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Configuration of an efficient seawater pretreatment system for simultaneous organic and particulate matters removal

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ABSTRACT

In this study, the high-rate fibre filter (HRF) using the fibre media and the biological aerated filter (BAF) followed by granular media filter (GMF) using anthracite and granular activated carbon (GAC) was evaluated as an effective pre-treatment for simultaneous organic and particulate matter removal. As a result, the HRF bed was more effective in reducing particulate matters, while the BAF bed was effective in reducing conventional pollutants as well as particulate matters. The performance results of combined HRF/BAF/GMF system in terms of pollutants and headloss achieved 12–35% higher reduction and about 1.7 times slower development than those of the combined HRF/GMF system. The performance of combined HRF/BAF system (FV 30/3 m/h) followed by GAC filter (FV 5 m/h) showed an excellent removal results of >80% for organics and nutrients and >90% for particulate matters, which typically cause membrane biofouling and colloidal fouling. This reveals that combined HRF/BAF/GMF system is an effective pretreatment system to control and reduce the extent of membrane fouling compared to conventional coagulation-granular filtration.

Keywords: Seawater pretreatment; High-rate fibre filter; BAF; Granular media filter

1. Introduction

Seawater has been widely used as an alternative source to fresh water, which has been attributed to limited water resources with an increase of water consumption and the shortage of catchement area in Korea. A characteristic of seawater containing particulate, colloidal, organic, mineral and microbiological contaminants depends on the type and location of the desalination plant intake [1]. The pollutants in the seawater have been affected by the problem of membrane fouling. Types of fouling mechanisms include scaling [2], colloidal fouling [3], biofouling and organic fouling [4]. A lot of research has been conducted to investigate the pre-treatment methods to reduce SWRO fouling such as filtrations using granular media (sand and anthracite) and membranes [5]. The seawater pre-treatment costs of the filtration processes using granular media (GM-FP) were not as expensive as that of the filtration processes using membranes (MB-FP), while the performance of GM-FP pre-treatments was not as effective as that of MB-FP [6]. To enhance the efficienciy of conventional media-filters with regard to filtration velocity and particulate matter removal, a coagulant was also used prior to media-filters to enhance the removal of colloidal and suspended particles [4]. In addition, the fibre filter as an alternative filter to conventional pretreatment filter has been studied for feasible application in seawater pretreatment process [7,8]. The biological aerated filter (BAF) was found to effectively remove the organic and

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nutrient as well as particulate matter in seawater [9] and saline wastewater [10]. An efficient pretreatment must be designed to face the worst water quality and provide a constant and good quality of feed water to seawater reverse osmosis (SWRO) [11]. Thus in this study, the high-rate fibre filter (HRF) using the fibre media and the BAF followed by different filtration using anthracite and granular activated carbon (GAC) was evaluated as an effective pre-treatment for simultaneous organic and particulate matter removal to control and reduce the extent of SWRO membrane biofouling as well as colloidal fouling.

2. Materials and methods

2.1. Experimental apparatus and materials

The pilot-scale plant as shown in Fig. 1 consisted of a raw seawater storage tank, the HRF bed, the BAF bed, and the anthracite filter (AF) and GAC filter (GF). The combination of filtration processes used for this study were: combined HRF and BAF beds followed by anthriate filter (HRF/BAF/AF); combined HRF and BAF beds followed by GAC filter (HRF/BAF/GF); HRF bed followed by anthriate filter (HRF/AF); and an HRF bed followed by GAC filter (HRF/GF). Each column was fabricated using a transparent acrylic cylinder of 5 cm in diameter and 200 cm in height. The HRF bed consisted of the following three major components: upper support net, filter media, and lower support net. The HRF bed was packed to 0.5 m with a cube media of polyethlene with an effective size of L 6.5 × W 6.5 × H 6.5 mm and a specific surface area of 3500 m^2/m^3. The filters using granular media consisted of the following three major components: underdrain, support gravel and filter media. The beds of the BAF, the A-F and the G-F were packed up to 80 cm with ceramic ball (CB) media (2.0 mm), anthracite (1.5 mm) and GAC (1.5 mm), respectively. The CB media has a hardness of 99%, an apparent density of 1.55 g/cm^3, and an average specific surface area 570 m^2/g.

