Desalination and Water Treatment
www.deswater.com

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doi: 10.5004/dwt.2011.2661

33 (2011) 329–336
September

Dual media filtration and ultrafiltration as pretreatment options of low-turbidity seawater reverse osmosis processes

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Received 30 November 2010; Accepted in revised form 27 March 2011

ABSTRACT

Well-controlled laboratory scale experiments were carried out to estimate the performance of dual media filtration (DMF) and ultrafiltration (UF) as a pretreatment for seawater reverse osmosis (SWRO) processes. Raw seawater was taken from the place close to the construction site of the SEAHERO test-bed of 45,000 m^3/d in capacity, which is planning to be operated from 2013. The raw seawater turbidity was rather low and the focus of this study is to find out the better process between DMF and UF for the pretreatment of low turbidity seawater. The UF process exhibited a good performance to produce qualified RO feed water and coagulation added the removal of aromatic organics and better resistance to the membrane fouling. However the DMF process could not make RO feed water to satisfy the SDI standard and variations in operation conditions did not change the product water quality. In order to enhance the performance of DMF process, a multi-pass design or an improved coagulation strategy for low turbidity water should be necessary, which makes a proper design of DMF more difficult. Therefore, UF can be a better option for the pretreatment of low turbidity seawater.

Keyword: Dual media filtration (DMF); Ultrafiltration (UF); Pretreatment; Low-turbidity seawater; Seawater reverse osmosis (SWRO)

1. Introduction

The Center for Seawater Desalination Plant, which was established in December 2006, launched its R&D project [seawater engineering and architecture of high efficiency reverse osmosis (SEAHERO)] in the middle of 2007 and aimed to get world top-level seawater reverse osmosis (SWRO) plant technologies [1]. An SWRO plant test-bed of 10 MIGD (~45,000 m^3/d) in capacity will be constructed in Busan, the second biggest city placed in the southeastern coast of the Korean Peninsula.

This study is included in the SEAHERO project and deals with the strategy for operation and management of the SWRO plant test-bed, especially the troubleshooting in the pretreatment process, which is one of the most important parts to optimize SWRO processes. Practically, SDI is the most acceptable index to check the quality of RO feed water [2]. So the troubleshooting in pretreatment means the product does not meet the SDI standard as a qualified RO feed water.

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Presented at the 3rd International Desalination Workshop (IDW 2010), November 3–6, 2010, Jeju, Korea
Organized by Center for Seawater Desalination Plant and European Desalination Society

Dual media filtration (DMF) has been one of the most popular pretreatment processes for decades because of its economic characteristics [3]. Recently membrane-based pretreatment processes such as microfiltration (MF) and ultrafiltration (UF) are getting the spotlight in the desalination market. MF and UF processes assure high quality RO feed water compared to conventional pretreatment processes like DMF [4].

In this study, the performances of DMF and UF were compared using the surface seawater drawn from the coastal area near the projected construction site of the SEAHERO test-bed. Since the raw seawater has low turbidity in the range of 1–6 NTU, the focus will be placed on the question which process will be better for the pretreatment of low turbidity seawater, DMF or UF.

2. Methods

2.1. Materials

The DMF test unit used in this study was packed with anthracite and silica sand with 1.02 and 0.44 mm of effective size, respectively and 1.26 of uniformity coefficient for both media. The UF membrane was the regenerated cellulose (Millipore, USA) and hydrophilic, with a molecular weight cut-off of 100 kDa. $FeCl_3{\cdot}6H_2O$ was used as a coagulant for both DMF and UF membrane systems. The concentration of ferric chloride stock solution was 0.25 M and the dosing solution was 10 g/L which was diluted at each coagulation test.

2.2. Raw seawater and analytical methods

Raw seawater was taken in the open sea close to the position where the SEAHERO desalination plant will be placed (Gijang-gun, Busan, Korea). The water quality data of the raw seawater are listed in Table 1, which were obtained from the analytical method as shown in Table 2. Although the turbidity of the raw seawater was rather low (placed in the range of 1.07–5.84), it was not qualified as RO feed water since SDI values were higher than 6. SDI standards for RO feed water are less than a specific value in the range of 3–5 according to the system designer's selection. The product water samples from UF and DMF pretreatments were collected and analyzed. The water quality parameters were turbidity, UV_{254}, SDI and particle counts.

