Biofilter as Pretreatment to Membrane Based Desalination: Evaluation in terms of Fouling Index

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Abstract

The removal of particulate matter and dissolved organic matter from seawater by the use of biofiltration was investigated. Granular activated carbon (GAC) and anthracite were used as bio filter media at two different filtration velocities. Filtrate quality was measured in terms of silt density index (SDI), modified fouling index (MFI) and turbidity removal. Reverse osmosis (RO) was used as a post treatment. Both biofilters demonstrated similar fouling reduction behavior in terms of SDI and MFI. Fouling potential in terms of MFI values decreased to 10 s/L^2 within the first 10-15 days of operation and kept constant up to the remaining experimental period of 55 days of operation for both GAC and anthracite biofilter. The filtrate turbidity was steady after 10 days and remained low at a value of 0.2-0.3 NTU and 0.28-0.31 NTU for anthracite and GAC biofilter respectively. Furthermore, the headloss development was low and within 20 cm for biofilter operated at a low velocity of 5 m/h. A post treatment of reverse osmosis after a pretreatment of GAC and anthracite biofilters showed a reduction in normalized flux decline (J/Jo) from 0.22 to 0.12 and 0.35 to 0.21 during the first 20 hours respectively. The RO flux for seawater declined at a faster rate and continued even after 3 days when no pretreatment was provided.

Keywords: Desalination, Biofilter, Seawater Reverse Osmosis, Flux decline

1. Introduction and Background

Membrane separation technologies, such as microfiltration (MF), ultrafiltration (UF) and nanofiltration (NF), can remove a whole spectrum of pollutants from wastewater, while Reverse osmosis (RO) has become the key technology for desalination. Membrane based Desalination technology led to a solution for fresh water shortage in tropical areas, and reverse osmosis (RO) systems are used widely for desalination process. If RO is used as a sole process in desalination, both colloidal and dissolved organic matter will be retained by RO membrane which will lead to severe fouling.

Feed pre-treatment is a key factor determining the success or failure of a desalination installation and influences the overall performance of the plant. Traditional pre-treatment is based on the removal of suspended material (by processes such as flocculation, and deep bed filtration), supported by an extensive chemical treatment, including biofouling control (chlorination, dechlorination), and scaling prevention (dosing of acids or antiscalant additives). As a result, the pre-treatment and cleaning accounts for a significant part of the total cost. The above pre-treatment do not remove dissolved organic matter which is mainly responsible for RO fouling. Thus it is necessary to go for a new generation of pre-treatment methods to reduce organic fouling and thus reduce the operational and energy costs of RO. It is found in many studies that biofilter can remove the greater part of organic matters from water and wastewater [1,2] Visvanathan et al. observed that, in continuous experiments, MBR gave better DOC removal efficiency than control membrane reactor. Hu et al. [2] studied the biofiltration (activated clay, zeolite) and found out that biofilter can reduce biofouling for RO.

In this study, the performance of biofiltration using different media such as GAC and anthracite was compared at two different velocities to determine the effectiveness of biofiltration as pretreatment in removing organic components for seawater. Comparison of the pre-treatment was also made in terms of reduction of the fouling potential of raw seawater. The use of GAC and anthracite as biofilter media has several advantages. GAC possesses an extremely large and irregular surface of the order of several hundred m^2/g of carbon that provides a large number of available sites for the adsorption of organic substrates and microorganisms [3]. During the biofilter operation the GAC structure can protect microbes from shear loss. On the other hand anthracite as medium is cheaper and provides similar advantages like GAC. To assess the efficiency of pretreatments, fouling indices are employed. In this study modified fouling index (MFI) and SDI are used to determine the fouling potential after different pretreatments.

The objective of this paper is to compare the two biofiltration (analysis of anthracite and GAC as a media) as a pretreatment method in terms of membrane fouling reduction. The reduction of the fouling potential of raw seawater by the use of GAC and anthracite biofiltration processes was studied in terms of modified fouling index (MFI), silt density index (SDI), turbidity removal and head loss development with filter bed. A post treatment of seawater reverse osmosis (SWRO) was also investigated to determine the extent of reduction in flux decline by the pretreatment.

