NOVEL PRE-TREATMENT METHOD FOR SEAWATER REVERSE OSMOSIS: FIBRE MEDIA FILTRATION

J. J. Lee[*]; *M. A. H. Johir*[*]; *K. H. Chinu*[*]; *H. K. Shon*[*]; *S. Vigneswaran*[*1]; *J. Kandasamy*[*]; *C. W. Kim*[**]; *K. Shaw*[***]

[*] *Faculty of Engineering and Information and Technology, University of Technology, Sydney, P.O. Box 123 Broadway, NSW 2007, Australia*

[**] *Dept. of Civil and Environmental Engineering, Pusan National University, Busan, 609-735, Korea (ROK)*

[***] *Veolia Water Solutions and Technologies Australia*

[1]*correspondng author: s.vigneswaran@eng.uts.edu.au;*

Abstract

A high rate fibre filter was used as a pre-treatment to seawater reverse osmosis (SWRO) to reduce membrane fouling. Seawater was drawn from Chowder Bay where the Sydney Institute of Marine Science, Australia is located. A lab-scale fibre filter with a height of 1000 mm and a diameter of 30 mm was used in conjunction with in-line coagulation. The effect of operating the fibre filter with different packing densities (105, 115 kg/m^3) and filtration velocities (40, 60 m/h) was investigated in terms of silt density index (SDI_{10}), modified fouling index (MFI), pressure drop (ΔP), turbidity and molecular weight distribution (MWD). The use of in-line coagulation improved the performance of fibre filter as measured by the MFI and SDI. Regardless of filtration velocity and packing density the MFI and SDI_{10} values remained low as did the turbidity until the end of the filtration run. The MWD analysis showed the removal efficiencies of organic materials like biopolymers, fulvic acids, low MW acids for even experiments with the highest filtration velocity (60 m/h) and lowest packing density (105 kg/m^3). This pre-treatment has a small foot print as it has the capacity of operating at a very high filtration velocity.

Key-words: Fibre media filtration – desalination – pretreatment – fouling index – organic matter – molecular weight distribution

1. Introduction

Due to the scarcity of water resources, seawater has been considered as an alternative water resource. Desalination plants have been used in more than 120 countries and those using reverse osmosis membrane are increasingly becoming common [1, 2]. However seawater reverse osmosis (SWRO) in desalination is seriously affected by membrane fouling.

Pre-treatment is generally used to minimize the organic fouling of SWRO membranes. Sand and dual media filters as pre-treatment are currently used to remove suspended solids. However, higher filtration velocities of both filters are required for the better performance of pre-treatment filtration. The filtration velocity of fibre media filter is 10 times higher than that of sand and dual media filters.

The fibre media filter showed superior performance in the treatment of tertiary wastewater. Several wastewater treatment plants (more than 2 millions m^3/day) in Korea apply fibre filters for obtaining treated water of high quality [3]. Previous studies have researched the optimal coagulant dosage for operation at high filtration velocities for water treatment [4], the effect of different operational parameters (packing density and filtration velocity) on the required height of fibre filter and the characterizations of the filtrate [5], evaluating the possibility of applying the fibre filter as an alternative to the process of flocculation-sedimentation for water treatment [6], optimisation of the backwashing process in fibre filter for water treatment [7], algae removal [8]. A study of a fibre filter treating seawater operated over several months evaluated the optimal operating conditions and the combination of coagulant and reagents [9].

The objectives of this study were to investigate the performance of the fibre filter as pre-treatment to SWRO desalination. In-line coagulation and different packing densities of fibre filter and operating velocities of the filter were evaluated in terms of MFI, SDI_{10} and MWD.

2. Materials and methods

Seawater

Seawater was drawn from Chowder Bay where the Sydney Institute of Marine Science (SIMS), Australia is located. The average turbidity of the seawater ranged from 0.5 to 3 NTU. Dissolved Organic Carbon (DOC) during the operation of fibre filter was below 1 mg/L. The pH was about 8.

Coagulation

Ferric chloride ($FeCl_3 \cdot 6H_2O$) was used as the in-line coagulant of influent seawater to fibre filter. The optimum coagulant dose was 1 and 2 mg/L based on in-line flocculation and jar jests respectively. In this study, flocculation was carried out using 1 mg/L of ferric chloride ($FeCl_3 \cdot 6H_2O$) as it was the optimum dose based on in-line flocculation. Ferric chloride was chosen in these experiments as it is capable of removing colloidal organic matter in seawater.

