepared beforehand. Prior to proceeding with the polymerization process, the support layer was dried from any visible water droplet using a rubber roller. Afterward, the RO-MPD solution is poured followed by n-Hexane TMC solution. The membrane was dried in oven for 5 minutes before submerged in water bath for 24 hours (Lau & Ismail, 2011)

2.5 Forward Osmosis Experiment

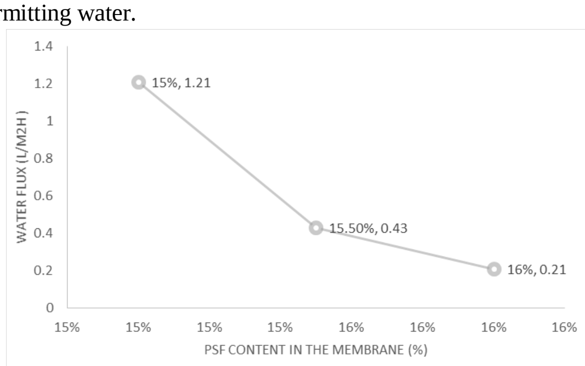
Before starting the experiment, saline solutions need to be prepared. NaCl solution was prepared in 2 Molar concentrations as draw solution whereas RO water was prepared for 1000ml as feed solution. The membrane was cut into a small rectangle shape and installed into the FO Unit. Then, pump was activated and FO unit process started. The reading at mass and conductivity was recorded every 30 minutes for about 1 hour 30 minutes. The process repeated using the other of 15.5 wt% psf and 16 wt% psf membranes.

2.6 Reverse Osmosis Experiment

After the 15 wt% psf membrane was cut into circle shaped, the membrane was installed at base part before RO water is filled into the RO unit. Then, pressure was set at the gas tank for 16 bar at first where the gas tank connected with the unit. After 30 minutes, the time taken was measured for producing 1ml solution and salt rejection value. These steps were repeated for other membrane samples. In RO membrane separation, high pressure is applied to feed solution on one side of the membrane so that water molecules pass through the membrane against osmotic pressure (Shen, Keten, & Lueptow, 2016)

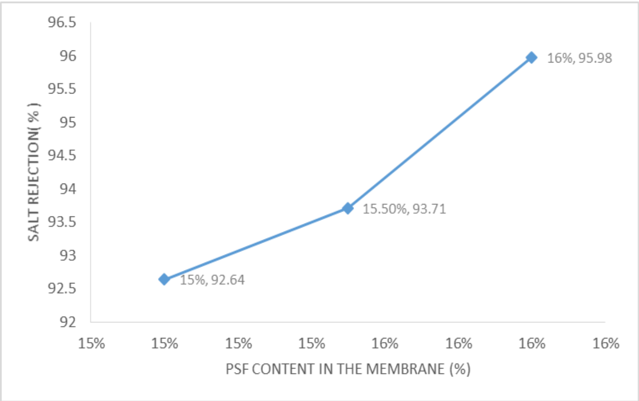
3. Results and discussion

The result and analysis below is related to the effect of different percentage of the *psf* content to the water flux and the salt rejection in the membrane. For FO, pilot scale FO experimental set-up was used to circulate the feed and draw solution by using low-pressure pump (Kim, Phuntsho, Ali, Choi, & Shon, 2018). As for RO testing, small scale of RO experimental unit was set up in the laboratory using high pressure, 16 bar compare to FO method that only used ambient pressure. Both method was used to analyse the effect of different *psf* loading in the membrane to reject salt while permitting water.



Graph 1: Percentage *psf* content in membrane against the value of water flux in L/m^2h

Based on the data shown on Graph 1, for 15% of *psf* content the value of the water flux is 1.21 L/m^2h and decrease to 0.43 L/m^2h when the *psf* content is increase by 0.5%. Following the pattern, the value of water flux continuously decrease to 0.21 L/m^2h at 16% of *psf* content in the membrane. The graph shows that the higher the percentage of *psf* content in the membrane, the lower the water flux in L/m^2h recorded. This may due to increasing of the *psf* content and the support layer became denser and less porous which would lead to a lower water flux through the membrane (Ding et al., 2014). It is because high percentage of *psf* causes less water to pass through as the membrane pore become lesser and it will be difficult for water to pass through.