Table 1
Characteristics of raw seawater quality

Parameters	Range	Average
Temperature, °C	17–23	20
pH	7.9–8.3	8.0
Turbidity, NTU	1.07–5.84	2.63
TOC, mg/L	0.8–2.1	1.5
UV_{254}, cm^{-1}	0.008–0.012	0.010
Alkalinity, mg/L as $CaCO_3$	99.0–106.0	102.6
Conductivity, μs/cm at 25°C	46,600–50,200	48380
TDS, mg/L	29,298–33,609	32230
SDI, min^{-1}	>6	6.2

Table 2
Analytical methods and instruments

Item	Analytical methods and instruments
pH	pH meter (Horiba, F-54 BW)
Turbidity, NTU	Turbidimeter (HACH, 2100N)
TOC, mg/L	TOC Analyzer (Shimadzu, TOC-VCPH)
UV_{254}, cm^{-1}	UV-Spectrophotometer (Shimadzu, UV-1650)
Alkalinity, mg/L as $CaCO_3$	Standard Methods [5]
Conductivity, μs/cm at 25°C	pH meter (Horiba, F-54 BW)
TDS, mg/L	pH meter (Horiba, F-54 BW)
SDI, min^{-1}	ASTM D4189-95 [2]
Particle counts	WQO 2000

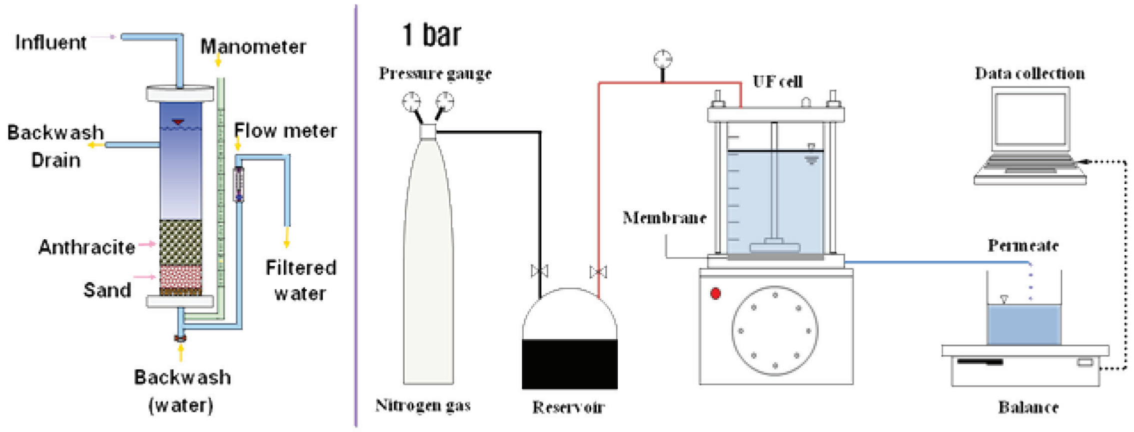
Table 3
Configuration of the lab-scale DMF test

Parameters		Values
Column height, mm		500
Column diameter (I.D), mm		55
Effective size, mm	Anthracite	1.02
	Sand	0.44
Uniformity coefficient	Anthracite	1.26
	Sand	1.26
Bed depth, mm	Anthracite	150
	Sand	150

2.3. Lab-scale DMF and UF operation

Fig. 1a depicts a schematic of the lab-scale DMF test units used in this study. Details on the configuration of the DMF unit are listed in Table 3. We tested DMF with two filtration rates, 7 and 10 m/h, respectively.

The UF test unit consists of membrane cell, feed reservoir, weighing balance and data acquisition system, as shown in Fig. 1b. The test solution was stored in a 5.0 L reservoir and fed to the membrane cell by pressurized nitrogen gas. UF tests were performed in a constant room temperature for 1 h of operation time. Permeate flux data were collected by measuring the filtrate mass using a PC connected to an analytical electronic top-loading balance.



(a) DMF (b) UF

Fig. 1. Schematics of experimental devices, (a) DMF and (b) UF.

During the operation period, a constant pressure of 1.0 bar was maintained.

DMF and UF operation procedures included three unit operations; (1) 1 min of rapid mixing (R.M) after coagulant addition (3–9 mg/L of $FeCl_3 \cdot 6H_2O$), (2) flocculation, and (3) filtration. For flocculation unit process, several conditions were tested; flocculation times of 2 and 5 min, and low and high flocculation mixing intensities (G values of 22 and 60 s^{-1}). Variations in each unit operation were introduced to set different operation conditions.

