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Article · July 2016

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Journal of Engineering Science and Technology
Vol. 11, No. 7 (2016) 1031 - 1040

EFFECTS OF PRESSURE AND TEMPERATURE ON ULTRAFILTRATION HOLLOW FIBER MEMBRANE IN MOBILE WATER TREATMENT SYSTEM

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Abstract

In Sabah, Malaysia, there are still high probability of limited clean water access in rural area and disaster site. Few villages had been affected in Pitas due to improper road access, thus building a water treatment plant there might not be feasible. Recently, Kundasang area had been affected by earthquake that caused water disruption to its people due to the damage in the underground pipes and water tanks. It has been known that membrane technology brought ease in making mobile water treatment system that can be transported to rural or disaster area. In this study, hollow fiber membrane used in a mobile water treatment system due to compact and ease setup. Hollow fiber membrane was fabricated into small module at 15 and 30 fibers to suit the mobile water treatment system for potable water production of at least 80 L/day per operation. The effects of transmembrane pressure (TMP) and feed water temperature were investigated. It was found that permeate flux increases by more than 96% for both 15 and 30 fiber bundles with increasing pressure in the range of 0.25 to 3.0 bar but dropped when the pressure reached maximum. Lower temperature of 17 to 18˚C increase the water viscosity by 15% from normal temperature of water at 24˚C, making the permeate flux decreases. The fabricated modules effectively removed 96% turbidity of the surface water sample tested.

Keywords: Surface water, Hollow fiber, Membrane, Ultrafiltration, Pressure.

1. Introduction

Access to clean water sources has been limited in rural area and disaster sites. In rural area, limited soil ground might unable a water treatment plant to be build. In addition to that, conventional water treatment system are not suitable and economical for application in rural areas [1]. Furthermore, rural area such as Pitas, Sabah has no proper roadway in and out. Therefore, providing clean water via modular water truck is costly, if not difficult.

Fortunately, water treatment system can be compacted into a smaller size unit. In Bangladesh, a team of researchers developed water treatment unit coupled with bicycle pumping system to provide clean water supply from tube well [2]. There are others in different forms too [3-4]. Innovation of compact water treatment system with mobility as shown by [4] brings the water treatment to another level of convenience where such system can be easily brought to any natural water source i.e. river and lake while being able to provide clean water to a group of people. Interestingly, most of these innovations are utilising membrane as the main filter media to treat water. This is due to its effectiveness and easy to use feature.

As water treatment filter media, membrane has shown potential in treating surface water, groundwater as well as seawater. With highest packing density, ease of backwashing, and compact design [5-6], hollow fiber membrane is a good choice for mobile water treatment system. Hollow fiber has becoming favourite choice amongst membrane configuration due to its large membrane per module unit volume, which yield in higher productivity [7-9]. These researchers also added that such advantage results in hollow fiber to be self-supporting mechanically which leads to good flexibility together with easy handling during fabrication and operation.

Application of appropriate operating parameters plays critical role in membrane processes [10-12] where operating parameters such as pressure and temperature influence the changes in membrane permeate flux throughout the operation [12-13]. Wang et al. [10] added that polymeric membrane tend to react to any changes in temperature as it can be more sensitive to temperature while Wu et al. [14] found that retention of contaminants in feed water decreased with pressure increment. Hence, knowing the effect of operating conditions could also help in reducing effect of fouling in a membrane water treatment system [15].

The objective of this study is to design and developed an ultrafiltration hollow fiber (UF-HF) membrane module for application in a mobile water treatment system. Packing density is a predominant parameter of membrane module design [16] and as mentioned earlier, hollow fiber is well-known for its high packing density. Nevertheless, Günther et al. [17] reported that hollow fiber module with high packing density has disadvantages where mass transfer and permeate flow in the module can become limited. Thus, this study aimed to develop membrane module with moderately lower packing density.

Mobile water treatment system in the scope of this study is defined as a transportable with ease to deploy, stand alone, low cost and easy to use by its user. To accommodate such application, the UF-HF membrane module was designed in small-scaled consisted of maximum 30 fibers per bundle. The paper investigates the effects of transmembrane pressure (TMP) and feed water temperature (FWT) on the UF-HF membrane permeate flux performance for application in surface water treatment.