Graph 2: Percentage *psf* content in membrane (%) against the value of salt rejection (%)

From the pattern shown in the graph 2, higher percentage of *psf* content in the membrane had caused increase in percentage of the salt rejection of the membrane. For 15% of *psf* content in the membrane, the percentage of salt rejection was 92.64% and increase to 93.71% when the *psf* content reach 15.5%. The highest salt rejection recorded was 95.98% by using the membrane that contained 16% of *psf* loading. From the pattern above it was shown that by using high percentage of *psf* content, the dope solution to cast the membranes will be more viscous. As a result, the pores of the membranes will be less and the salt rejection will be high as the routes for the water to pass through the membrane decrease (Aryanti, Noviyani, Kurnia, Rahayu, & Nisa, 2018; Ding et al., 2014).

The result collected is consistent with previous research by (Choi et al., 2017) which show that the higher *psf* content result in high percentage of salt rejection. This is due to the content of *psf* affect the dope viscosity and less pore will be produced. The lesser the pore produce in the membrane, the higher the salt rejection and the lower the water permeability will be (Ding et al., 2014).

Psf as a material for polymer membranes has gained considerable importance throughout the past decades due to its out-standing properties, such as the acceptance of a wide pH range and organic media, as well as very good thermal and mechanical stability (Hoffmann, Silau, Pinelo, Woodley, & Daugaard, 2018). As a suggestion to find the best desalination membrane, using wide range of *psf* content is recommended. It is recommended as the different percentage of *psf* do have its capability to reject salt and to permeate water. Using different percentage of *psf* content also can affect the viscosity of the dope solution and porosity of the membrane as well as its membranes performance for desalination process. Based on this research, it is shown that the higher the percentage of *psf*, the lower the water flux and the higher the salt rejection would be. Next, it is also recommended to use different hydrophilic material to identify the effectiveness of the membranes to reject salt and to permeate water. Different hydrophilic material have its own speciality that can affect the membrane performance. Aside from that, the addition of nanomaterial in the *psf* based substrate also has potential to increase the hydrophilicity of the membrane (Sirinupong et al., 2017).

4. Conclusion

In this study, TFC membranes were prepared using various percentage of *psf* content. Based from the study, increase of *psf* content will reduced the water flux but at the same time, it will increase the salt rejection. It is because of the *psf* concentration effect the viscosity of the dope solution as well as its porosity of the TFC membrane (Ding et al., 2014). The water permeability of TFC membranes decreased with increasing *psf* concentration because of low porous support layer structure (Ding et al., 2014). To conclude, high *psf* content will reduced the viscosity of the dope solution which will then concise the membrane structure to have less pore that would lead to a higher solute rejection and lower water flux through the membrane.

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Appendix

A.1. *For Reverse Osmosis (RO).*

Psf 15%

	Time Taken in Producing 1ml	Conductivity (µS)
Water RO	8 minutes 30 seconds	2206.4
Salt Flux	12 minutes	215.6

Psf 15.5%

	Time Taken in Producing 1ml	Conductivity(µS)
Water RO	6 minutes 15 seconds	3990
Salt Flux	8 minutes	251

Psf 16%

	Time Taken in Producing 1ml	Conductivity(µS)
Water RO	4 minutes 40 seconds	4000
Salt Flux	3 minutes	161.0

A.2. *For Forward Osmosis (FO)*

Psf 15%

Time interval (minutes)	Mass (g)	Conductivity (µS)
30	1979.6	48
30	1982.5	97.6
30	1984.7	139.7

Psf 15.5%

Time interval (minutes)	Mass (g)	Conductivity (µS)
30	2387.2	19.4
30	2388.0	22.8
30	2389.0	26.2

Psf 16%

Time interval (minutes)	Mass (g)	Conductivity (µS)
30	2449.8	17.3
30	2450.2	20.5
30	2450.7	24.0

A.3. Calculation of water flux and the salt rejection.

To calculate the water flux, this formula is applied:

$$J_v = \frac{\Delta V}{A_m.\Delta t} = \frac{\Delta m_{draw}}{A_m.\Delta t.\rho_{H_2O}}$$

To calculate the salt rejection, this formula is used:

$$R = \left(1 - \frac{C_p}{C_f}\right) \times 100$$

Table 1: Data related to percentage of the salt rejection.