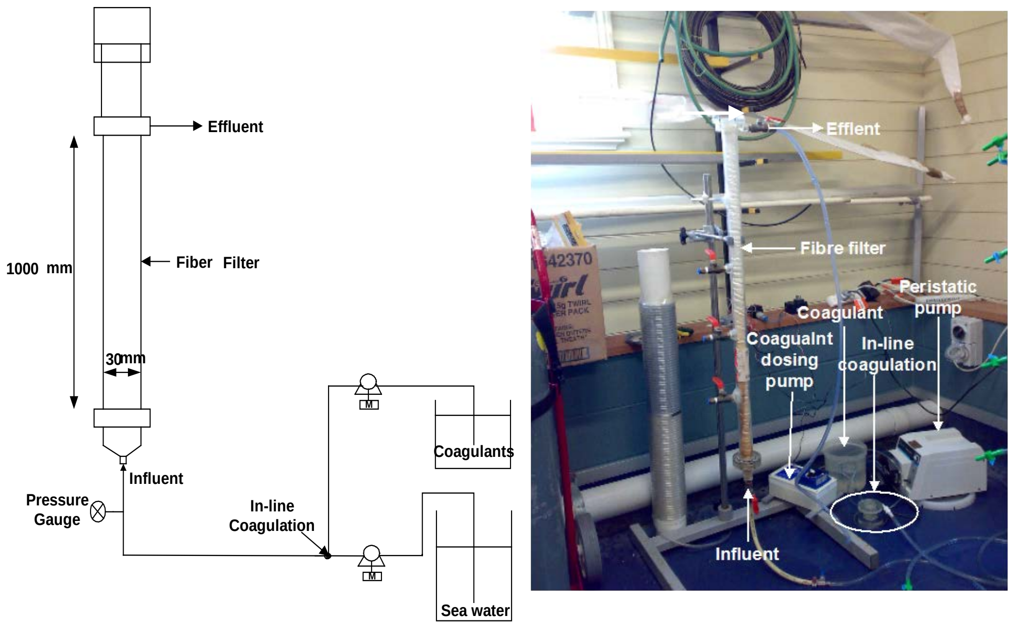

Figure 1. Schematic and on-site picture of fibre filter

Fibre filter
A lab-scale fibre filter was installed at SIMS. The schematic and photo of fibre filter are shown in Figure 1. The experiment was performed using a vertical column in up-flow mode. The height and diameter of the fibre filter were 1000 mm and 30 mm, respectively. A bundle of micro-fibre was used as a filter media.

Operational conditions
Experiment were conducted with and without in-line coagulation to a fibre filter with a packing density 115 kg/m^3 operated at a filtration velocity of 20 m/h to examine the effect of in-line coagulation.

Another set of experiments was carried out to investigate the effect of different packing densities (105 and 115 kg/m^3) and filtration velocities (40 and 60 m/h) of the fibre filter.

Analytical methods

MWD characteristics
MWD measurements of treated seawater effluent from different experimental testing conditions were taken to investigate organic removal. High pressure size exclusion chromatography (HPSEC, Shimadzu Corp., Japan) with a SEC column (Protein-pak 125, Waters Milford, USA) was used to determine the MW distributions of EfOM. Standards of MW of various polystyrene sulfonates (PSS: 210, 1800, 4600, 8000, and 18000 daltons) were used to calibrate the equipment.

SDI and MFI experimental setup
A dead-end filtration unit was used to study the effect of pre-treatment on membrane fouling. The schematic diagram of filter experimental set-up is shown in Figure 2. New membranes were used in each experiment to avoid residual fouling allowing a proper comparison of results obtained under different conditions. Seawater, with and without pre-treatment, was pressurized into a flat sheet membrane module (diameter of 47 mm). The operating transmembrane pressure was controlled at 2 bars by means of a pressure regulating valve.