2. Materials and Methods

The following subsections will provide the details of the characterization methods used to determine surface water characteristics as well as procedures employed to prepare hollow fiber module for water filtration experiments under two different variables, i.e., transmembrane pressure (TMP) and feed water temperature (FWT).

2.1. Feed water

Synthetic feed water was prepared by diluting 16L of actual surface water obtained from lake in Faculty of Science and Natural Resources, Universiti Malaysia Sabah (GPS coordinate 6.031232, 116.121209). The feed water turbidity was measured by using HACH 2100AN Turbidimeter and found to be in the range of 14 to 15 NTU. A portable measuring device (HANNA HI 9811-5) was used to monitor the feed water temperature throughout the experiments.

2.2. Hollow fiber membrane module

The hollow fiber membrane was obtained commercially (country of origin: China) with specifications given by the supplier as shown in Table 1. Two bundles of 15 and 30 fiber of hollow fiber membrane were introduced into PVC tube of 1.5 cm diameter and 30 cm length. Both sides of modules were potted using epoxy resin with one closed end and one opened end. The modules were developed in a cross-flow mode configuration as shown in Fig. 1. The effective areas for both modules in correspondence to the number of fibers per bundle were as calculated as 0.0153 m^2 and 0.0305 m^2 for 15 and 30 fibers per bundle, respectively.

Table 1. Properties of hollow fiber membrane module obtained from commercial 10-inch hollow fiber ultrafiltration filter.

Material	Polyvinylidene fluoride (PVDF)
Fiber diameter (O.D/I.D)	1.35 mm/0.7 mm
Nominal MWCO	120 kDa
Filtration mode	Outside-in
Operating temperature	5 to 40^{o}C
Operating pressure	0.2 to 1.5 bar

2.3. Water filtration experimental setup

The UF-HF membrane module was then incorporated into a custom made laboratory scale membrane testing rig as illustrated in Fig. 2, one module at a time. Before the experiments were started with synthetic feed water, pure water permeation (PWP) procedure was conducted for both of the module to determine the initial membrane resistance, R_m.

Feed water is pumped from feed water tank with the booster pump (KEMFLO Booster Pump) at constant feed flow rate of 1 L/min. Permeate water was collected at the permeate tank and measured on a mass balance (Mettler Toledo PB3002-S) within a constant filtration run time. Throughout the filtration run, transmembrane pressure (TMP) was monitored using a pressure gauge (YN-40ZT).

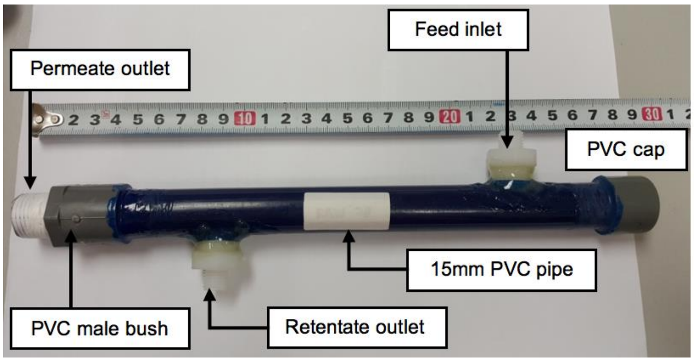

Fig. 1. UF-HF membrane module developed in this study.

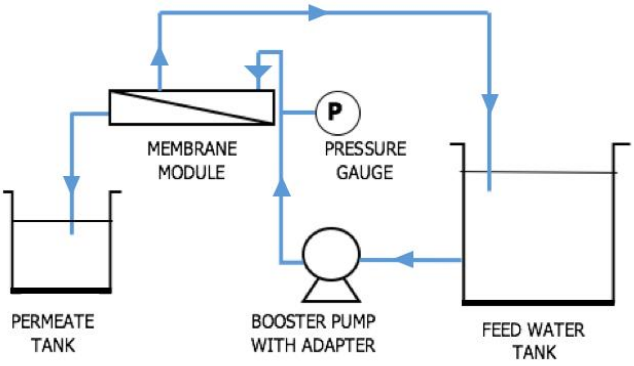

Fig. 2. Schematic diagram of water filtration system.

