Hybrid Filtration Method for Pre-treatment of Seawater Reverse Osmosis (SWRO)

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Abstract

Hybrid processes combining fibre filter with deep bed filtration process such as (i) fibre filter and sand filter, (ii) fibre filter and anthracite and (iii) fibre filter and dual media filter were investigated as pre-treatments to SWRO. Seawater was drawn from Chowder Bay, Sydney. The effect of different pretreatment hybrid systems was investigated in terms of silt density index (SDI_{10}), modified fouling index (MFI), headloss across the filters and reduction in turbidity and dissolved organic carbon (DOC). The in-line flocculation in fibre filter improved the performance of the pretreatment hybrid system as measured by the MFI, SDI_{10}, headloss, turbidity and DOC removal. The lowest SDI_{10} and MFI were found with a fibre filter operated at a filtration velocity of 40 m/h followed by dual media filter operated at a filtration velocity of 5 m/h. The lowest headloss and turbidity was found with a fibre filter operated at a filtration velocity of 40 m/hr followed by anthracite operated at a filtration velocity of 5 m/h. This system also gave an effluent with the lowest DOC of 0.64 mg/L corresponding to a removal efficiency of about 70%.

Keywords: Hybrid filtration, desalination, pretreatment, fouling index, dissolved organic carbon

1. Introduction

Seawater reverse osmosis (SWRO) desalination opens up an alternative water resource that can help to solve the increasing problem of limited freshwater resources [1]. Although SWRO desalination has been used over the last few decades, membrane fouling remains the main problem with this process. Pre-treatment prior to reverse osmosis is an important step towards reducing membrane fouling.

Pre-treatment methods to reduce SWRO fouling such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), sand filter, dual-media filter, etc. have been investigated [2], [3], [4], [5], [6]. The costs of pre-treatment processes prior to SWRO such as UF, NF, MF are still expensive. Although processes such as sand filter, dual-media filter, etc. for pretreatment to SWRO are being applied in full scale applications of SWRO, the performance of these pretreatments is not as effective as that of MF, UF and NF [7]. Another disadvantage of the conventional pretreatments is their relatively low filtration velocity (maximum velocity of 20 m/h).

A high rate fibre filter was developed and its high efficacy for the tertiary treatment of wastewater was proved in terms of high filtration velocity and good removal of particulate matter. Several wastewater treatment plants (more than 2 millions m^3/day capacity) in Korea now apply fibre filters for obtaining treated water of high quality. The turbidity was reduced to less than 2 NTU and COD to less than 10 ppm [8]. The fibre filter was also studied for the possible application in drinking water treatment process [9], [10]. The fibre filter was used for seawater pretreatment at optimal operating conditions using a combination of coagulant and reagents and was evaluated on the basis of headloss, particle count, turbidity and SDI_3 [11]. The fibre filter was operated at filtration velocities ranging between 50-200 m/hr and achieved headlosses of about 130 mbar and turbidity of below 0.1 NTU. The effluent contained about 300 particles larger than 1 μm/mL, less than 15 particles larger than 5 μm/mL and achieved a removal efficiency of 98% for particles sized above 5 μm. However, the fibre filter did not decrease the value of SDI_3.

In this study, the fibre filter followed by different deep bed filtration processes (sand filter, anthracite and dual media filter) was evaluated as pretreatment to SWRO with an aim of developing a better pretreatment process. The different combination of pretreatment hybrid systems operated with and without in-line flocculation of influent seawater were investigated and compared against each other. The evaluation was carried out on the basis of measurements of SDI_{10}, MFI, headloss across the filters and reduction in turbidity and dissolved organic carbon (DOC).

2. Materials and Methods

2.1 Seawater:

This study was conducted with seawater drawn at the Sydney Institute of Marine Science

(SIMS), Chowder Bay, Sydney, Australia. Experiments were performed during a rainy period resulting in seawater with a high turbidity (Average turbidity: 1.95 NTU). The average DOC of seawater during the experiments was about 2 mg/L. The pH was about 8.2. The salinity and conductivity were 37-40 g/L and 51.8-55.5 ms/cm, respectively.