Percentage *Psf* (%)	Percentage Salt Rejection (%)
15	92.64
15.5	93.71
16	95.98

Table 2: Data related to value of water flux.

Percentage *Psf* (%)	Value of Water Flux (L/m^2h)
15	1.21
15.5	0.43
16	0.21

References

[1] Ali, E. S., Alsaman, A. S., Harby, K., Askalany, A. A., Diab, M. R., & Ebrahim Yakoot, S. M. (2017). Recycling brine water of reverse osmosis desalination employing adsorption desalination: A theoretical simulation. Desalination, 408, 13–24. https://doi.org/10.1016/J.DESAL.2016.12.002

[2] Aryanti, P. T. P., Noviyani, A. M., Kurnia, M. F., Rahayu, D. A., & Nisa, A. Z. (2018). Modified Polysulfone Ultrafiltration Membrane for Humic Acid Removal During Peat Water Treatment. IOP Conference Series: Materials Science and Engineering, 288(1), 012118. https://doi.org/10.1088/1757-899X/288/1/012118

[3] Blanco-Marigorta, A. M., Lozano-Medina, A., & Marcos, J. D. (2017). A critical review of definitions for exergetic efficiency in reverse osmosis desalination plants. Energy, 137, 752–760. https://doi.org/10.1016/J.ENERGY.2017.05.136

[4] Cara, K. (2014). What percent of the earth is land and how much is water? | eNotes. Retrieved May 28, 2018, from https://www.enotes.com/homework-help/how-much-percent-earth-land-how-much-water-46469

[5] Chen, G., Liu, R., Shon, H. K., Wang, Y., Song, J., Li, X.-M., & He, T. (2017). Open porous hydrophilic supported thin-film composite forward osmosis membrane via co-casting for treatment of high-salinity wastewater. Desalination, 405, 76–84. https://doi.org/10.1016/J.DESAL.2016.12.004

[6] Choi, W., Jeon, S., Kwon, S. J., Park, H., Park, Y.-I., Nam, S.-E., … Lee, J.-H. (2017). Thin film composite reverse osmosis membranes prepared via layered interfacial polymerization. Journal of Membrane Science, 527, 121–128. https://doi.org/10.1016/J.MEMSCI.2016.12.066

[7] Darwish, M. A., Abdulrahim, H. K., Hassan, A. S., Mabrouk, A. A., & Sharif, A. O. (2014). The forward osmosis and desalination. Desalination and Water Treatment, 1–27. https://doi.org/10.1080/19443994.2014.995140

[8] Ding, C., Yin, J., & Deng, B. (2014). Effects of Polysulfone (PSf) Support Layer on the Performance of Thin-Film Composite (TFC) Membranes. J Chem Proc Eng, 1(1), 1–8. Retrieved from http://www.jscholaronline.org/articles/JCPE/Effects-of-Polysulfone-(PSf)-Support-Layer-on-the-Performance.pdf

[9] Ge, Q., Ling, M., & Chung, T.-S. (2013). Draw solutions for forward osmosis processes: Developments, challenges, and prospects for the future. Journal of Membrane Science, 442, 225–237. https://doi.org/10.1016/j.memsci.2013.03.046

[10] Hoffmann, C., Silau, H., Pinelo, M., Woodley, J. M., & Daugaard, A. E. (2018). Surface modification of polysulfone membranes applied for a membrane reactor with immobilized alcohol dehydrogenase. Materials Today Communications, 14, 160–168. https://doi.org/10.1016/J.MTCOMM.2017.12.019

[11] Kim, J. E., Phuntsho, S., Ali, S. M., Choi, J. Y., & Shon, H. K. (2018). Forward osmosis membrane modular configurations for osmotic dilution of seawater by forward osmosis and reverse osmosis hybrid system. Water Research, 128, 183–192. https://doi.org/10.1016/j.watres.2017.10.042

[12] Lau, W. J., & Ismail, A. F. (2011). Progress in Interfacial Polymerization Technique on Composite Membrane Preparation. 2nd International Conference on Environmental Engineering and Applications International Proceedings of Chemical, Biological and Environmental Engineering, 17, 173–177. Retrieved from https://pdfs.semanticscholar.org/7978/39ff57198d0a6a49792d70039d64 56d648a1.pdf