2.4. Performance analysis of membrane water treatment system

Membrane permeate flux has been used to characterise the productivity of membrane filtration system [18]. It can also be referred to as the membrane permeability. It has been used in previous studies as membrane operational performance indicator [15, 19-21].

The permeate flux, J can be calculated by using Darcy-Weisbach and Hagen-Poiseulle equations as follows:

$$J = \frac{Q_p}{A_m} \quad (1)$$

$$J = \frac{\Delta P}{(\mu \times R_t)} \quad (2)$$

where Q_p is the permeate flow rate (L/h), A_m is the effective area of membrane bundle (m^2), ΔP is the transmembrane pressure (bar), μ is dynamic water viscosity ($N.s/m^2$) and R_t is the total resistance (m^{-1}).

3. Results and Discussion

From the PWP procedure conducted, the initial membrane resistance determined were 2.47×10^{13} m^{-1} and 1.84×10^{13} m^{-1} for 15 and 30 fibers bundle (f.b), respectively. It was also calculated that the packing densities for both modules were 12.15% (15 f.b) and 24.31% (30 f.b). The membrane permeates flux in correspondence to varying TMP and FWT is shown in Figs. 3 and 4.

From Fig. 3, permeate fluxes for both modules increase linearly with TMP. The optimum TMP for both modules was obtained at range of 2.8 to 3.2 bar. Module with 15 fiber bundle (f.b) recorded permeate flux of 100 to 120 L/m^2h while the flux doubled for 30 f.b with 180 to 200 L/m^2h. These ranges of permeate flux obtained are in accordance with other work [22]. The difference in values shown that number of fiber influenced the membrane permeation flux.

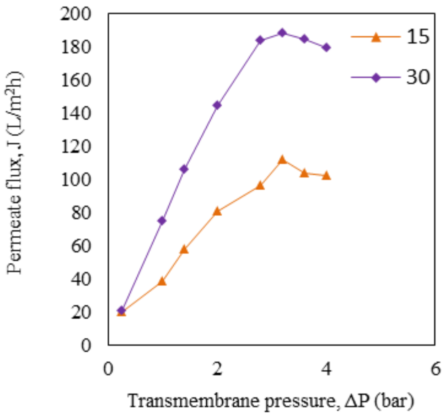

Fig. 3. Effect of TMP on UF-HF membrane permeate flux.

The permeation by both UF-HF modules obeyed the Darcy’s Law [23-24] where this linear relationship shown that permeate flux is dependent solely on membrane resistance under such low pressure (0 to 2 bar). When TMP reached approximately 3.4 bar, the permeate fluxes started to decline. These declinations indicated that the limit of Darcy’s Law has been surpassed where membrane resistance no longer affects the permeation fluxes. Since the manufacturer has suggested maximum operating TMP of 1.5 bar (Table 1), TMP of 3.0 bar and above is considered high for the hollow fiber membrane used. Thus, it is highly possible that the permeate flux decreases due to densification of membrane [25] as well as compaction of deposit layer on the membrane surface [26-27].

Furthermore, declination of permeate flux after TMP reached 3.4 bar could be caused by few other factors such as mass transfer condition at the fiber lumen and hydrophobic nature of the membrane material [28-29]. The latter factor then leads to concentration polarisation due to absorption of particles other than water. As occurrence of concentration polarization increased, water permeability into the membrane reduces due to additional resistance at the membrane surface [28, 30].

It is clear from Fig. 3 that while TMP drives the clean water particles into the membrane, number of fiber also influenced the permeate flux. Module with 30 f.b has 96% higher permeate flux compared to 15 f.b. Within and outside of the Darcy’s law region, the more fiber in a bundle, the higher is the permeate flux obtained for the same range of TMP. This shown that number of fiber in a bundle facilitates the rate of permeation.