2.2 Pre-treatment hybrid systems:

Fig 1 shows the schematic of the hybrid pretreatment system that was installed at SIMS. The hybrid system consisted of a fibre filter followed by one type of deep bed filter. The combination of filtration systems used were:

1) Fibre filter followed by sand filter
2) Fibre filter followed by anthracite filter
3) Fibre filter followed by dual media filter

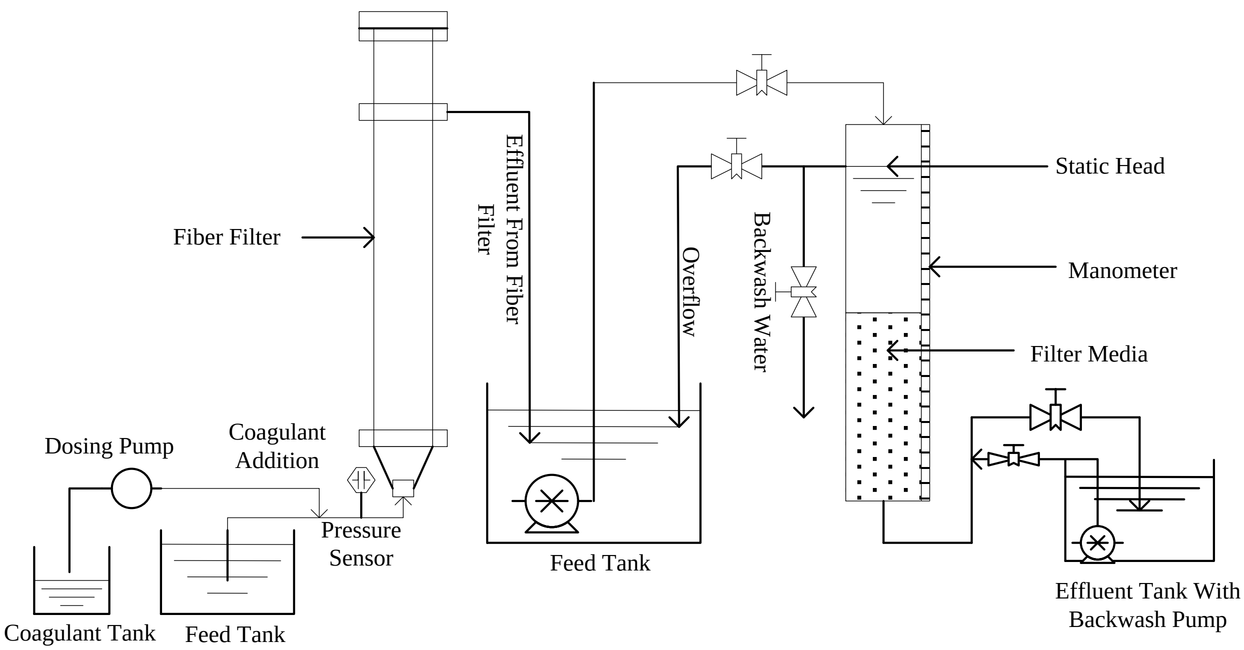


Fig 1 Schematic of hybrid system.

The height and diameter of the fibre filter were 1000 mm, 30 mm, respectively. The experiment for the fibre filter was performed using a vertical column with up-flow direction. A bundle of micro-fibre was used as the filter media. The deep bed filtration used as a post treatment to fibre filter contained the sand, anthracite, dual media filter. These height and diameter were 800 mm and 45 mm respectively. Table 1 shows the details for physical properties of anthracite and sand.