2.2. Operational conditions and analyses

The influent was fed by upflow into the bottom of the HRF and downflow into the top of the beds of the BAF, the A-F and the G-F. Applied filtration velocities (FV) were <50 m/h for the HRF, <5 m/h for the BAF, and <10 m/h for the A-F and G-F bed. For the HRF, the distance between the upper and the lower support nets remained 0.5 m during filtration, but were expanded up to 0.8 m during backwash. For the BAF process, the initial flow velocity was less than 1m/h until sufficient microbial growth was attained and dissolved oxygen (DO) in the BAF bed was maintained at 3.0 mg/L. The filters were backwashed during 5 min with each phase or when head-loss reached up to 1.0–1.2 m. Raw seawater used for this study was on-shore surface seawater collected from Yongho Bay, Busan, Korea. Influent seawater characteristics were as follows: water temperature, 19.4–23.5°C; pH 7.8–8.1; total dissolved solid (TDS) 36.9–38.5 mS/cm; turbidity 1.87–2.23 NTU; COD 1.7–2.1 mg/L; NH4-N 0.73–1.04 mg/L; TP 0.08–0.10 mg/L; and silt density index (SDI10) 7.97–8.95. Samples of the influents and the effluents from each process were collected and analyzed for the following parameters: pH, turbidity, TDS, COD, NH4-N, and TP. pH and TDS were measured with standard probes (Hach). Nitrogen and phosphorus were measured by a spectrophotometer (Varian-Cary 50, Australia).

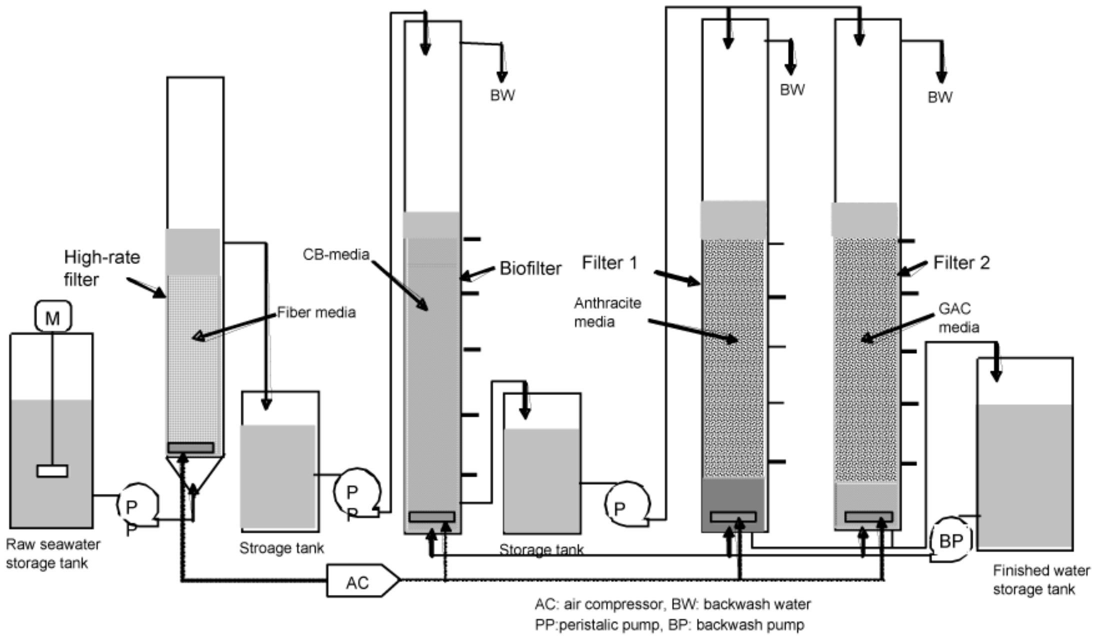

Fig.1. Schematic diagram of pilot-scale plant for seawater pretreatment.