3. Results and discussion

3.1. Performance of DMF

In general, DMF needs to be stabilized to exhibit stable filtrate (product) water quality. As shown in Fig. 2, it took 10–20 min from the start-up of the operation for the stabilization in this study. The filtrate turbidity values after the stabilization were placed in the range of 0.1–0.15 NTU, which were less than the turbidity standard of 1 NTU for RO feed water [6]. The change in coagulation and flocculation conditions did not make a dramatic change in the filtrate turbidity as shown in Fig. 2.

Coagulation condition (i.e. coagulant dose) did not affect turbidity removal efficiency very well as shown in Fig. 3. However, UV_{254} removal efficiency increased from 16% to 25% with the increase of coagulant dose. UV_{254} is the best detector of aromatic organics, which can be problematic to membrane because of their hydrophobic nature [7–9]. Therefore the removal of UV_{254} in pretreatment can be helpful to decrease RO fouling. By the way, the flocculation conditions could not be related to the removal efficiencies of turbidity nor UV_{254} as shown in Fig. 3.

Although DMF exhibited more than 95% of turbidity removal efficiency, SDI values of DMF filtrate with various coagulation and flocculation conditions were close to 6 and not quite different from that of raw seawater without any pretreatment as shown in Fig. 4. In addition, decrease of filtration rate from 10 m/h to 7 m/h did not change the filtrate SDI at all while the decrease of filtration rate in DMF process generally helps to increase the filtrate water quality. As a result, it can be hypothesized that the main sources to increase SDI values in this case could be materials which are undetectable to the turbidity meter and are not easily removed by DMF. Even if the filtrate turbidity values were about 0.15 NTU which is small enough to be RO feed water [10], the DMF filtrate cannot be RO feed water because it did not meet the SDI standard.

3.2. Performance of UF

A number of references reported that UF processes can produce a high quality RO feed water [4,11–13]. The result in Fig. 5 can be regarded as an additional reference of this trend. SDI values of UF permeate (product) were close to 2, which meets the SDI standard clearly. Variation in coagulant doses and flocculation conditions did not change the SDI values very well. According to Fig. 6, turbidity removal efficiencies by UF were higher than 99% regardless of coagulation and flocculation conditions. In all cases, turbidity was reduced to around 0.05 NTU in the UF permeate. As a result, it can be said that the removal tendency of materials affecting SDI and turbidity was highly dependent upon the performance of UF alone.

UV_{254} removal efficiency by UF increased from 16% to 32% with the increase in coagulant doses as shown in Fig. 6, which is a similar trend to the DMF case discussed earlier. Thinking of the same range of coagulant dose (3–6 mg/L) as the DMF case, the UV_{254} removal efficiencies by UF were very similar to those by DMF, which were in the range of 16–25%. Although UF exhibited much