Table 1 Details for physical properties of anthracite and sand

Anthracite		Sand	
Specification	Estimated value	Specification	Estimated value
Effective size (mm)	1.0 ~ 1.1	Effective size (mm)	0.55 ~ 0.65
Uniformity coefficient	1.30	Uniformity coefficient	< 1.5
Acid solubility (%)	1	Acid solubility (%)	< 2
Specific gravity	1.45	Specific gravity	2.65
Bulk density (kg/m^3)	660 ~ 720	Bulk density (kg/m^3)	1500
Manufacturing company	James Cumming & Sons P/L	Manufacturing company	Australia and Riversands P/L

2.2.1 Operational conditions:

Seawater was first treated by the fibre filter and the effluent was collected in a trap tank. The filtration velocity of the fibre filter was 40 m/h and the packing density was 115 kg/m^3. A preliminary study conducted with different filtration velocities (20, 40 and 60 m/h) showed similar headloss development and this is the reason why 40m/h was chosen in this study. To examine the effect of in-line flocculation, experiments were conducted with and without in-line flocculation of influent seawater to the fibre filter followed by sand filtration at a filtration velocity of 5 m/h. The coagulant selected was $FeCl_3 \cdot 6H_2O$. A dose of 1 mg/L of $FeCl_3$ was used. Another set of experiments was carried out to investigate the effect of different deep bed filters as post-treatment to fibre filter. Each filter (sand, anthracite, dual media filter) were run at filtration velocities of 5 and 10 m/h. The filters were operated for 5 hours. Although both filters were run for a short period of time, they were run until they required backwashing. Thus, the results will be representative and similar to long term data as after each backwash, the filter media will be cleaned and will follow same cycle of results.

2.3. Analytical methods

2.3.1 SDI and MFI experimental setup:

A dead-end filtration unit was used to investigate the effect of pre-treatment on membrane fouling. The schematic diagram of the filtration unit is shown in Fig 2. New membranes were used in each experiment to avoid residual fouling and to allow 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 trans-membrane pressure was controlled at 2 bars by means of a pressure regulating valve.

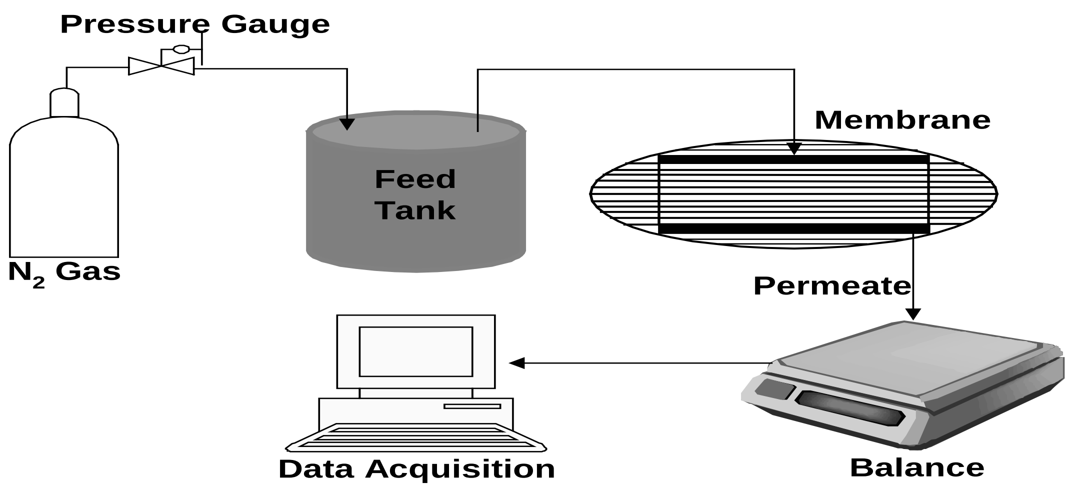


Fig 2 MFI and SDI experimental setup.

2.3.2 Dissolved Organic Carbon (DOC)

All samples were filtered through a 0.45 micron filter prior to DOC measurements. A Shimadzu TOC-V CSH analyzer with an auto sampler was used to measure the DOC.