2. Materials and Methods

In this study, seawater was collected from Chowder Bay, Sydney. During the experiments the characteristics of seawater was monitored regularly. The seawater characteristics are presented in Table 1.

Table 1 characteristics of the seawater

pH	8.10
Conductivity (mS/cm)	50.1
TDS(mg/L)	35000
Turbidity (NTU)	0.5-0.7

Raw seawater was pretreated with granular activated carbon (GAC) biofilter and anthracite biofilter. The physical properties of the GAC and anthracite are shown in Table 2. The most important characteristics of GAC are their extremely large surface area (more than 1000 m^2/g GAC) and high porosity. This facility makes the GAC in adsorbing substances and microorganisms in seawater. GAC and anthracite are washed with distilled water then dried at 103 ^oC and desiccated prior to use.

Table 2 Physical properties of Anthracite and GAC

Anthracite		GAC	
Specification	Estimated Value	Specification	Estimated Value
Effective Size (mm)	1.0-1.1	Nominal size, mm	0.3
Bulk Density (kg/m^3)	660 to 720	Bulk density, kg/m^3	748
Uniformity Coefficient	1.30	Iodine number, mg /(g.min)	800
Acid Solubility	1%	Maximum Moisture content	5 %

In this study, biofiltration experiments were conducted using transparent acrylic filter columns.

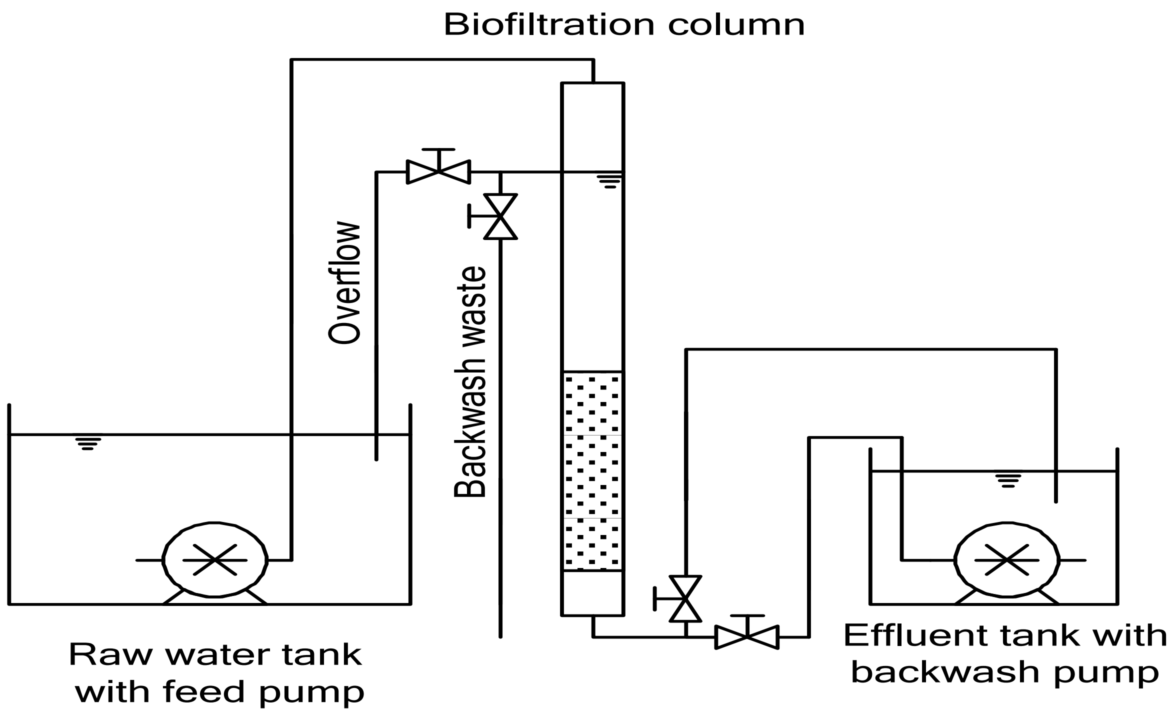

Fig. 1 Schematic diagram of biofiltration column

These columns have an internal diameter of 9.5 cm and a length of 150 cm with sampling ports along the length and in the bottom of the column. Prepared filter media (GAC and anthracite) were packed in 4 columns (2 anthracite and 2 GAC filter columns) up to a depth of 80 cm. The columns were operated in down-flow filtration mode at two different velocities 5 and 10 m/h. Seawater was pumped from a feeding water tank to the top of the columns and then passed through the filter bed. Biofiltration experiments were run continuously for a duration of 8 weeks. The filters were backwashed for a period of 5 minutes each day to control excessive biofilm growth. Effluent samples were collected at the bottom of the column for analysis.