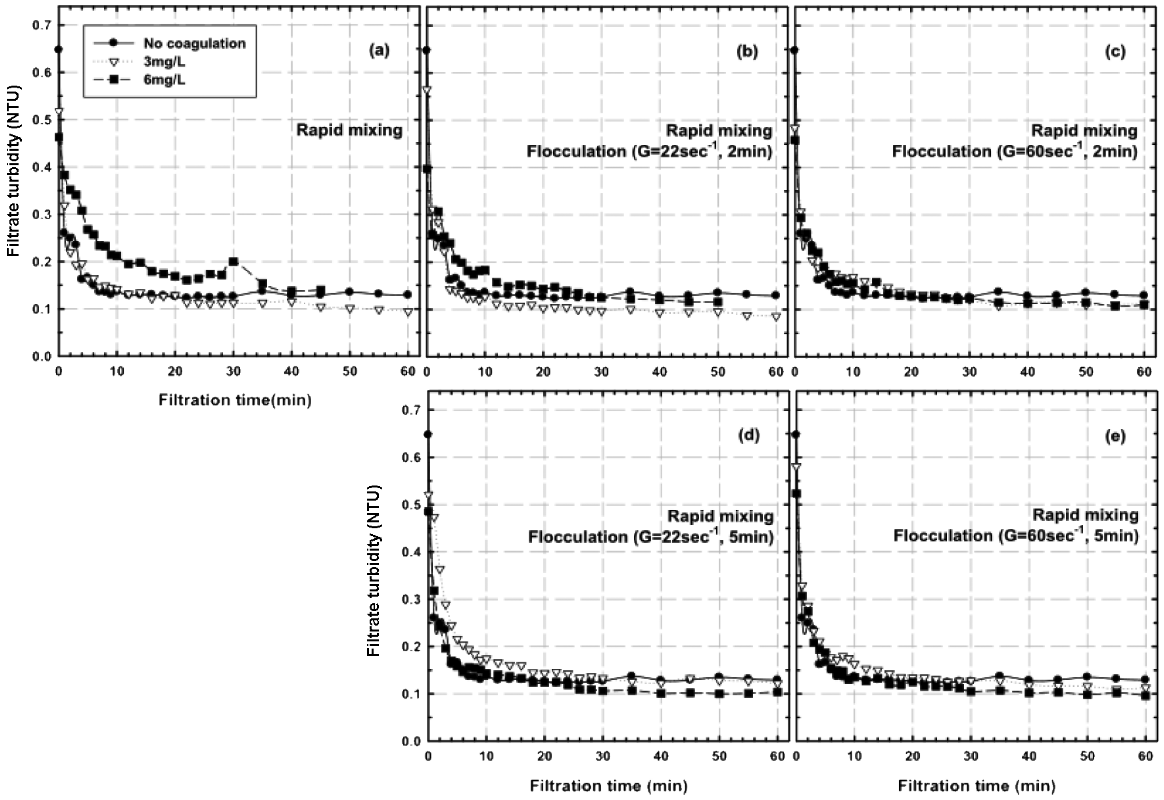


Fig. 2. The filtrate turbidity in DMF operated with various flocculation conditions.

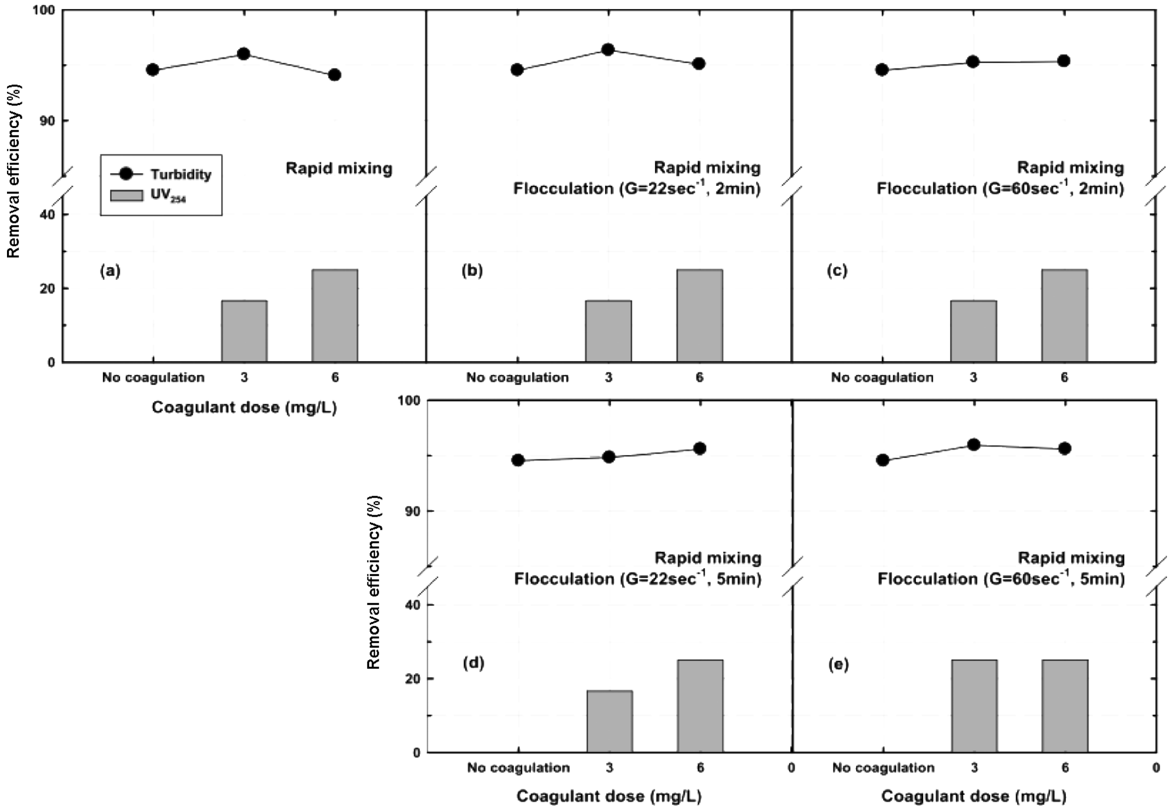


Fig. 3. Effects of the coagulation and flocculation conditions on the removal efficiencies of UV_{254} and turbidity in DMF.

