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# Effects of various characteristics of seawater on the performance of dual media filters

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ABSTRACT

In this study, effects of various water quality parameters (TDS, turbidity, DOC) on seawater filtration were evaluated using the laboratory scale dual media filter (DMF). For this purpose, DMF was operated with and without in-line coagulation to filter four different types of artificial seawater. The standard seawater (type 1) was used as a control condition. The type 2 feed was used to examine the effect of TDS, type 3 for the effect of turbidity and type 4 for the effect of organic matter. According to this study, high TDS was beneficial in turbidity removal when DMF filtration was performed without coagulation. High ionic strength reduced the electrical repulsion, helping particle capture by the filter media. In-line coagulation diminished the beneficial effect of TDS. Backwash with wash water alone was found insufficient to clean the media effectively when DMF was filtering highly turbid seawater. Coagulation helped backwash of DMF and restored the turbidity removal performance after backwash when filtering highly turbid seawater. Coagulation also lessened the extent of the solid breakthrough. Coagulation helped the organic removal by DMF, but deteriorated the turbidity removal performance instead.

*Keywords:* Seawater; Coagulation; Dual media filtration; Backwash; TDS; Turbidity; DOC

## 1. Introduction

Currently, with water shortages due to the limited availability of freshwater sources, and the reduced cost of reverse osmosis (RO) membrane technology, municipal systems worldwide are considering whether they can use seawater as a drinking water source [1,2]. For seawater desalination, RO membranes are focused mainly on removing salts and dissolved ions. However, some particulate matters in the source water can potentially foul the membrane, which results in poor-quality effluent and increase operation costs [3]. So, the RO system requires appropriate pre-treatment.

Dual media filtration (DMF) is a conventional system traditionally used for the production of drinking water. According to Cline [4], a conventional DMF is most efficient at removing particles down to 10–20 μm, with supplement of appropriate coagulation and other system operation. The other advantage of DMF is the cost benefit. The cost of media replacement is extremely low, since the life is long and the media itself is inexpensive. In addition, it does not tend to foul and is generally considered to be very sturdy. Recently, low pressure membrane filtration such as microfiltration or ultrafiltration has been proved to be more efficient at the particle removal but these kinds of process require higher capital and operating costs than DMF [5,6].

Physically, inside DMF, there is a porous media, which the feed water passes through to remove particles

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held in suspension. The action that takes place in DMF is extremely complex. Particles are removed by combination of interception, Brownian motion, and sedimentation. Sand and anthracite are commonly used for a DMF media. Sand–anthracite media filter provides high suspended solid removal efficiency since most removals are achieved by the upper anthracite layer for a substantial period of time, whereas the lower sand layer provides additional removal producing high quality filtrate [7]. For these reasons, DMF has been the choice of seawater desalination pretreatment and has been widely used even in far away communities because of its simple technology and low construction and operation costs.

There are many experimental studies about DMF as seawater pretreatment for RO [5,8–11]. However, there is a lack of experimental data focusing on the effects of varying water quality parameters on the DMF performance, so some crucial points are still unknown. This paper focuses on the study of parameters that influence the DMF performance. Understanding how and why the DMF performance was unsatisfactory depending on experimental and field conditions would be helpful for improvement of the filtration efficiency. The study objectives are to examine how different feed water qualities would affect the DMF performance. Thus, the feed seawater was varied in terms of ionic concentration (total dissolved solids, TDS), inorganic concentration, and dissolved organic carbon (DOC) concentration. The effects of varying water quality parameters on filtrate quality, head loss development, backwash efficiency were examined.

## 2. Materials and methods

### 2.1. Feed water

The base composition of feed water is shown in Table 1. Tap water was used to prepare artificial seawater. Four types of artificial seawater are used in this study (Table 2). The artificial seawater is prepared according to the standard methods [12]. Type 1 feed represents the standard seawater, type 2 the seawater high in TDS level (45,000 mg/l), type 3 the seawater high in turbidity (20 NTU), and type 4 the seawater high in organic concentration (DOC 10 mg/l). Kaolin is used to induce turbidity and Aldrich humic acid to induce DOC. Type 1 is used as a control condition. Type 2 is selected to examine an effect of TDS on the DMF performance. Types 3 and 4 are selected to examine effects of turbidity and DOC. The pH of seawater is 8.0.