3. Results and discussion

3.1. Performance of high-rate fibre filter and BAF pretreatment system

Fig. 2 presents the performance results of HRF process on organic and particulate matter (turbidity and SDI) reduction with filtration velocity and packing density. Applied filtration velocity and packing density (PD) were in the range of 10–50 m/h and from 90 to 95 kg/m^3, respectively. As a result, the removal efficiency for PD 90 and 95 kg/m3,with filtration velocity were: COD, 3.9–23.9% and 6.1–25.0%; turbidity, 31.6–74.4% and 39.1–75.8; and SDI, 14.2–56.4% and 23.8–59.6%, respectively. During experimental period, a slight decrease in the removal of each pollutant took place in the HRF bed due to solids instant breakthrough by high flow rate and gradually recovering to reduce the pollutants within 2–3 h of operation. Pollutant removal efficiency in the HRF bed kept slightly increasing for approximately 2 days and kept stable for operational time of 3 days.

Compared to high filtration velocity (>30 m/h) and high packing density (95 kg/m^3) in the HRF bed, low filtration velocity (<30 m/h) and high packing density led to better removal efficiency achieving lower organic and particle concentration in the filtrate water. This may be due to longer detention time and smaller porosity, which results in the premature filter be able to trap smaller particle as the filter clogs. On the other hand, high filtration velocity and low packing density in the HRF bed led to low removal efficiency, resulting in the washout of the pollutants captured into the filter media due to the increase of shear force by rapid water flow, while filtration cycle times of the filter bed was kept longer due to an even deposition of pollutants in the bed compared to the HRF with high packing density operated at high filtration velocity (Fig. 3).

These results suggest that the HRF with low packing density operated at a high filtration velocity is an optimum operating condition with regard to filtrate quality parameters and filtration cycle time and is possible to effectively decrease fouling potential of the SWRO membrane by reducing effectively pollutants [12].

Fig. 4 presents the performance results of BAF process on conventional pollutants and particulate matter reduction with filtration velocity. When the filtration velocity was increased to 2.0, 3.0, 4.0 and 5.0 m/h after 20 days of operation at filtration velocity of 1.0 m/h, the removal efficiency were: COD 52.3–75.6%; NH_4-N, 41.5–68.3%; TP, 46.7–75.6%; turbidity 53.6–78.3%; and SDI 45.9–74.0%. During this period, a slight decrease in the removal of each pollutant with each phase took place in the BAF bed and gradually recovered to reduce the pollutants within a day of operation.

The high removals of both COD and nutrient were achieved at filtration velocity of <3 m/h, while the high removal of turbidity and SDI was achieved at a filtration

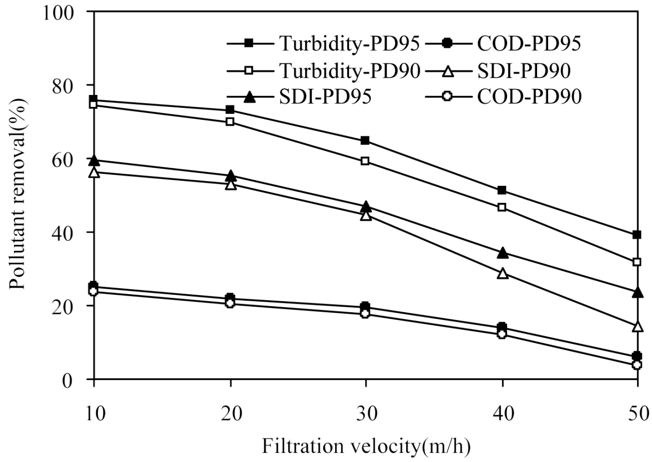

Fig. 2. Performance efficiency of HRF bed with packing density and filtration velocity.

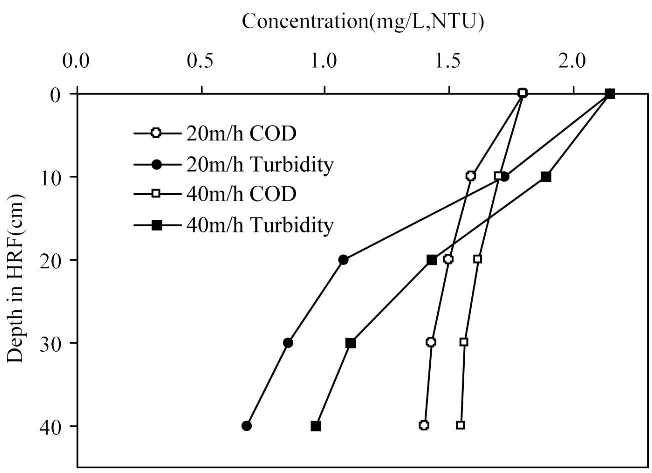

Fig. 3. Profile of pollutants distribution in depth of the HRF bed.