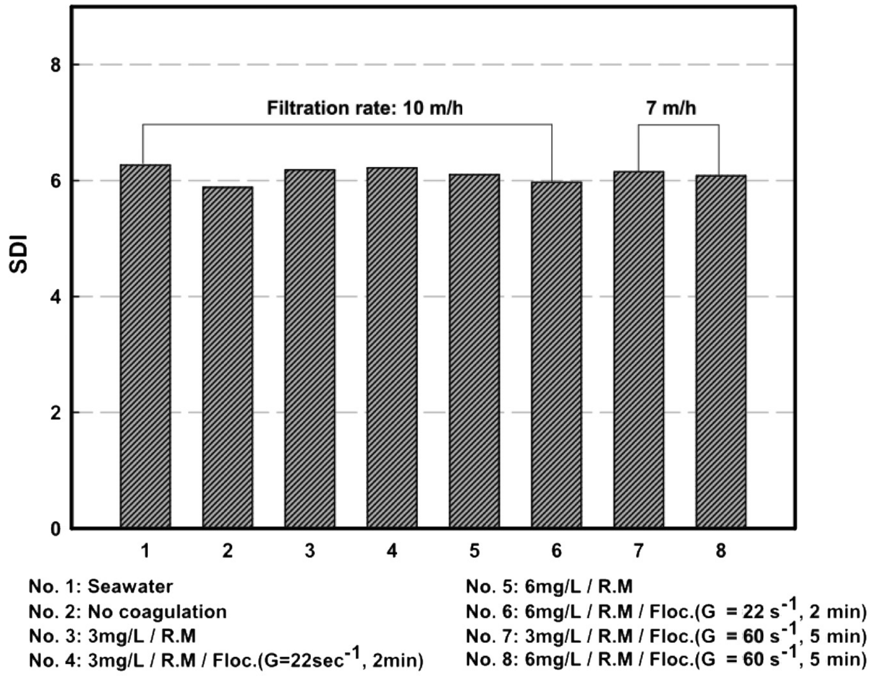


Fig. 4. SDI values for DMF filtrate with various operation conditions.

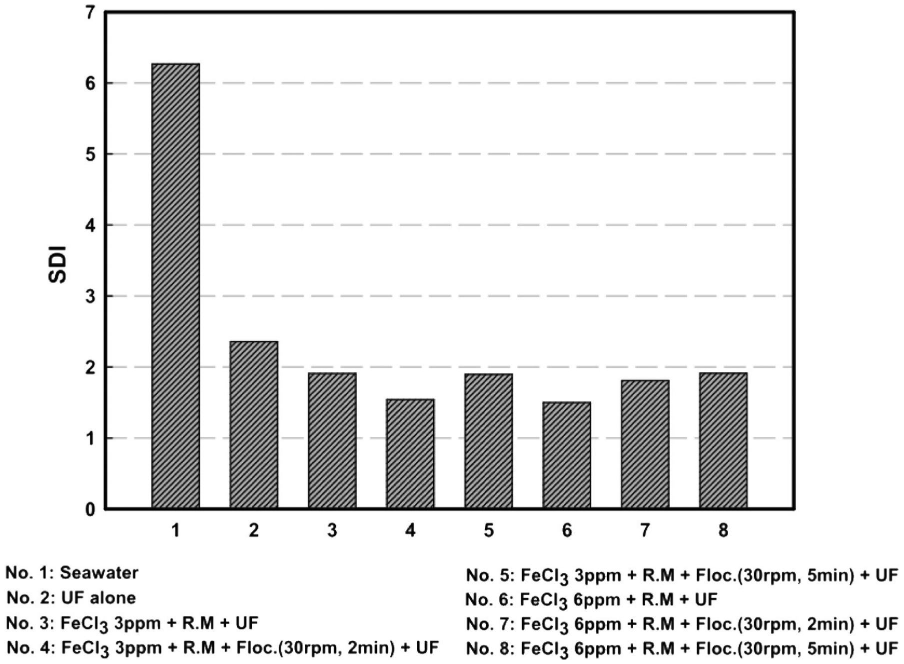


Fig. 5. SDI values for UF permeate with various operation conditions.

higher performance in terms of turbidity removal and SDI decrease than DMF, it did not play an important role to remove aromatic (or hydrophobic) organics by itself.