For FWT effect, the results obtained in Fig. 4 revealed that permeation flux reduces with decreasing temperature. This is supported by [31] where it was found that regardless of the feed water quality, increased temperature increases the permeate flux. In this study, permeate flux of 30 f.b dropped significantly by 19.2% for feed water temperature drop from 30 to 18˚C. Compared to that, module with 15 f.b dropped rather steadily with only 6.6% changes within the same temperature range.

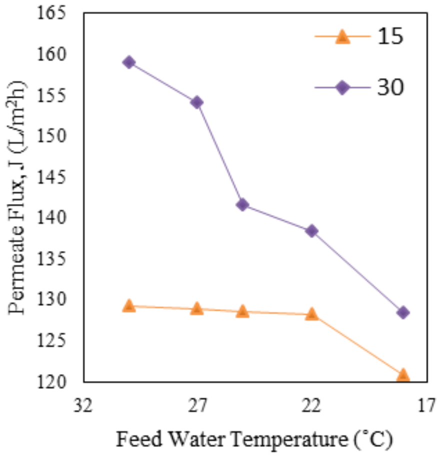

Fig. 4. Effect of FWT on UF-HF membrane permeate flux.

It is worth to note that PVDF UF membrane is a thermally stable [32]. Hence, the membrane properties have less or no influence on the permeate flux in this work. This is confirmed again in this study where there was almost no difference for permeation at 22˚C and 25˚C for 15 f.b module.

The dropping effect could be attributed to the momentum and energy of water which reduces as temperature drops due to velocity of water molecule Brownian motion [33], thus reducing its ability to pass through the membrane layer. Even so, high temperature does not necessarily increase the permeation flux because low mass transfer coefficient could cause higher possibility of fouling occurrence [34]. Therefore, it is found that even though the membrane is thermally-stable, the feed water temperature still affected the permeate flux.

The quality of treated (permeate) water is shown in Fig. 5 as compared to its initial quality in terms of turbidity. From these comparisons, it can be said that the fabricated UF-HF membrane modules with both 15 and 30 fiber per bundle were able to perform well with turbidity removal of 96.5 ± 0.3%.

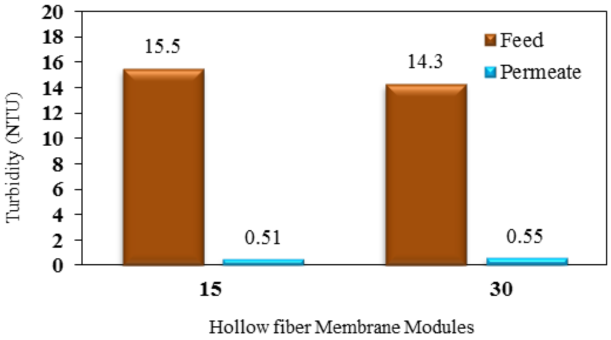

Fig. 5. Quality of feed and permeate water filtered using the fabricated UF-HF modules.

4. Conclusions

The influence of pressure and temperature in operating the custom made small-scale ultrafiltration hollow fiber (UF-HF) membrane modules were successfully evaluated. This work concluded that;

- The permeation fluxes by both 15 and 30 fiber bundles were dependent on the membrane resistance until the transmembrane pressure reached 3.4 bar.
- It was found that the optimum transmembrane pressure for the modules is 2.8 to 3.2 bar that produced permeate flux at range of100 to 120 L/m^{2}h for 15 fiber bundle and 180 to 200 L/m^{2}h for 30 fiber bundle. This range of permeate flux obtained were within the range recommended for membrane process in water treatment system.
- The effect of feed water temperature was also studied. Lower temperature of 18 to 22˚C reduces the permeation flux.
- The ultrafiltration hollow fiber membrane modules were able to produce permeate at higher temperature of 27 to 30˚C due to the thermal stability property of polyvinyl difluoride (PVDF) as its material.
- The fabricated UF-HF membrane modules were able to remove up to 96% of turbidity from the feed water.

Acknowledgements

The authors would like to acknowledge the financial support from of the Ministry of Higher Education (MOHE) and Universiti Malaysia Sabah Research Grant Scheme (SGPUMS) Grant No. SBK0003-TK-2012.