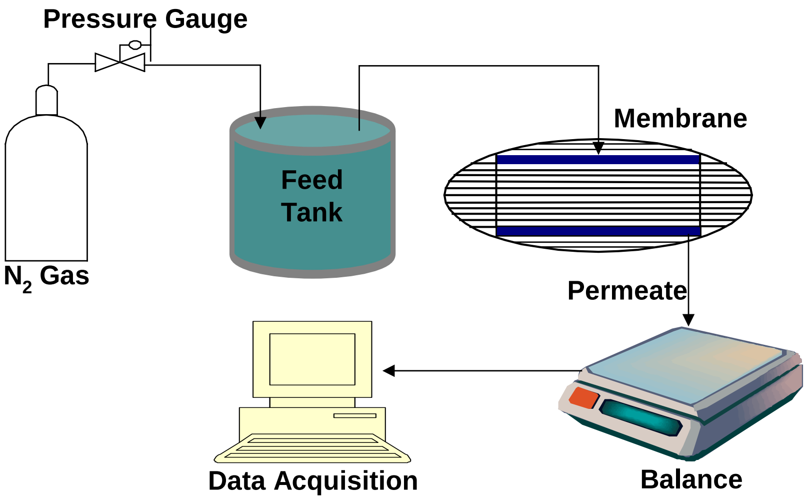

Figure 2. MFI and SDI experimental setup

3. Results and discussion

3.1 SDI and MFI

Effect of in-line coagulation

Table 1 shows the values of MFI and SDI_{10} with and without in-line coagulation of seawater influent to the fibre filter. The SDI_{10} and MFI values of initial seawater were 7.40-8.75 and 138-214 s/L^2, respectively. Here, it should be noted that seawater characteristics vary from season to season and place to place. Following fibre filtration at a velocity of 20 m/h and packing density of 115 kg/m^3 without in-line coagulation, the SDI_{10} and MFI values were 7 and 30 s/L^2, respectively. When 1 mg/L of $FeCl_3$ was used as the in-line coagulant with the same fibre filter operating condition, the SDI_{10} and MFI values were decreased down to 6 and 4 s/L^2, respectively. The SDI_{10} values decreased slightly in contrast to the MFI values which decreased remarkably. This suggests that in-line coagulation decreases the fouling potential of the membrane.

Table 1. MFI and SDI_{10} values with and without in-line coagulation (MFI of seawater influent = 138-214 s/L^2, SDI_{10} of seawater influent = 7.40-8.75)

Filtration Velocity (m/h)	Packing Density (kg/m^3)	Coagulants (mg/L)	MFI (s/L^2)	SDI_{10}
20	115	0	30	7
		1	4	6

Effect of different packing densities and filtration velocities

Table 2 shows the values of MFI and SDI_{10} with fibre filter of different packing densities and filtration velocities. A dosage of $FeCl_3$ (1 mg/L) was used as the in-line coagulant for all conditions. As stated above, the SDI_{10} and MFI values of untreated seawater were 7.40-8.75 and 138-214 s/L^2, respectively. When fibre filter was operated at different packing densities and filtration velocities, the SDI_{10} and MFI values decreased down to 4 and 2 s/L^2 respectively. The decrease in the MFI values was notable. This suggests that it is possible to decrease fouling potential of the membrane with a fibre filter of low packing density operated at a high filtration velocity.

Table 2. MFI and SDI_{10} values with different packing densities and filtration velocities (MFI of seawater influent = 138-214 s/L^2, SDI_{10} of seawater influent =7.40-8.75)

Filtration Velocity (m/h)	Packing Density (kg/m^3)	MFI (s/L^2)	SDI_{10}
40	105	2	4
	115	2	4
60	105	2	4
	115	2	4

3. 2. Pressure drop and turbidity

Effect of in-line coagulation

Figure 3 presents the pressure drop (ΔP) with and without in-line coagulation of fibre filter operated at a velocity of 20 m/h and packing density of 115 kg/m^3. The ΔP without in-line coagulation was 4 mbar, suggesting that the retentions of suspended particles were marginal. The ΔP with in-line coagulation of filtration increased to 33 mbar. Table 3 shows the increase of ΔP from the initial filtration to the end of the filtration period of 90 minutes and turbidity with and without in-line coagulation. The average of turbidity was about 1.75 NTU during experiments which coincided a rainy period. Turbidity with and without in-line coagulation of fibre filtration decreased from 1.75 NTU (raw seawater) to 0.16 NTU and 0.49 NTU, respectively. It can be concluded that the fibre filtration with in-line coagulation removes 91% of turbidity.