### 2.2. Laboratory scale filter column

As shown in Fig. 1, the small filter column with 2.2 cm in diameter and 25 cm in height is used in this study.

Table 1
The base composition of artificial seawater (TDS of 34,000 mg/l)

| Composition | Concentration, mg/l |
|---|---|
| NaF | 3.0 |
| $SrCl_2\cdot6H_2O$ | 20.0 |
| $H_3BO_3$ | 30.0 |
| KBr | 100.0 |
| KCl | 700.0 |
| $CaCl_2\cdot2H_2O$ | 1470.0 |
| $Na_2SO_4$ | 4000.0 |
| $MgCl_2\cdot6H_2O$ | 10,780.0 |
| NaCl | 23,500.0 |
| $Na_2SiO_3\cdot9H_2O$ | 20.0 |
| $Na_4EDTA$ | 1.0 |
| $NaHCO_3$ | 200.0 |

Table 2
Four types of artificial seawater

| Parameter | Type-1 | Type-2 | Type-3 | Type-4 |
|---|---|---|---|---|
| TDS, mg/l | 34,000 | 45,000 | 34,000 | 34,000 |
| Turbidity, NTU | 2.1 ± 0.2 | 2.2 ± 0.1 | 20.0 ± 0.8 | 2.4 ± 0.6 |
| DOC, mg/l | – | – | – | 9.9 ± 0.5 |

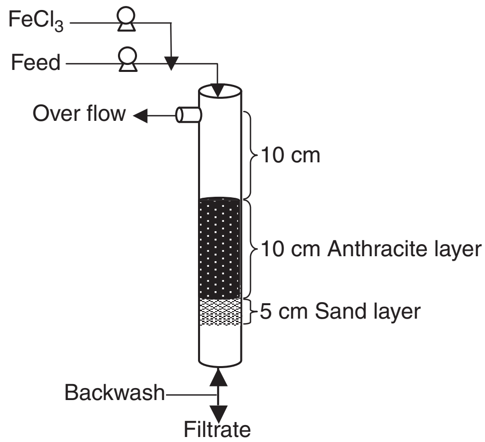


Fig. 1. Schematic of laboratory scale DMF.

The DMF bed consists of anthracite layer (0.9–1.2 mm) and sand layer (0.45–0.70 mm). Specific gravity of anthracite is 1.5, effective size is 0.9 mm, and uniformity coefficient is 1.2. Specific gravity of sand is 2.65, effective size is 0.7 mm, and uniformity coefficient is 1.4. The anthracite layer is 10 cm in depth, and the sand layer is 5 cm. The space (10 cm) above media layer is provided for observing the head loss development during the filtration.

The filtration rate was controlled at 120 m/d. The feed water was supplied to each column by a peristaltic pump at the rate of 31.5 ml/min into the top of the column to let water pass through the media layer from the anthracite layer to the sand layer. To promote particle aggregation within the column, ferric chloride ($FeCl_3$) was added as coagulant at concentration of 4 mg/l. The coagulant was fed using the in-line method. Coagulant was added to the feed line so that coagulant can mix with the feed before passing through the media layers. The coagulant was fed by a micro-tube pump at the rate of 1.3 ml/min. The concentration of coagulant stock solution was 100 mg/l. It was prepared freshly before experiments. One cycle of filtration is 8 h. After 8 h, backwash water was pumped into each column for 10 min by flowing continuously upward at the rate of 1300 m/d. The filter column was backwashed by wash water alone, using upward high flow rate of tap water, resulting in a 20% bed expansion. All experiments were conducted at room temperature (20 °C).

### 2.3. Analytical methods

While in filtration, the filtrate turbidity level and DOC concentration as well as head loss were measured. During the first hour, the filtrate qualities and head loss were measured every 10 min and then, the sampling interval was extended to an hour for remaining hours. Turbidity was measured using a turbidity meter. Head loss was observed by checking the water level over the dual media filter within the column. DOC was detected by TOC analyzer (TOC-$V_{CSH}$ 5000A, Shimadzu).