3. Results and Discussion:

3.1 SDI and MFI:

3.1.1 Effect of in-line flocculation:

Table 2 shows the values of SDI_{10} and MFI for runs with and without in-line flocculation of the influent seawater to the fibre filter followed by sand filtration. The SDI_{10} and MFI values of raw seawater were 8.75 and 214 s/L^2, respectively. It should be noted that seawater characteristics vary from season to season and from place to place. In this study SDI_{10} was measured instead of SDI_{15} because in these experiments the rate of filtration through 0.45 μm filter was high resulting 10 L of water being was filtered well before 15 minutes. A larger volume of water was necessary to measure the SDI_{15} and this was not possible with the equipment available for these experiments. After fibre filtration at a filtration velocity of 40 m/h (packing density: 115 kg/m^3) and sand filtration at a filtration velocity of 5 m/h without in-line flocculation, the SDI_{10} and MFI values were 5.5 and 6.6 s/L^2, respectively. With the same hybrid system together with an addition of 1 mg/L of $FeCl_3$ as the in-line coagulant, the SDI_{10} and MFI values decreased to 3 and 1.6 s/L^2 respectively (Table 2). This suggests that the hybrid system with in-line flocculation can effectively reduce the fouling potential of membranes.

3.1.2 Effect of different media:

When deep bed filter with various filter media was operated at filtration velocities of 5 and 10 m/h as a post treatment to the fibre filter, the SDI_{10} values ranged from 2.6 to 4.5 and the MFI values varied from 1.4 to 3.6 s/L^2. The packing density and filtration velocity of the fibre filter were 115 kg/m^3 and 40 m/h respectively. The lowest values of the SDI_{10} and MFI were 2.6 and 1.4 s/L^2 obtained when the fibre filter was operated at a filtration velocity of 40 m/h followed by a dual media filter operated at a filtration velocity of 5 m/h (Table 3).

Table 2 SDI_{10} and MFI values of fibre filtration followed by sand filtration with and without in-line flocculation of influent seawater (packing density: 115 kg/m^3; filtration velocity of fibre filter: 40 m/h; MFI of raw seawater: 214 s/L^2; SDI_{10} of raw seawater: 8.75)

Filtration types	Sand filtration velocity (m/h)	$FeCl_3$ dose (mg/L)	SDI_{10}	MFI (s/L^2)
Fibre filter and sand filter	5	0	5.5	6.6
		1	3	1.6

Table 3 MFI and SDI_{10} values with different pre-treatment methods coupled with in-line flocculation (1 mg/L dose) of the influent seawater (packing density: 115 kg/m^3; filtration velocity of fibre filter: 40 m/h; MFI of raw seawater: 214 s/L^2; SDI_{10} of raw seawater: 8.75)

Filtration types	Filtration velocity (m/h)	SDI_{10}	MFI (s/L^2)
Fibre filter and sand filter	5	3	1.6
	10	3	1.6
Fibre filter and anthracite	5	3	1.9
	10	4.5	3.6
Fibre filter and dual media filter	5	2.6	1.4
	10	3	1.4

3.2 Headloss and turbidity:

3.2.1 Effect of in-line flocculation:

Fig 3 presents the headloss across the filters with and without in-line flocculation of influent seawater to the fibre filter (packing density: 115 kg/m^3) operated at a filtration velocity of 40 m/h followed by sand filter operated at a filtration velocity of 5 m/h. The headloss across the filters with and without in-line flocculation were 6.8 cm and 9.5 cm, respectively. Table 4 shows the increase of headloss from the initial filtration to the end of the filtration period of 300 minutes and the turbidity with and without in-line flocculation. The average turbidity of raw seawater was about 1.95 NTU. Turbidity with and without in-line flocculation of the influent seawater to the fibre filtration decreased from 1.95 NTU (raw seawater) to 0.35 NTU and 0.45 NTU, respectively. It can be concluded that the fibre filtration coupled with in-line flocculation removes 82% of turbidity without excess headloss development.