SDI and MFI were measured each day to assess the membrane fouling reduction by biofiltration. The schematic diagram of experimental set-up of SDI/MFI is shown in Figure 2. New membranes were used in each experiment to avoid the effect of residual fouling and to compare the results obtained under different conditions. Seawater, with and without pretreatment, was pressurized into a flat sheet membrane module (diameter of 47 mm).

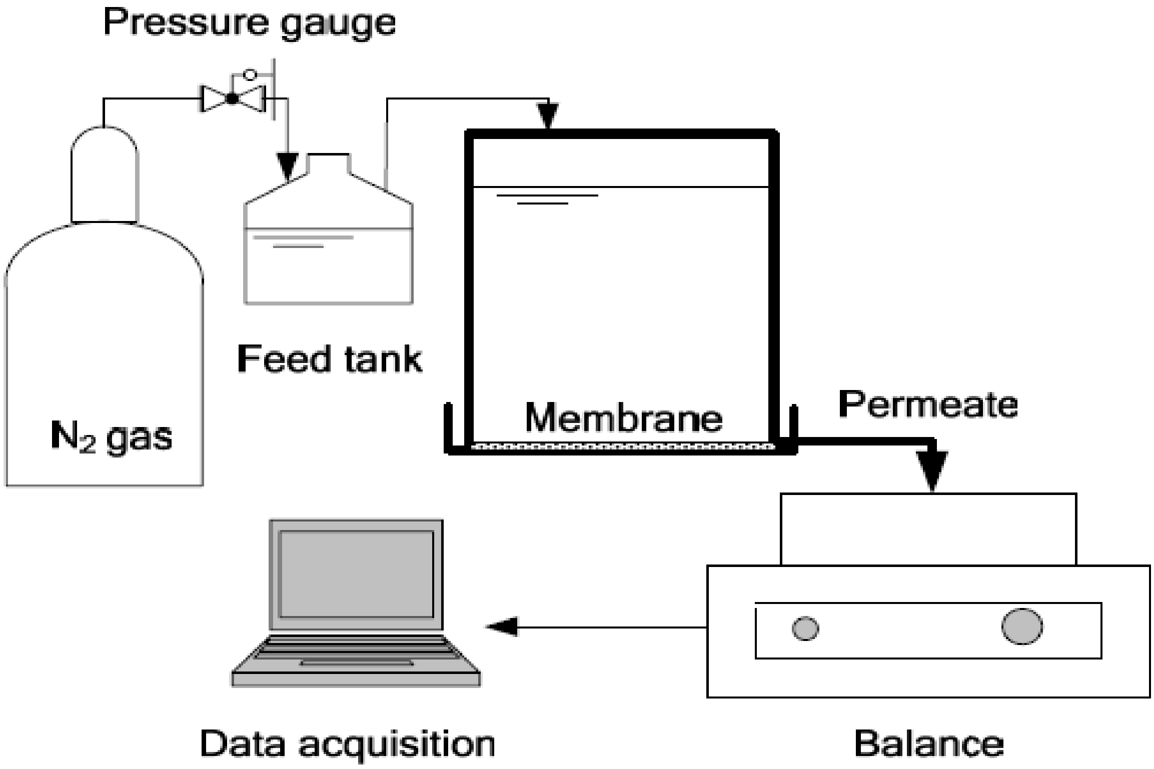

Fig. 2 MFI and SDI experimental setup

The operating transmembrane pressure was controlled at 2 kPa by means of pressure regulating valve. MFI was calculated according to the method presented by Schippers and Verdouw [5] and SDI following the method described in the American standard testing and methods (ASTM D4189-95).