References

1. Nor, N.M.; and Ismail, S. (2015). Ultrafiltration membrane fouling and cleaning: A case study in Hutan Lipur Perangin Sik, Kedah. *Journal of Engineering Science and Technology*, 10 (Special Issue on SOMCHE 2014 & RSCE 2014 Conference), 1-13.

2. Oh, J.I.; Yamamoto, K.; Kitawaki, H.; Nakao, S.; Sugawara, T.; Rahman M.M.; and Rahman, M.H. (2000). Application of low-pressure nanofiltration coupled with a bicycle pump for the treatment of arsenic-contaminated groundwater. *Desalination*,132, 307-314.
3. Groendijk, L.; and de Vries, H.E. (2009). Development of a mobile water maker, a sustainable way to produce safe drinking water in developing countries. *Desalination*, 248, 106-113.
4. Barbot, E.; Carretier, E.; Wyart, Y.; Marrot, B.; and Moulin, P. (2009). Transportable membrane process to produce drinking water. *Desalination*, 248, 58-63.
5. Thakur, B.K.; and De, S. (2012). A novel method for spinning hollow fiber membrane and its application for treatment of turbid water. *Separation and Purification Technology*, 93, 67-74.
6. Childress, A.E.; Le-Clech, P.; Daugherty, J.L.; Chen, C.; and Leslie, G.L. (2005). Mechanical analysis of hollow fiber membrane integrity in water reuse applications. *Desalination*, 180, 5-14.
7. Yeh H.M.; Wu H.P.; and Dong J.F. (2003). Effects of design and operating parameters on the declination of permeate flux for membrane ultrafiltration along hollow-fiber modules. *Journal of Membrane Science*, 213, 33-44.
8. Sijun, Z.; Branford-white, C.; Limin, Z.; Chunju, H.; and Qingrui, W. (2009). Preparation, characterization and performance of phenolphthalein polyethersulfone ultrafiltration hollow fiber membranes. *Desalination and Water Treatment*, 1, 201-207.
9. Bolong, N.; Ismail, A.F.; Salim, M.R.; Rana, D.; Matsuura, T.; and Tabe-Mohammadi, A. (2010). Negatively charged polyethersulfone hollow fiber nanofiltration membrane for the removal of bisphenol A from wastewater. *Separation and Purification Technology*, 73(2), 92-9.
10. Wang, Z.; Yao, J.; Zhou, C.; and Chu, J. (2007). The influence of various operating conditions on the permeation flux during dead-end microfiltration. *Desalination*, 212, 209-18.
11. Ye, Y.; Sim, L.N.; Herulah, B.; Chen, V.; and Fane A.G. (2010). Effects of operating conditions on submerged hollow fibre membrane systems used as pre-treatment for seawater reverse osmosis. *Journal of Membrane Science*, 365, 78-88.
12. Mah, K.H.; Yussof, H.W.; Seman, M.N.A.; Jalanni, N.A.; and Zainol, N. (2015). Study on factors affecting separation of xylose from glucose by nanofiltration using composite membrane developed from triethanolamine (TEOA) and trimesoyl chloride (TMC). *Journal of Engineering Science and Technology*, 10 (Special Issue on SOMCHE 2014 & RSCE 2014 Conference), 92-100.
13. Benito, J.M.; Ebel, S.; Gutiérrez, B.; Pazos, C.; and Coca, J. (2001). Ultrafiltration of a waste emulsified cutting oil using organic membranes. *Water, Air, & Soil Pollution*, 128(1-2), 181-195.
14. Wu, H.; Niu, X.; Yang, J.; Wang, C.; and Lu, M. (2016). Retentions of bisphenol A and norfloxacin by three different ultrafiltration membranes in regard to drinking water treatment. *Chemical Engineering Journal*, 294, 410-416.