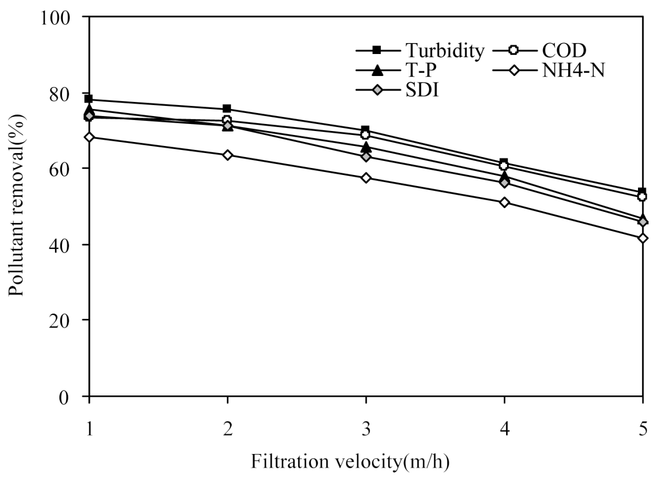

Fig. 4. Performance efficiency of BAF bed with filtration velocity.

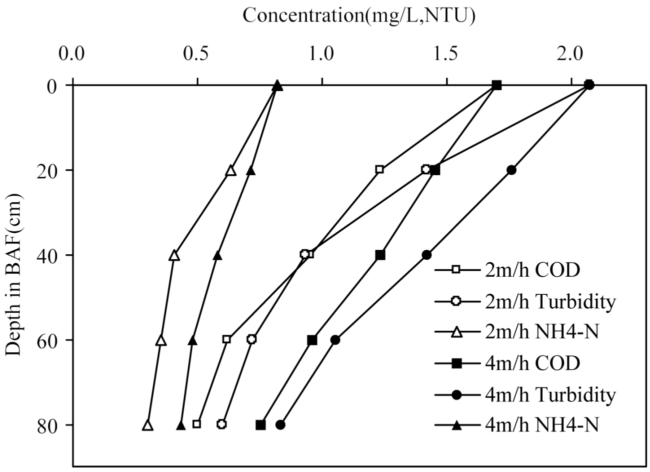

Fig. 5. Profile of pollutants distribution in depth of the BAF bed.

velocity of <2 m/h. Low filtration velocity (<3 m/h) in the BAF bed provided not only better filtrate quality but also a shorter filtration cycle time due to faster clogging of the upper layer of the BAF bed according to larger biofilm growth and particle deposition (Fig. 5) [13]. This result indicates that the BAF bed with longer contact time led to a greater reduction in organic carbon and shorter filtration cycle time [14], while shorter contact time led to lower organic reduction because high water flow velocity can remove loosely attached large microbial aggregates [15]. This suggested that optimal operating condition of BAF bed were a filtration velocity of <3 m/d with regard to filtrate quality parameters and filtration cycle time.

3.2. Effects of filter configuration on organic and nutrient removal

Table 1 lists the comparative results of a combined performance of filtration systems on conventional pollutant removal. Applied filtration velocities of the HRF bed with packing density (<95 kg/m^3), the BAF bed and the GMF beds were 30 m/h, 2 m/h and 5–10 m/h, respectively. The removal rate of combined HRT/BAF/GMF system with filtration time was 25–35% higher than that of the combined HRF/GMF system. This reveals that longer filtration of the GMF beds with the BAF bed resulted in an effective biofiltration and biodegradation in the BAF bed due to an increased biomass with an increase of filtration time.