3. Results and Discussion

Biofiltration experiments were conducted on-site at chowder bay, Sydney from April, 2008 to August 2008. Variation of seawater turbidity and temperature was monitored as shown in Figure 3 (a). Apart from the raining period, seawater temperature was fairly uniform (around 15 ^{o}C). The turbidity was also consistent in the range of 0.5-0.7 NTU. Turbidity increased slightly during the rainy period up to 1.10 NTU.

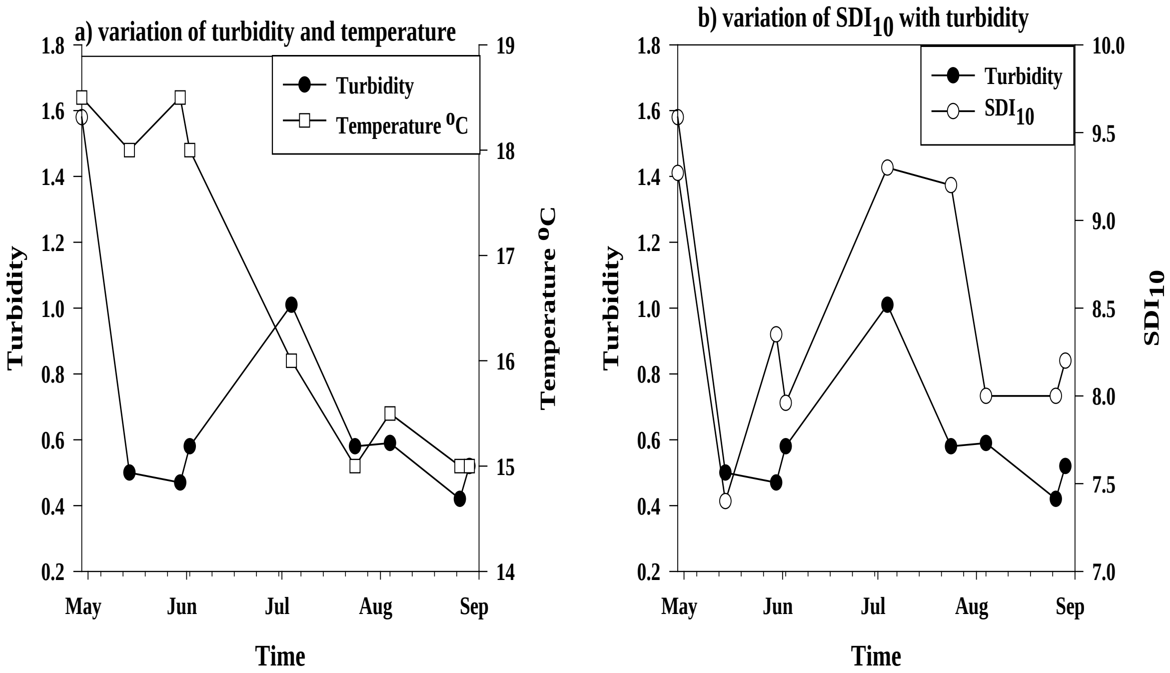

Fig. 3 Seawater characteristics during the experimental period

SDI of 10 min (SDI_{10}) was also monitored for seawater during the test period. Figure 3 b presents the turbidity and SDI_{10} of seawater. SDI_{10} is fluctuated in the range of 7.5 ~ 9.2 during this period. It is observed that SDI values increased with the increase of turbidity. SDI_{10} increased up to 9.2 when the turbidity was high with the value of 1.10 NTU during the rainy period.

The performance of GAC and anthracite biofilters were closely monitored during the experimental period at two different velocities 5 and 10 m/h.

For the filter operation at a filtration velocity of 5 m/h, anthracite column resulted in lower filtrate turbidity than GAC biofiltration (at the initial stage). The filtrate turbidity value for anthracite and GAC filters was 0.2-0.3 NTU and 0.28-0.31 NTU respectively (Figure 4). It can also be noticed that the filtrate turbidity was inferior at higher filtration velocity of 10 m/h. Similar results was also observed in an early study reported in the literature [3].