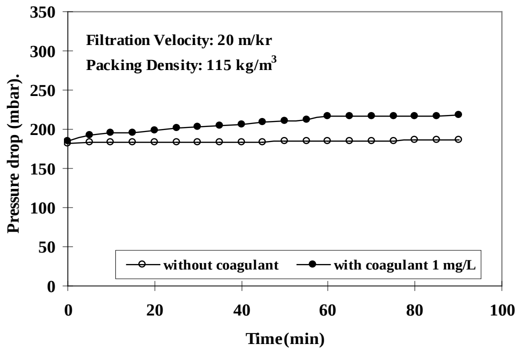

Figure 3. Pressure drop with and without in-line coagulation

Table 3. ΔP and turbidity with and without in-line coagulation (turbidity of initial seawater: 1.75 NTU)

Filtration Velocity (m/h)	Packing density (kg/m^3)	Coagulants (mg/L)	ΔP (mbar)	Turbidity (NTU)
20	115	0	4	0.49
		1	33	0.16

Table 4. ΔP and turbidity with different packing densities and filtration velocities (Average turbidity of seawater: 1.75 NTU)

Filtration Velocity (m/h)	Packing Density (kg/m^3)	ΔP (mbar)	Turbidity at 30 min of operational time (NTU)	Turbidity at 90 min of operational time (NTU)
40	105	38	0.35	0.22
	115	42	0.28	0.14
60	105	41	0.27	0.23
	115	49	0.32	0.23

Effect of different packing densities and filtration velocities

Figure 4 shows ΔP with different fibre filter packing densities and filtration velocities. The ΔP with a packing density of 105 kg/m^3 and 115 kg/m^3 operated at filtration velocities of 40 m/h was 38 mbar and 42 mbar, respectively. The ΔP with a packing density of 105 kg/m^3 and 115 kg/m^3 operated at filtration velocity 60 m/h was 41 mbar and 49 mbar, respectively. Table 4 shows the increase of ΔP from its initial filtration to the end of the filtration period of 90 minutes and turbidity with different fibre filter packing densities and filtration velocities. The increase of ΔP is proportional to that of the packing density and filtration velocity. The lowest turbidity was 0.14 NTU for a packing density of 115 kg/m^3 and filtration velocity of 40 m/h. The values of turbidity at other operating conditions were between 0.22 and 0.23

NTU. Regardless of packing density and filtration velocity, turbidity remained low until the end of the filtration period.

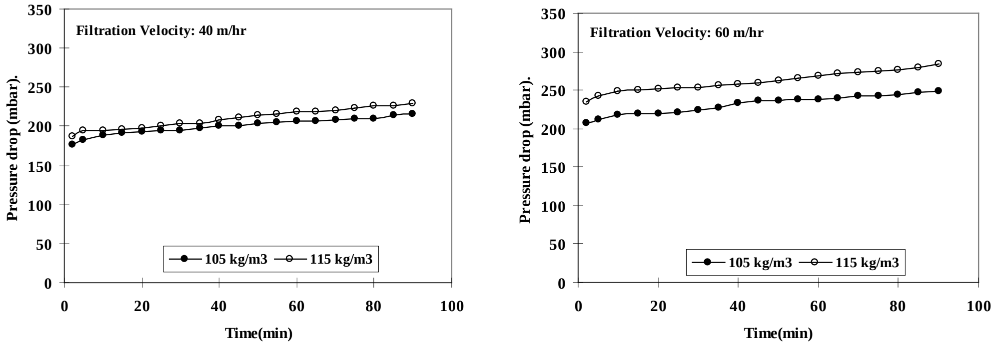

Figure 4. Pressure drop with different packing densities and filtration velocities

3. 3. Molecular Weight Distribution (MWD)

Effect of in-line coagulation

Figure 5 shows MWD of organic matter in seawater without and with in-line coagulation to the fibre filter. The MW of organic matter in the initial seawater ranged from about 960 Da to 220 Da with the highest MW fraction at around 330 Da. The MW fraction of 960, 730, 330 and 220 Da found in this study can be represented as follows: 960 Da - biopolymers (polysaccharides and proteins), 730 Da - fulvic acids (not including humid acid), 330- low MW acids (hydrolysates of humic substances, 220 Da – amphiphilics and neutrals) [10-13]. The fibre filter preferentially removed the relatively large MW such as 730 Da and 960 Da, while the relatively small MW (330 Da and 220 Da) was not removed. The inclusion of the in-line coagulation process gave better removal of organic matter at 960 Da and 730 Da.