[13] Le, N. L., & Nunes, S. P. (2016). Materials and membrane technologies for water and energy sustainability. Sustainable Materials and Technologies, 7, 1–28. https://doi.org/10.1016/J.SUSMAT.2016.02.001

[14] Lee, K. P., Arnot, T. C., & Mattia, D. (2011). A review of reverse osmosis membrane materials for desalination—Development to date and future potential. Journal of Membrane Science, 370(1–2), 1–22. https://doi.org/10.1016/j.memsci.2010.12.036

[15] Li, D., & Wang, H. (2010). Recent developments in reverse osmosis desalination membranes. Journal of Materials Chemistry, 20(22), 4551. https://doi.org/10.1039/b924553g

[16] Mukherjee, N. (2015). Forward Osmosis: An overview | Nikhilesh Mukherjee | Pulse | LinkedIn. Forward Osmosis : An Overview. Retrieved from https://www.linkedin.com/pulse/forward-osmosis-overview-nikhilesh-mukherjee

[17] Pang, R., & Zhang, K. (2018). Fabrication of hydrophobic fluorinated silica-polyamide thin film nanocomposite reverse osmosis membranes with dramatically improved salt rejection. Journal of Colloid and Interface Science, 510, 127–132. https://doi.org/10.1016/J.JCIS.2017.09.062

[18] Phuntsho, S., Hong, S., Elimelech, M., & Shon, H. K. (2014). Osmotic equilibrium in the forward osmosis process: Modelling, experiments and implications for process performance. Journal of Membrane Science, 453, 240–252. https://doi.org/10.1016/J.MEMSCI.2013.11.009

[19] Shen, M., Keten, S., & Lueptow, R. M. (2016). Rejection mechanisms for contaminants in polyamide reverse osmosis membranes. Journal of Membrane Science, 509, 36–47. https://doi.org/10.1016/j.memsci.2016.02.043

[20] Sirinupong, T., Youravong, W., Tirawat, D., Lau, W. J., Lai, G. S., & Ismail, A. F. (2017). Synthesis and characterization of thin film composite membranes made of PSF-TiO2/GO nanocomposite substrate for forward osmosis applications. Arabian Journal of Chemistry. https://doi.org/10.1016/J.ARABJC.2017.05.006

[21] Tang, C. Y., Kwon, Y.-N., & Leckie, J. O. (2009). Effect of membrane chemistry and coating layer on physiochemical properties of thin film composite polyamide RO and NF membranes: II. Membrane physiochemical properties and their dependence on polyamide and coating layers. Desalination, 242(1–3), 168–182. https://doi.org/10.1016/J.DESAL.2008.04.004

[22] US Department of Commerce, N. O. and A. A. (n.d.). Can humans drink seawater? Retrieved from https://oceanservice.noaa.gov/facts/drinksw.html

[23] Wang, Y.-N., Goh, K., Li, X., Setiawan, L., & Wang, R. (2018). Membranes and processes for forward osmosis-based desalination: Recent advances and future prospects. Desalination, 434, 81–99. https://doi.org/10.1016/J.DESAL.2017.10.028

[24] Zhang, M., Liu, R., Wang, Z., Zhao, B., Song, J., Park, M. J., … He, T. (2016). Dehydration of forward osmosis membranes in treating high salinity wastewaters: Performance and implications. Journal of Membrane Science, 498, 365–373. https://doi.org/10.1016/J.MEMSCI.2015.10.013

[25] Zhao, L.-B., Xu, Z.-L., Liu, M., & Wei, Y.-M. (2014). Preparation and characterization of PSf hollow fiber membrane from PSf–HBPE–PEG400–NMP dope solution. Journal of Membrane Science, 454, 184–192. https://doi.org/10.1016/J.MEMSCI.2013.11.057

[26] Zhao, L., & Ho, W. S. W. (2014). Novel reverse osmosis membranes incorporated with a hydrophilic additive for seawater desalination. Journal of Membrane Science, 455, 44–54. https://doi.org/10.1016/J.MEMSCI.2013.12.066

[27] Zhao, S., Zou, L., Tang, C. Y., & Mulcahy, D. (2012). Recent developments in forward osmosis: Opportunities and challenges. Journal of Membrane Science, 396, 1–21. https://doi.org/10.1016/J.MEMSCI.2011.12.023