## 3. Results and discussion

### 3.1. Effect of TDS

In order to examine an effect of TDS on the DMF performance, the feed water was prepared at two TDS concentrations of 34,000 mg/l and 45,000 mg/l. The filtration results of two types of feed water are shown in Fig. 2. Without coagulation, DMF performed better at removing particles from the feed having a higher TDS (type 2). The turbidity removal efficiency was approximately 50% for type 2, while it was around 40% for type 1. Turbidity removal is well reflected by head loss development. Fig. 3 shows that filtration of the high TDS feed (type 2) resulted in higher head loss development than that of the standard seawater (type 1).

In order to describe the deposition of particle in media filtration, the DLVO theory was considered. The DLVO theory describes the colloid stability in aqueous suspension. According to the DLVO theory, the stability of colloidal particles in aqueous suspension depends

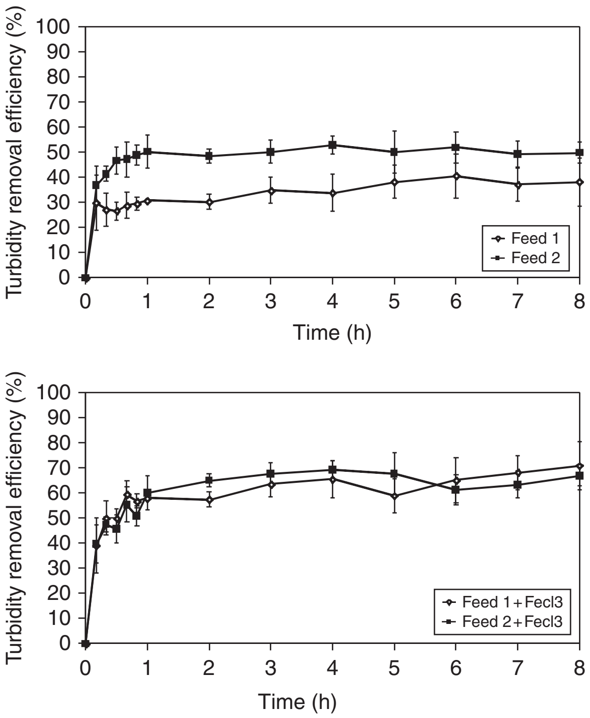


Fig. 2. Turbidity removal efficiency of DMF treating the types 1 and 2 feed with and without coagulation during the filtration cycle.

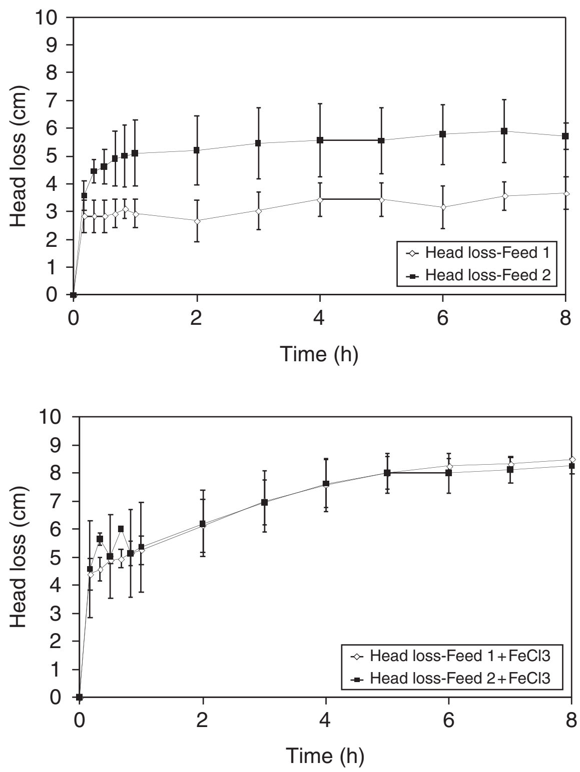


Fig. 3. Head loss development of DMF treating the types 1 and 2 feed with and without coagulation during the filtration cycle.

upon two forces of electrical repulsion and van der Waals attraction. Repulsion energy becomes low when the solution has high ionic strength. The attraction gets high when the inter-particle distance becomes short [13]. The DLVO theory suggests that at high ionic strength, repulsion energy between particles as well as particle and media gets low, which promotes a condition that particles deposit on media. This explains why without coagulation addition, the turbidity removal efficiency from the type 2 feed was higher than the standard seawater (type 1). Further information about the DLVO theory can be found elsewhere [14,15].