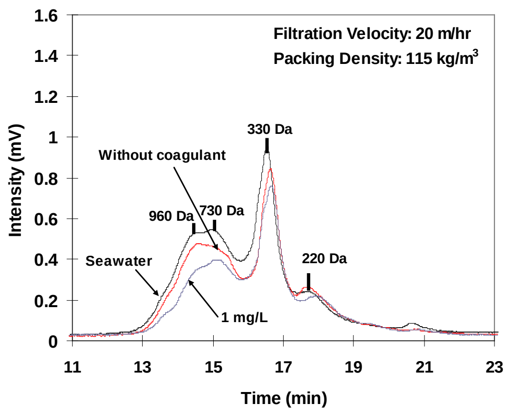

Figure 5. MWD of organic matter with and without in-line coagulation

Effect of different packing densities and filtration velocities

Figure 6 shows MWD of organic matter in seawater with different fibre filter packing densities and filtration velocities. The MW of organic matter in the initial seawater ranged from about 1140 Da to 110 Da with the highest MW fraction at around 380 Da.

The fibre filter preferentially removed the relatively large MW such as 1140 Da, 860 Da and the small MW (380 Da) while the relatively smaller MW (110 Da) could not be removed at both filtration velocities (40 m/h and 60 m/h). Better removal of organic matter at 1140 Da and 860 Da were observed in fibre filters with a packing density of 115 kg/m^3 and filtration velocity of 40 m/h, compared with a packing density of 105 kg/m^3. When removal of organic matter at all MW was compared with different fibre filter packing densities at a filtration velocity of 60 m/h, removal efficiencies were virtually similar. Regardless of the operating velocity of fibre filter, removal of organic matter at 1140 Da, 860 Da, 380 Da were observed.

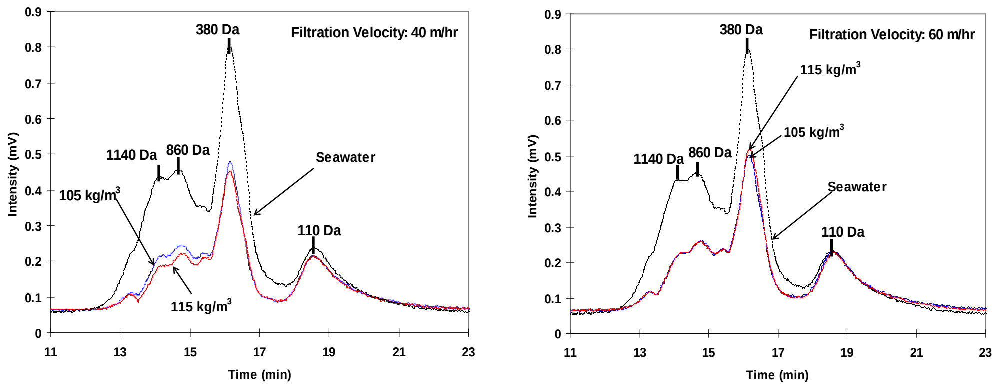

Figure 6. MWD of organic matter with different packing densities and filtration velocities ($FeCl_3$ dose = 1 mg/L)

Conclusions

Fibre filter as pre-treatment of SWRO in terms of MFI, SDI_{10}, pressure drop (ΔP), turbidity and MWD was investigated. The following conclusions were obtained:

1. The use of in-line coagulation gave the lowest values of SDI_{10} and MFI.

2. When fibre filter was operated with different packing densities (105 and 115 kg/m^3) and different filtration velocities (40 and 60 m/h), the SDI_{10} and MFI values were 4 and 2 s/L^2, respectively.

3. The pressure drop (ΔP) with and without in-line coagulation was 33 and 4 mbar respectively. Turbidity with and without in-line coagulation decreased from 1.75 NTU to 0.16 NTU and 0.49 NTU, respectively. The increase of ΔP was proportional to the fibre filter packing density and filtration velocity. Regardless of fibre filter packing density and filtration velocity, turbidity remained low until the end of the filtration period.

4. The fibre filter preferentially removed the relatively large MW such as 730 Da and 960 Da, while the relatively small MW (330 Da and 220 Da) could not be removed. The in-line coagulation process together with fibre filtration gave better removal of organic matter at 960 Da and 730 Da.

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