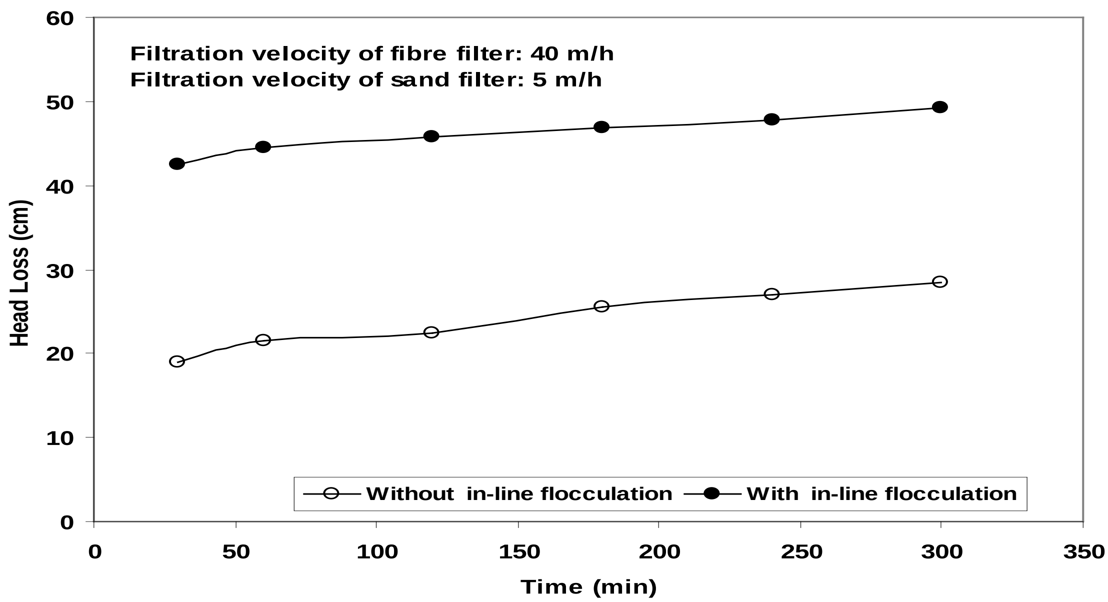


Fig 3 Headloss across the filters with and without in-line flocculation of the influent seawater (packing density: 115 kg/m^3; filtration velocity of fibre filter: 40 m/h; turbidity of raw seawater: 1.95 NTU).

Table 4 Headloss across the filters and turbidity with and without in-line flocculation of the influent seawater (packing density: 115 kg/m^3; filtration velocity of fibre filter: 40 m/h; turbidity of raw seawater: 1.95 NTU)

Filtration types	Filtration velocity (m/h)	$FeCl_3$ dose (mg/L)	Headloss (cm)	Turbidity at 300 min of operational time (NTU)
Fibre filter and sand filter	5	0	9.5	0.45
		1	6.8	0.35

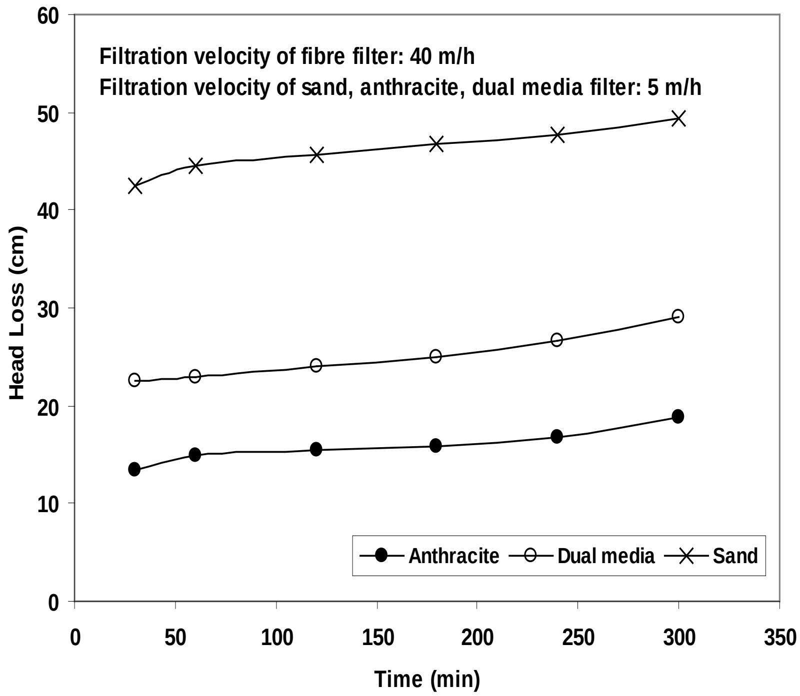
3.2.2 Effect of different pre-treatment hybrid filtration:

Fig 4 shows the headloss across different hybrid pretreatment systems. The headloss across the fibre filter operated at a filtration velocity of 40 m/h (packing density: 115 kg/m^3) followed by a sand filter operated at filtration velocities of 5 and 10 m/h was 6.8 cm and 17.8 cm, respectively. The headloss across the fibre filter operated at filtration velocity of 40 m/h and anthracite filter operated at filtration velocities of 5 and 10 m/h after a period of 300 minutes was 5.4 cm and 9.8 cm, respectively. The headloss across the fibre filter operated at a filtration velocity of 40 m/h followed by a dual media filter operated at filtration velocities of 5 and 10 m/h after a period of 300 minutes was 6.5 cm and 11.0 cm, respectively. In all cases, the headloss development was minimal. Table 5 shows the increase of headloss from its initial filtration to the end of the filtration period of 300 minutes and the turbidity with different hybrid filtration systems. The headloss increased with the filtration velocity. The values of turbidity at other hybrid pretreatment system were between 0.32 and 0.41 NTU. Regardless of the type of hybrid filtration, turbidity remained low until the end of the filtration period.

3.3 Dissolved Organic Carbon (DOC):

3.3.1 Effect of in-line flocculation:

Table 6 presents the DOC values with and without in-line flocculation of the influent seawater to the fibre filter. The average DOC of raw seawater was about 2 mg/L. DOC values with and without in-line flocculation of the influent seawater decreased from 2 mg/L (raw seawater) to 1.20 mg/L and 1.70 mg/L, respectively. The hybrid filtration with in-line flocculation of the influent seawater improved the DOC removal.



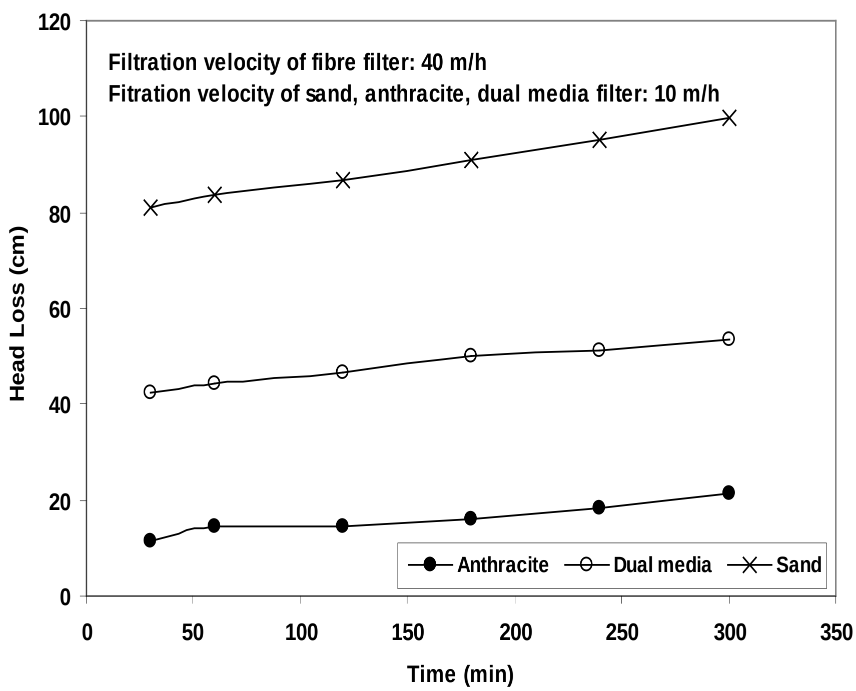


Fig 4 Headloss across filters for different pre-treatment systems (packing density: 115 kg/m^3; filtration velocity of fibre filter: 40 m/h; turbidity of raw seawater: 1.95 NTU).