15. Miller, D.J.; Paul, D.R.; and Freeman, B.D. (2013). A crossflow filtration system for constant permeate flux membrane fouling characterization. *Review of Scientific Instruments*, 84(3), 1-11.
16. Bogati, R.C. (2014). *Membrane Fouling and Its Control in Drinking Water Membrane Filtration Process*. M.Sc. Thesis. Department of Environmental Engineering, Lakehead University, Canada.
17. Günther, J.; Hobbs, D.; Albasi, C.; Lafforgue, C.; Cockx, A.; and Schmitz, P. (2012). Modeling the effect of packing density on filtration performances in hollow fiber microfiltration module: A spatial study of cake growth. *Journal of Membrane Science*, 389, 126-36.
18. Shammas, N.K.; and Wang, L.K. (2011). *Membrane Systems Planning and Design*. Handbook of Environmental Engineering, Membrane and Desalination Technologies, Springer.
19. Chu, K.H.; Yoo, S.S.; Ahn, J.Y.; Jo, J.S.; and Ko, K.B. (2014). Determining flux behavior via a modified flux-step method for surface water treatment: Pilot-scale ultrafiltration membrane operation. *Desalination*, 341, 19-26.
20. Guerra, K.; Pellegrino, J.; and Drewes, J.E. (2012). Impact of operating conditions on permeate flux and process economics for cross flow ceramic membrane ultrafiltration of surface water. *Separation and Purification Technology*, 87, 47-53.
21. Lipp, P.; Witte, M.; Baldauf, G.; and Povorov, A.A. (2005). Treatment of reservoir water with a backwashable MF/UF spiral wound membrane. *Desalination*, 179, 83-94.
22. Howe, K.J.; Hand, D.W.; Crittenden, J.C.; Trussell, R.R.; and Tchobanoglous, G. (2012). *Principles of Water Treatment*. John Wiley & Sons, Inc.
23. Park, G.L.; Schäfer, A.I.; and Richards, B.S. (2011). Renewable energy powered membrane technology: The effect of wind speed fluctuations on the performance of a wind-powered membrane system for brackish water desalination. *Journal of Membrane Science*, 370, 34-44.
24. Xia, S.; Li, X.; Liu, R.; and Li, G. (2004). Study of reservoir water treatment by ultrafiltration for drinking water production. *Desalination*, 167, 23-6.
25. Kitpati, S. (2001) *Pilot scale experimental investigation of membrane filtration for water and watewater reuse*. Asian Institute of Technology.
26. Guo, X.; Zhang, Z.; Fang, L.; and Su, L. (2009). Study on ultrafiltration for surface water by a polyvinylchloride hollow fiber membrane. *Desalination*, 238, 183-91.
27. Steinhauer, T.; Lonfat, J.; Hager, I.; Gebhardt, R.; and Kulozik, U. (2015). Effect of pH, transmembrane pressure and whey proteins on the properties of casein micelle deposit layers. *Journal of Membrane Science*, 493, 452-9.
28. Baker, R.W. (2004). *Membrane Technology and Applications*. 2nd edition. John Wiley & Sons, Inc.
29. Peter-Varbanets, M.; Margot, J.; Traber, J.; and Pronk, W. (2011) Mechanisms of membrane fouling during ultra-low pressure ultrafiltration. *Journal of Membrane Science*, 377, 42-53.

30. Nguyen, H.T,T.; and Nithyanandam, R. (2016. Fractionation of hydrolyzed microcrystalline cellulose by ultrafiltration membrane. *Journal of Engineering Science and Technology*, 11(1), 136-148.
31. Xu, J.; Singh, Y.B.; Amy, G.L.; and Ghaffour, N. (2016). Effect of operating parameters and membrane characteristics on air gap membrane distillation performance for the treatment of highly saline water. *Journal of Membrane Science*, 512, 73-82.
32. Praneeth, K.; Bhargava Suresh, K.; James, T.; and Sridhar, S. (2014). Design of novel ultrafiltration systems based on robust polyphenylsulfone hollow fiber membranes for treatment of contaminated surface water. *Chemical Engineering Journal*, 248, 297-306.
33. Shengji, X.; Xing, L.; Ji, Y.; Bingzhi, D.; and Juanjuan, Y. (2008). Application of membrane techniques to produce drinking water in China. *Desalination*, 222, 497-501.
34. Benítez, F.J.; Acero, J.L.; Leal, A.I.; and González, M. (2009) The use of ultrafiltration and nanofiltration membranes for the purification of cork processing wastewater. *Journal of Hazardous Materials*, 162, 1438-1445.