Addition of coagulant to the UF process not only affects the removal of aromatic organics but also changes the fouling behaviors occurred in the UF membrane. When coagulant was added to the UF system, the gradient of flux decline was decreased [14]. The permeate flux decreased slower as coagulant dose increased as shown in Fig. 7 while the effect of variation in flocculation condi-

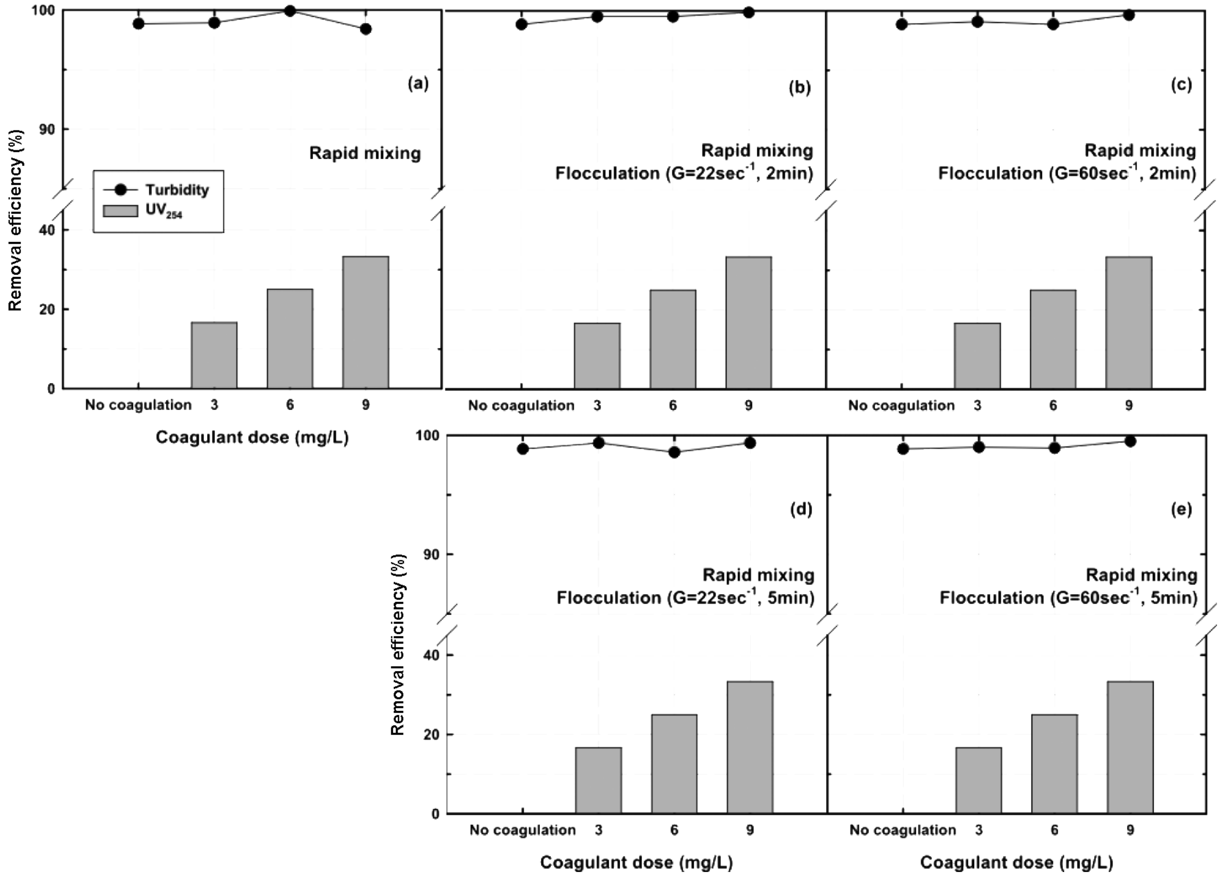


Fig. 6. Effects of the coagulation and flocculation conditions on the removal efficiencies of UV_{254} and turbidity in UF.

tions was almost negligible, which is a similar trend to the case shown in the DMF tests. From the tested conditions in this study, it might be concluded that flocculation followed by rapid filtration processes such as DMF and UF could not affect the performances of DMF and UF in terms of product water quality and fouling behavior. Coagulant addition and rapid mixing are enough to enhance the performance of UF. This kind of trend was already reported in a previous reference [15].