This result is in agreement with earlier findings. Fitzpartick and Spielman [16] implied that the ionic property plays an important role in the particle removal of filtration. Chang and Vigneswaran [17] suggested that the filter performance is strongly dependent on the magnitude of the ionic strength. Zachary and Elimelech [18] also indicated that the filter removal efficiency becomes higher when the ionic strength gets higher. Particles at high ionic strength tend to deposit on the media and act as particle collectors.

As shown in Fig. 2, in-line coagulation improved the DMF performance of turbidity removal. After in-line coagulation being provided, the turbidity removal efficiency increased from 40% (average filtrate turbidity of 1.31 NTU) to 58% (average filtrate turbidity of 0.87 NTU) for the standard seawater (type 1). For the type 2 feed, the turbidity removal efficiency was 48% (average filtrate water of 1.15 NTU) without coagulation. The coagulant addition increased the efficiency to 60% (average filtrate turbidity of 0.87 NTU). It seemed that an agglomeration process occurring after coagulation in media filtration overcame effects of electrostatic and van der Waals attraction in a solution [19]. Coagulation increased particle size, which helped particle capture by the filter media. Adding more ions in the feed water helped to promote better turbidity removal when operated without coagulation due to reduced repulsion. However, coagulation diminished this beneficial effect. As beneficial effects of high ionic strength diminished, the head loss profiles for both feeds became similar, as shown in Fig. 3.

### 3.2. *Effect of turbidity*

To examine an effect of turbidity on the DMF performance, the feed water with turbidity of 20 NTU (type 3) was prepared. The filtration with highly turbid seawater was compared to that with the standard seawater (type 1). Fig. 4 shows the turbidity removal profile for both type 3 and type 1 feeds with and without coagulation. During the first hour of operation, the performance of DMF treating the type 3 feed was better than that of the

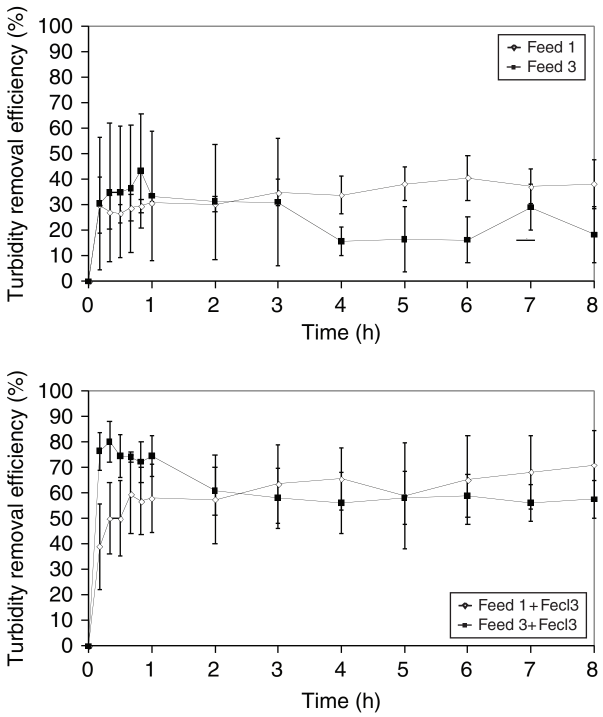


Fig. 4. Turbidity removal efficiency of DMF treating the types 1 and 3 feed with and without coagulation during the filtration cycle.

standard seawater. Then, the turbidity removal profiles for both feed waters became similar during the succeeding two hours. After the operation exceeded 3 h, the performance of DMF treating the type 3 feed deteriorated. Its turbidity removal efficiency dropped to around 20%, being lower than that of the standard seawater. Due to in-line coagulation, the difference was only noted during the first hour of operation. When in-line coagulation was provided, the initial performance of DMF treating the type 3 feed was excellent, reaching 80% after 20 min of operation. It then gradually decreased to 60% after 2 h and stabilized throughout the rest of operation.