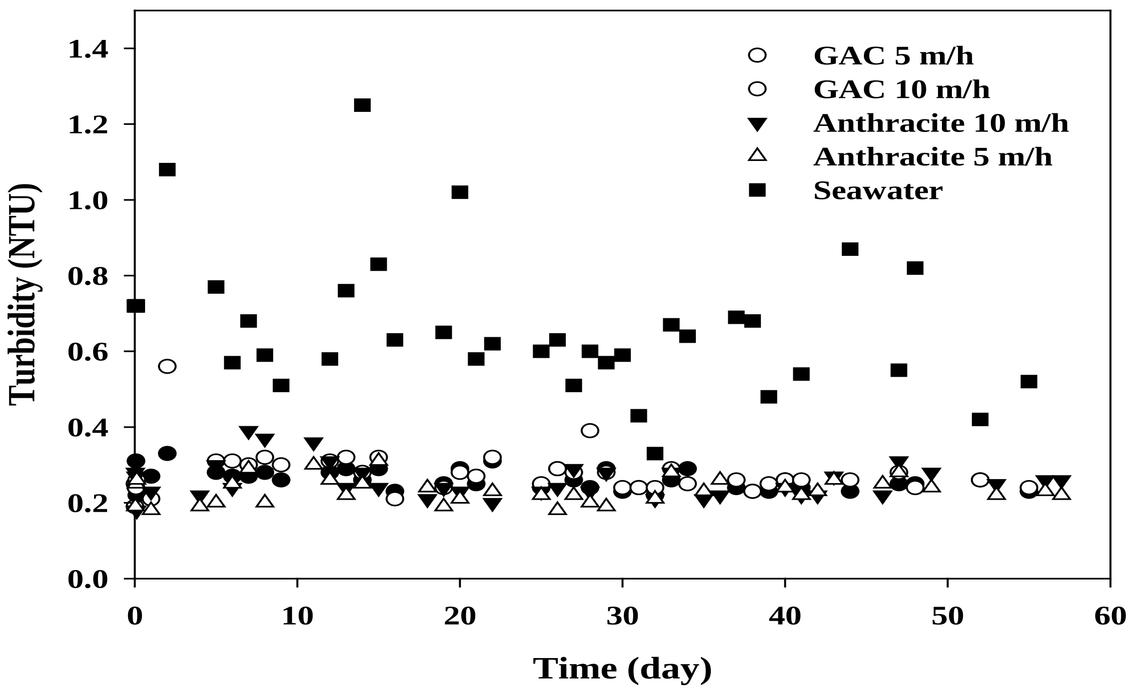

Fig. 4 Effect of filtration velocity on filtrate turbidity

Similar filtrate turbidity was observed for both GAC and Anthracite biofiltration column after 55 days (0.2-0.22 NTU). Figure 5 presents the profiles of MFI and SDI_{10} of GAC and Anthracite biofilter operated at different filtration velocities (5 and 10 m/h). The average SDI_{10} and MFI of seawater were 7.5-9.2 and 250 s/L^2 respectively. SDI_{10} of the filtrate fluctuated during initial period for both GAC and anthracite biofilters. Initial SDI_{10} value was 5.5-7.5 for Anthracite at both velocities (Figure 5 a). SDI_{10} fluctuated more when it was operated at higher filtration velocity of 10 m/h.

For GAC biofilter SDI_{10} ranged at 8-8.8. The value of SDI_{10} dropped to 5-5.5 on day 5 for both filters (which was only a one-off event). After the maturation stage (after 15 days of operation) both biofilters operated in a consistent manner and the SDI_{10} values were low at 3.5-4 and 3-4 for GAC and anthracite column respectively. As anticipated, lower filtration velocity (5 m/h) provided a better filtrate quality in terms of SDI.