3.3. Factors affecting SDI

The UF membrane produced the high quality RO feed water with SDI values close to 2 while DMF made the product water with SDI values close to 6, which is not acceptable as RO feed water. The product turbidity of DMF and UF were about 0.15 and 0.05 NTU, respectively. In the case of DMF, low turbidity values of about 0.15 NTU did not assure low SDI value enough to be fed to RO system. As discussed earlier, the main sources to increase SDI values could be materials which tend to be undetectable to the turbidity meter.

Instead of turbidity, particle counts can be an alternative method to be related to SDI values. Fig. 8 shows the results of particle size distribution in the case of DMF and UF with a coagulant dose of 6 mg/L and various flocculation conditions. Particles whose diameters are smaller than 5 μm turned out to be the main sources to increase SDI values as shown in Fig. 8. As an additional verification of this fact, the raw seawater filtered by 1.2 and 0.45 μm pore size filters were collected and analyzed. The SDI values were 4.0 and 2.0 for the sample filtered by 1.2 and 0.45 μm pore size filters, respectively. Particles with several μm in diameter are not easily removed by DMF as discussed in a literature [16] and increase SDI values as shown in Fig. 8.

4. Conclusions

The performances of DMF and UF processes as a pretreatment for SWRO processes were discussed by carrying out the lab-scale experiments using the raw seawater with rather low turbidity. UF process showed a good performance to produce high quality RO feed water with low SDI values while DMF could not. The performance of UF can be better with coagulation in terms of aromatic organic removal and less fouling behaviors. Coagulant