Application of the BAF bed prior to the GMF system could achieve a high filtration velocity of >10 m/h in the GMF beds, which was shown to be stable and efficient in reducing organics as well as nutrients. The performance efficiency of the HRF (packing density 95 kg/m^3) followed by the BAF bed on organic and nutrient removal was similar to those of the fibre filter (packing density 115 kg/m^3) with coagulation-flocculation [8]. For granular media filters, there is a slight difference between the two types of filter media with regard to specific surface area of media, which showed that the removal rate of the GAC filter was 5–7% higher than those of the anthracite filter. Thus this reveals that in order to enhance the removal rate of dissolved pollutants in the seawater, the application of filter media having higher adsorption and biological activity to the filters with larger specific surface area of media is needed, compared to conventional filter media such as sand or gravel.

3.3. Effects of filter configuration on particle removal and headloss development

Table 2 lists the comparative results of a combined performance of filtration systems on particulate matter removal and headloss development. When the filters of the combined system were operated under the same condition with those applied to organic and nutrient removal, the removal rate of combined HRT/BAF/GMF system on turbidity and SDI reduction was 12–30% higher than that of the combined HRF/GMF system, while the headloss across the combined HRF/BAF/GMF system developed approximately 1.7 times lower than those of the combined HRF/GMF system.

Table 1
Comparative performance of combination of filtration systems on conventional pollutant removal

Filtration types	Filtration velocity (m/h)	COD (mg/L)	NH_4-N (mg/L)	TP (mg/L)
Influent	—	1.5	0.74	0.085
HRF/anthracite	30/5	1.0	0.51	0.038
	30/10	1.2	0.61	0.048
HRF/GAC	30/3/5	0.9	0.48	0.034
	30/3/10	1.1	0.55	0.043
HRF/BAF/anthracite	30/5	0.3	0.27	0.016
	30/10	0.4	0.28	0.018
HRF/BAF/GAC	30/3/5	0.2	0.19	0.010
	30/3/10	0.3	0.28	0.017

Table 2
Comparative performance of combination of filtration systems on particulate matter removal and headloss development

Filtration types	Filtration velocity (m/h)	Turbidity (NTU)	SDI	Headloss (cm)
Influent	—	2.15	8.92	—
HRF/anthracite	30/5	0.38	2.55	9.2
	30/10	0.61	3.86	18.3
HRF/GAC	30/3/5	0.35	2.25	14.7
	30/3/10	0.52	3.54	26.5
HRF/BAF/anthracite	30/5	0.13	1.23	5.6
	30/10	0.17	1.34	9.1
HRF/BAF/GAC	30/3/5	0.09	0.89	8.8
	30/3/10	0.15	1.27	14.5

Low filtration velocity (<5 m/d) in terms of turbidity and SDI achieved 10–15% and 2–3% higher reduction than those of high filtration velocity (>10 m/d), while the headloss development at high filtration velocity was 1.6–2.0 times faster than that of low filtration velocity. In the GMF beds, the effects of different media filter showed that the removal rate of the GAC filter was 10–15% higher than those of the anthracite filter, while the headloss across the GAC filter was developed faster than that of the anthracite filter. This reveals that the introduction of the BAF prior to the GMF resulted in not only longer filtration time in the GMF than that of the HRF/GMF system without the BAF bed but also a stable and efficient performance in reducing particulate matter at high filtration velocity of >10 m/h. This is attributed to effective biofiltration of the BAF. Regardless of pretreatment filter prior to the GMF, the GAC filter achieved generally higher pollutants removal and faster headloss development compared to the anthracite filter. This may be due to the lower porosity in the GAC filter, which resulted in larger biomass growth compared to the anthracite filter.

4. Conclusion

The HRF bed was more effective in reducing particulate matters, while the BAF bed was effective in reducing conventional pollutants as well as particulate matters. The performance results of combined HRF/BAF/GMF system in terms of pollutants and headloss achieved 12–35% higher reduction and about 1.7 times slower development than those of the combined HRF/GMF system. The performance of combined HRF/BAF system (FV 30/3 m/h) followed by GAC filter (FV 5 m/h) showed an excellent removal results of >80% for organics and nutrients and >90% for particulate matters, which typically cause SWRO membrane biofouling as well as colloidal fouling. This reveals that combined HRF/BAF/GMF system using the BAF process having both efficient biofiltration and strong advantage against shocking loads is an effective pretreatment system to control and reduce the extent of membrane fouling compared to conventional coagulation-granular filtration.

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