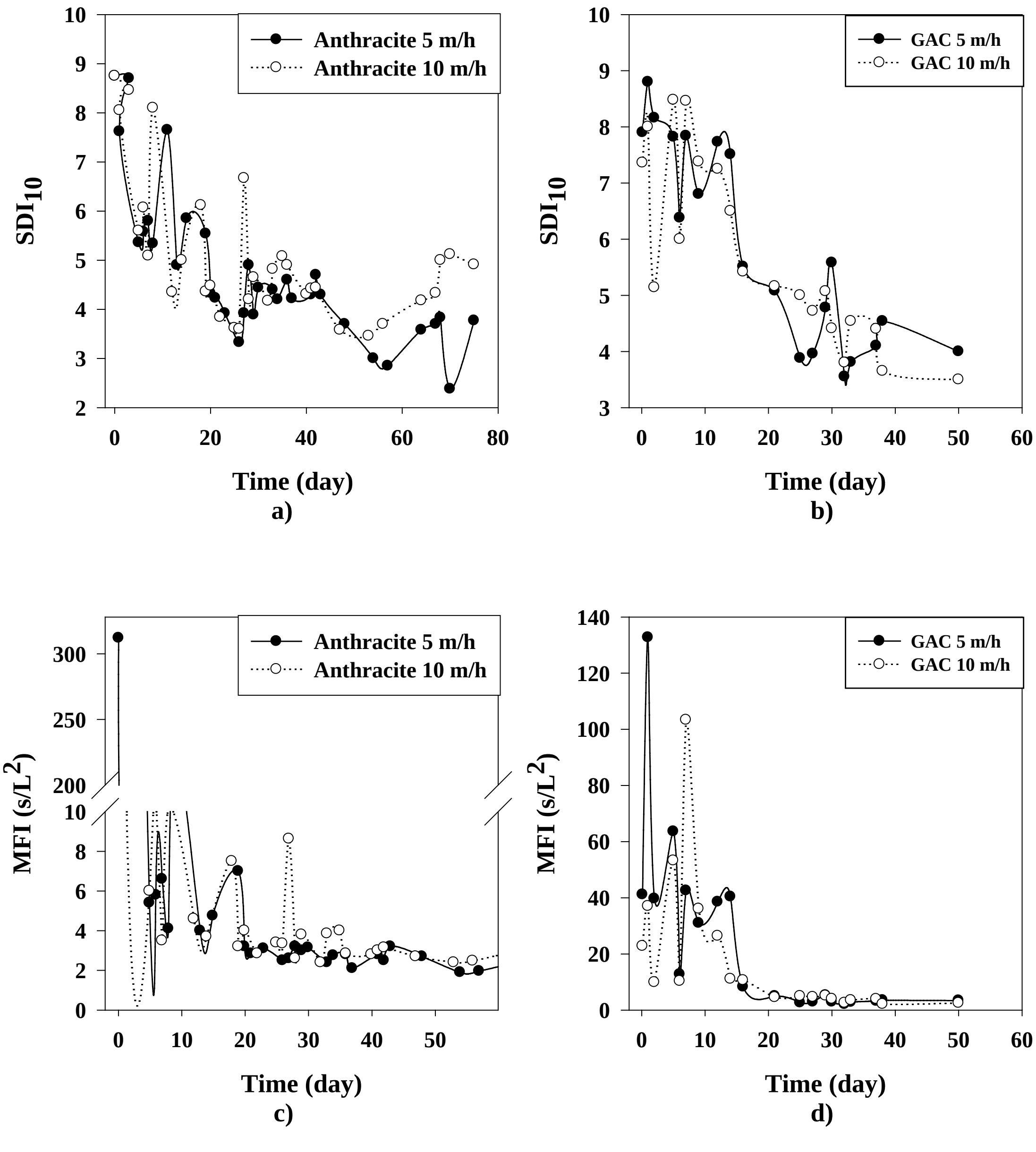

Fig. 5 SDI and MFI profiles for Anthracite and GAC biofilters at 5 m/h and 10 m/h

The modified fouling index results also indicated similar pattern. MFI value decreased during the first 5 days of operation and was stable after 10 days operation for both GAC and anthracite biofilters. During the initial period, the MFI value was found to be very high (176 and 312s/L^2 for anthracite biofiltration at 5 and 10 m/h respectively). After 5 days of operation MFI reduced to 5 and 10 s/L^2 for anthracite biofilter operated at 5 m/h and 10 m/h respectively. Similar trend was noticed for GAC biofiltration also. It took longer time to stabilize (10 days). From this period of 10 days, the MFI value was low and stable up to the end of experimentation period of 55 days of operation (for both GAC and anthracite). This suggests that it is possible to decrease the fouling potential to the RO membrane using a biofilter operated at 5-10 m/h. It is important to wait till the ripening time/ maturity period to obtain steady solid/organic removal in terms of MFI and SDI.