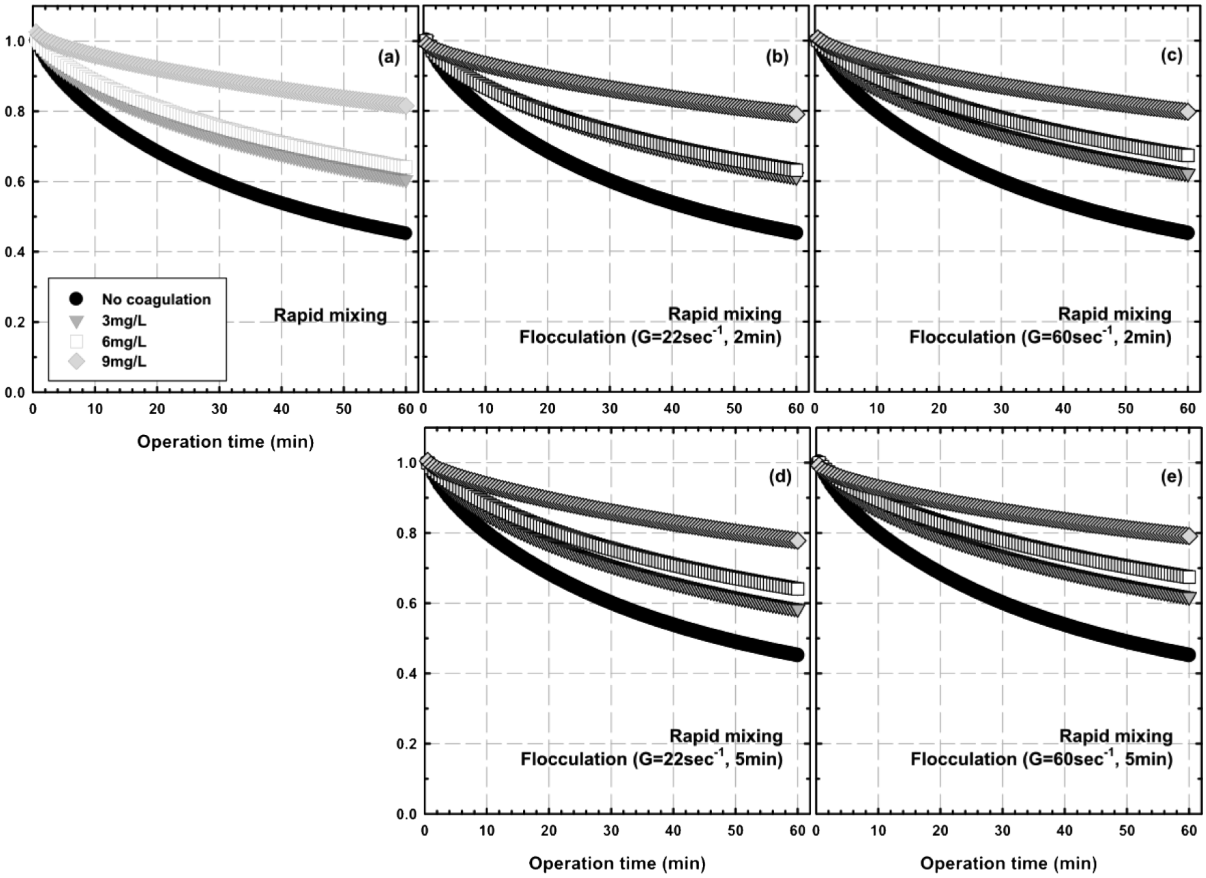


Fig. 7. Changes in UF permeate flux under various coagulation and flocculation conditions.

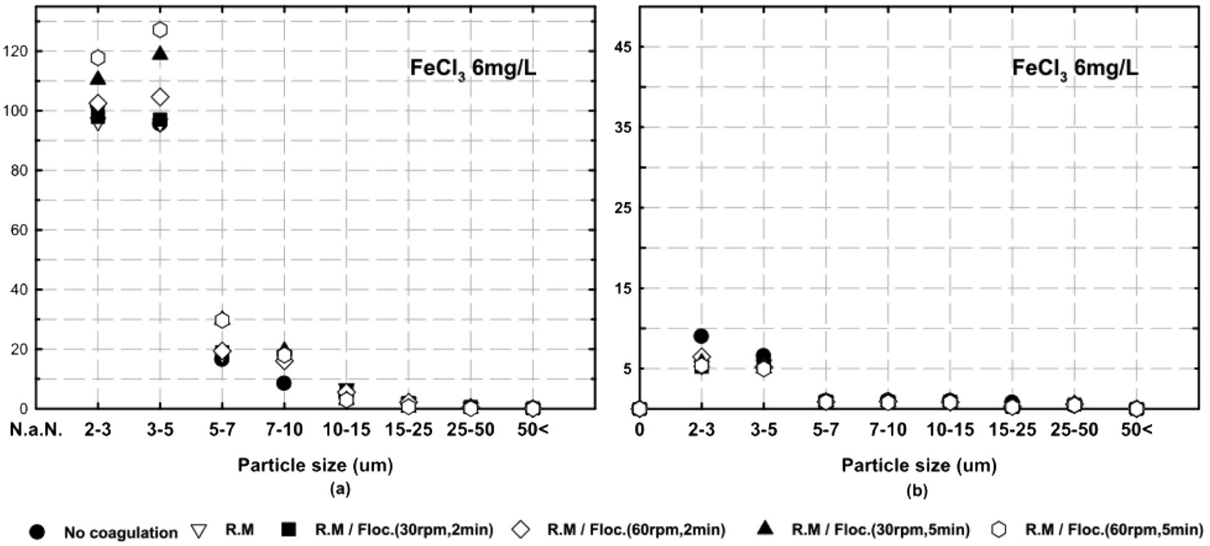


Fig. 8. Particle size distributions for (a) the DMF filtrate and (b) the UF permeate.

addition and rapid mixing were enough to enhance the performance of UF while several flocculation conditions did not affect it.

DMF process tested in this study failed to remove several μm sized particles which are main sources to increase SDI values. Variations in operation conditions including filtration rates, coagulation and flocculation conditions could not help DMF to produce qualified RO feed water.

Two possible reasons can be suggested to explain the low performance of DMF which has been the most popular pretreatment process for the SWRO system. First, the tested DMF process was operated with the single-pass mode. If the single-pass DMF filtrate is re-filtered by consecutive DMF (so-called, the double-pass mode), SDI might be decreased to produce RO feed water. Second, the turbidity of raw seawater may be too low to be effectively flocculated and removed by DMF.

For a low turbidity condition, improved coagulant performance can be achieved by supplementing the initial turbidity such as silica particles and/or by using a voluminous Fe precipitate which can enhance the rate of flocculation [17]. This can make the design and operation of DMF more difficult. Therefore, it can be concluded that membrane based pretreatment systems such as MF and UF are preferred in the case of a low turbidity condition.

Acknowledgement

This research was supported by a grant (10Sea-HeroB04-01-02) from the Plant Technology Advancement Program funded by the Ministry of Land, Transport and Maritime Affairs, Korea.

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