The phenomenon called "solid breakthrough" occurs in filtration because of clogging resulting from the accumulation of suspended solids in the filter column. However, the solid breakthrough was not observed in filtration of the standard seawater probably because the filtration cycle (8 h) was short. In DMF, the anthracite layer acts as an initial particle barrier. When the anthracite layer can no longer retain particles, the sand layer provides an additional removal [7]. However, since the amount of turbidity causing particles contained in type 3 feed was too high, the sand layer could not retain particles until the end of the cycle time (8 h). Subsequently, some of particles were dislodged from the media after 2–3 h of operation. The type 3 feed could not be efficiently treated by DMF alone because the capacity of the dual-media layer used in this study was insufficient to handle highly turbid seawater.

High amounts of particles affected backwash efficiency. Backwash with wash water alone was insufficient for cleaning the media when DMF was filtering the type 3 feed. This is clear from Fig. 5. DMF was operated continuously for 72 h to filter the type 3 feed. DMF was operated for 40 h before in-line coagulation was provided. In order to show an effect of high turbidity in the feed on backwash efficiency, turbidity removal profiles for DMF were divided into four periods (Fig. 5); two periods without coagulation (8–24 h, 24–40 h) and two periods after coagulation (40–56 h, 56–72 h). While filtering the type 3 feed without coagulation, DMF removed about 55% of incoming particles during the first 2–3 h of operation (8–24 h). Then, the performance rapidly dropped to 20%. After 24 h operation, the turbidity removal efficiency deteriorated further and barely approached to 20%. This indicates that backwash was not effective. The turbidity removal performance of DMF could not be restored by water wash alone when it was fed with high amount of turbidity causing particles.

The turbidity removal performance of DMF is satisfactory as long as the media layer can retain particles in the suspension. The solid breakthrough occurs after the media reaches its limit of holding particles. This is the reason of the DMF having high removal efficiency in the first three hours of operation until the solid breakthrough occurred. In-line coagulation improved the turbidity removal efficiency of DMF to 65% (average filtrate turbidity of 6.82 NTU). Without coagulation, turbidity removal efficiency was around 25% (average filtrate turbidity of 15.2 NTU). Coagulation also lessened the solid breakthrough. Fig. 5 shows that the solid breakthrough was more severe during 40–56 h of operation than during 56–72 h of operation. As filtration progressed, the extent of the solid breakthrough reduced.

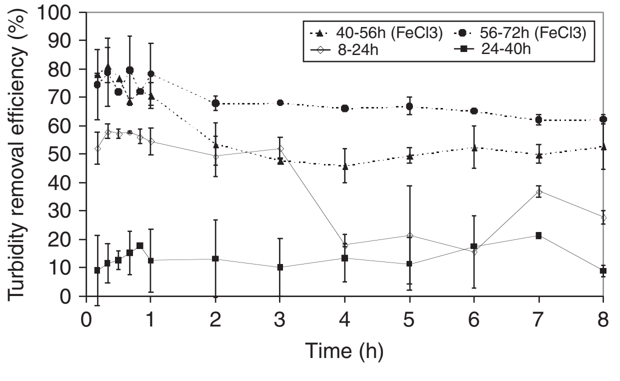


Fig. 5. Turbidity removal efficiency of DMF treating the type 3 feed with and without coagulation during various filtration periods (8–24, 24–40, 40–56 and 56–72 h).

It might be related to the change in particle characteristics resulting from coagulation. Positively charged hydrolysis products of coagulant would adsorb onto negatively charged particles in seawater. The resulting destabilized particles are then attracted to the media easily because the particle grows in size. The particle characteristics are changed while positively charged coagulant hydrolysis products adsorbs onto particles. The surface modified particles might be easier to retain by the media.