Fig. 6 a) and 6 b) present the headloss development for anthracite and GAC biofilters. Headloss development was faster for higher filtration velocity and finer grain size.

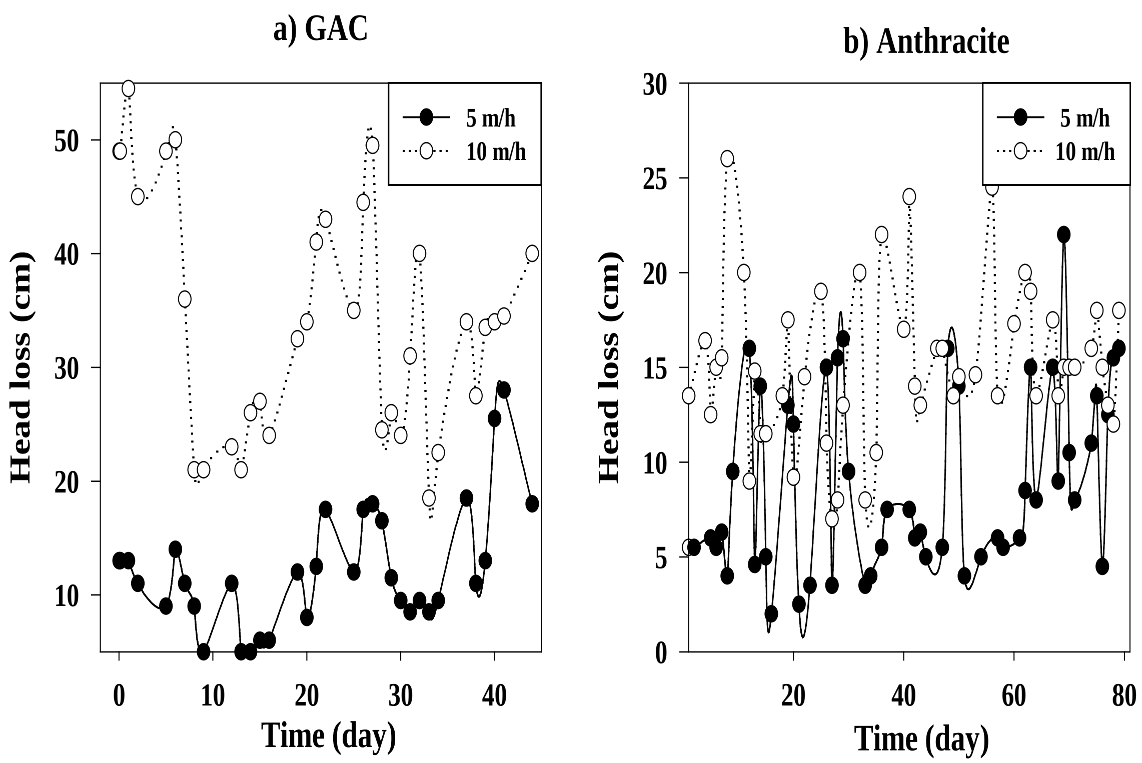

Fig. 6 Effect of filter media and filtration velocity on head loss development (filter medium depth = 80 cm)

When the biofilters were operated at 5 m/h, the headloss development was not significant. Compared to anthracite, headloss in GAC biofilter was higher. This may be due to the smaller size of GAC [1].The daily fluctuation of headloss was due to the backwash of biofilter which was performed once per day.

The pre-treatment efficiency was also assessed in-terms of reverse osmosis (RO) flux decline. The cross-flow Seawater Reverse Osmosis (SWRO) experimental set-up was used to determine the RO flux decline. The details on the experimental set-up and the RO membrane characteristics are presented elsewhere [2]. RO was operated continuously for 3 days. 5 L of feed water was used everyday to run the RO.

The performance of RO was studied in terms of normalized permeate flux (J/Jo) for both feeds (with and without pretreatment). Here, J is filtration flux at a given time and Jo is pure water filtration flux.