Table 5 Headloss and turbidity with different pre-treatment systems coupled with in-line flocculation (1 mg/L dose) of the influent seawater (packing density: 115 kg/m^3; filtration velocity of fibre filter: 40 m/h; turbidity of raw seawater: 1.95 NTU)

Filtration types	Filtration velocity (m/h)	headloss (cm)	Turbidity at 300 min of operational time (NTU)
Fibre filter and sand filter	5	6.8	0.35
	10	17.8	0.38
Fibre filter and anthracite	5	5.4	0.32
	10	9.8	0.41
Fibre filter and dual media filter	5	6.5	0.34
	10	11.0	0.36

Table 6 DOC values with and without in-line flocculation of the influent seawater after a period of 5 hr of operating time (packing density: 115 kg/m^3; filtration velocity of fibre filter: 40 m/h; turbidity of raw seawater: 1.95 NTU; average DOC of raw seawater: 2 mg/L)

Filtration types	Filtration velocity (m/h)	$FeCl_3$ dose (mg/L)	DOC (mg/L)
Fibre filter and sand filter	5	0	1.70
		1	1.20

Table 7 DOC values with different pre-treatment methods after a period of 5 hr of operating time with in-line flocculation (1 mg/L dose) of influent seawater (packing density: 115 kg/m^3; filtration velocity of fibre filter: 40 m/h; turbidity of raw seawater: 1.95 NTU; average DOC of raw seawater: 2 mg/L)

Filtration types	Filtration velocity (m/h)	DOC (mg/L)
Fibre filter and sand filter	5	1.20
	10	1.20
Fibre filter and anthracite	5	0.64
	10	0.91
Fibre filter and dual media filter	5	0.81
	10	0.90

3.3.2 Effect of different pre-treatment hybrid filtration:

Table 7 shows DOC values with different pretreatment systems after a period of 5 hours of operation time. $FeCl_3$ (1 mg/L) was used as the coagulant for all runs. When the fibre filter was operated at a filtration velocity of 40 m/h (packing density: 115 kg/m^3) followed by a deep bed filter (either sand filter or anthracite filter or dual media filter) operated at filtration velocities of 5 m/h, the DOC values decreased to 1.20, 0.64 and 0.81 mg/L, respectively. The same hybrid system where the deep bed filters (either sand filter or anthracite filter or dual media filter) were operated at a filtration velocity of 10 m/h gave DOC values of 1.20, 0.91 and 0.90 mg/L, respectively. The lowest DOC value was 0.64 mg/L obtained with a fibre filter operated at a filtration velocity of 40 m/h followed by an anthracite filter operated at a filtration velocity of 5 m/h.

4. Conclusions

The performance of different pre-treatment hybrid systems in terms of MFI, SDI_{10}, headloss, turbidity and DOC was investigated.

1. In this study the filtration velocity and packing density of fibre filter were kept 40 m/h and 115 kg/m^3 as they were found to be optimum values. Our earlier experimental study on fibre filter revealed that the fibre filter operated at 40 m/h with a packing density of 115 kg/m^3 showed comparatively good results than 20 m/h and 60 m/h filtration velocity. It is also found In-line flocculation of influent seawater to the fibre filter gave rise to the lower values of SDI_{10} and MFI.

2. When different pretreatment hybrid systems were operated at different filtration velocities (5 and 10 m/h), the SDI_{10} and MFI value ranged 2.6-3 and 1.4-3.6 s/L^2, respectively. The lowest SDI_{10} and MFI values of 2.6 and 1.4s/L^2 respectively were found with a fibre filter operated at a filtration velocity of 40 m/h followed by dual media filter operated at a filtration velocity of 5 m/h.

3. The headloss with and without in-line flocculation of influent seawater to the fibre filter were 6.8 and 9.5 cm, respectively. The lowest headloss was found at fibre filter operated at a filtration velocity of 40 m/h followed by an anthracite filter operated at a filtration velocity of 5 m/h. Turbidity with and without in-line flocculation decreased from 1.95 NTU to 0.35 NTU and

0.45 NTU, respectively. The lowest turbidity was found with a fibre filter operated at a filtration velocity of 40 m/h followed by a dual media filter operated at a filtration velocity of 5 m/h.

4. In-line flocculation of influent seawater together with fibre filtration and sand filtration gave a better removal of dissolved organics. The fibre filter operated at 40 m/h followed by an anthracite filter operated at 5 m/h removed 70% of DOC.

Acknowledgements

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