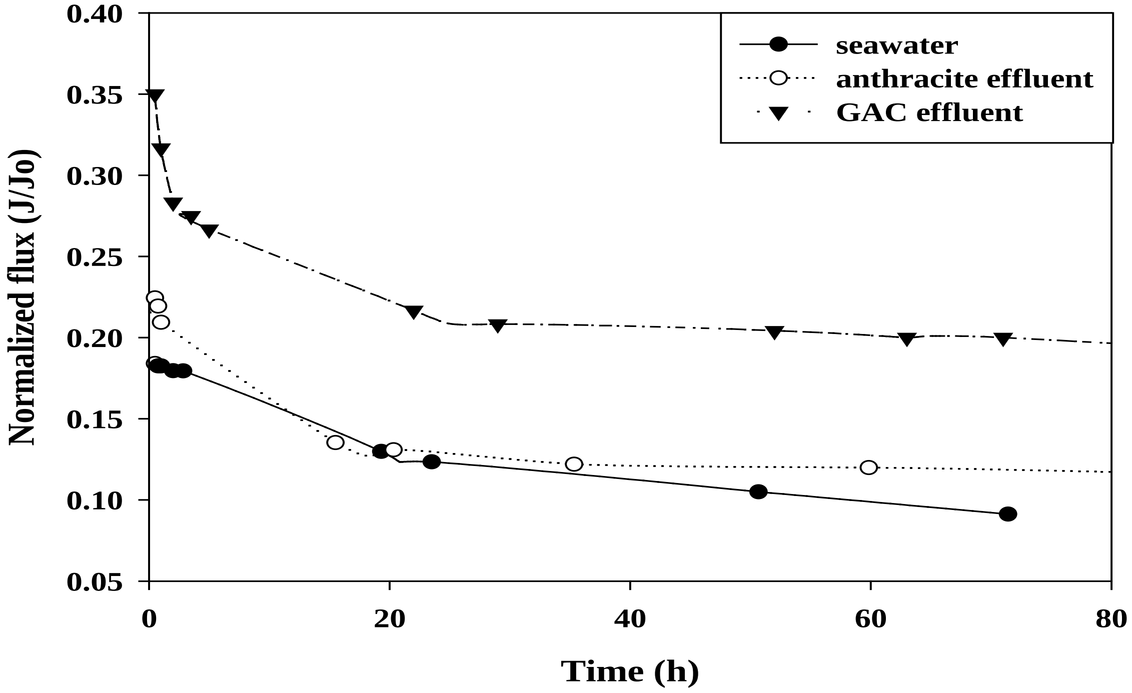

Fig. 7 Temporal variation of RO filtration flux for seawater with and without pretreatment (SR membrane, crossflow velocity = 0.5 m/s, operating pressure 6000 kPa, feeding volume: 5 L each day)

Reverse osmosis showed a reduced normalized flux decline (J/Jo) from 0.22 to 0.12 for pretreated feed with GAC biofilter and 0.35 to 0.21 for pretreated feed with anthracite biofilter during the first 20 hours. After this period of 20 hrs, there was no significant decline in flux. On the other hand, seawater without any pretreatment showed steeper flux decline and the decline continued even after 3 days of operation.

Advantage of Biofilter

The biofilter does not involve any chemical requirement and achieves significant removal of dissolved organics for a long period of time. It requires only minimum amount of backwash and can be a cost effective pre-treatment. Thus it can be a good substitute to the traditionally used deep bed filtration.

4. Conclusions

The detailed experimental results obtained indicates that biofiltration as a pre-treatment reduces a significant amount of organic matter and leads to lower fouling of RO. Fouling potential in terms of MFI values decreased to 10 s/L^2 within the first 10-15 days of operation and kept constant upto the remaining experimental period of 55 days of operation for both GAC and anthracite biofilter. The filtrate turbidity was steady after 10 days and remained low at a value of 0.2-0.3 NTU and 0.28-0.31 NTU for anthracite and GAC biofilter respectively. The headloss development was low for both the filters. A post treatment of reverse osmosis after a pretreatment of GAC and anthracite biofilters showed a reduction in normalized flux decline (J/Jo) from 0.22 to 0.12 and 0.35 to 0.21 during the first 20 hours respectively. The RO flux for seawater declined at a faster rate and continued even after 3 days when no pretreatment was provided.

Acknowledgements

This work was funded by Australian Research Council Discovery Research Grant (DP0772690).

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