In-line coagulation was also beneficial for restoring the turbidity removal performance of DMF after backwash. The turbidity removal performance of DMF was restored with coagulation by water wash alone. Fig. 5 shows that initial turbidity removal efficiency of DMF was around 50% without coagulation (8–24 h) and 75% with coagulation (40–56 h/56–72 h). After backwash, initial turbidity removal efficiency dropped to around 10% without coagulation (24–40 h), indicating that backwash with wash water alone was insufficient to restore the turbidity removal performance. However, the initial turbidity removal efficiency of 75% could be maintained when in-line coagulation was provided. This might be also related to the change in particle characteristics resulting from coagulation. Coagulation modified the particle characteristics so that retained particles by the media could be dislodged easily by water wash. Nonetheless, the final turbidity was still high, even with coagulant addition because initial turbidity of the type 3 feed was too high for the media layer to sufficiently handle. Increasing the media depth could be an option to improve the performance in filtration of highly turbid seawater.

Fig. 6 shows the head loss profiles for the type 1 and 3 feeds with and without coagulation. The type 3 feed caused higher initial head loss than the standard seawater. Without coagulation, head loss barely increased during the filtration cycle. As more particles were retained by the filter media with coagulation, head loss linearly increased with time. It is interesting to note that filtration of the standard seawater induced higher head loss development than that of the type 3 feed. It could be related to the porosity. The Carman–Kozeny equation shows that porosity is related to the filter head loss. In filtration of the standard seawater, in-line coagulation could produce small size flocs leading to low porosity. On the other hand, big flocs could be produced in filtration of the type 3 feed due to high amount of particles being added, leading to high porosity.

$$\frac{\Delta h}{L} = k \cdot \frac{\mu}{\rho_w g} \cdot \frac{(1-\varepsilon)^2}{\varepsilon^3} \cdot S_0^2 \cdot V_0$$

where $\Delta h$ is the head loss; $L$, the media depth; $K$, the Kozeny constant; $\mu$, the viscosity; $\rho_w$, the density; $\varepsilon$, the porosity; $S_0$, the specific surface area and $V_0$ is the filtration velocity.

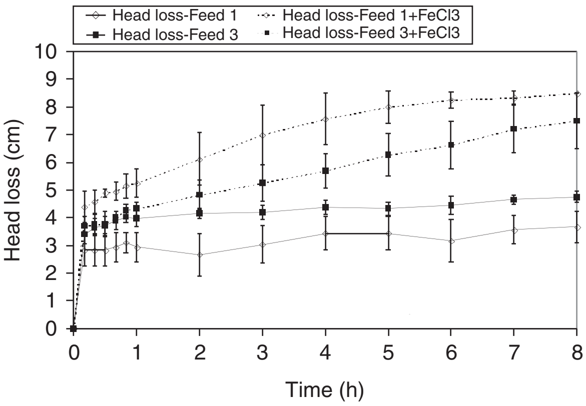


Fig. 6. Head loss development of DMF treating the types 1 and 3 feed with and without coagulation during the filtration cycle.

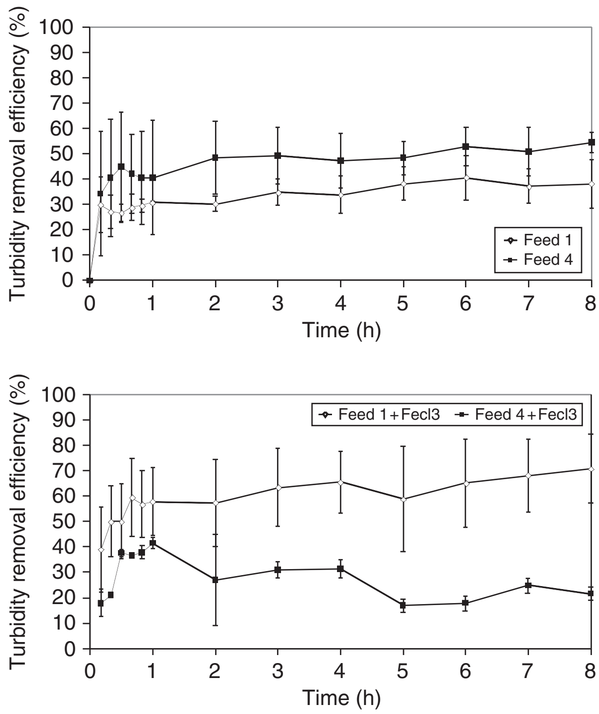


Fig. 7. Turbidity removal efficiency of DMF treating the types 1 and 4 feed with and without coagulation during the filtration cycle.

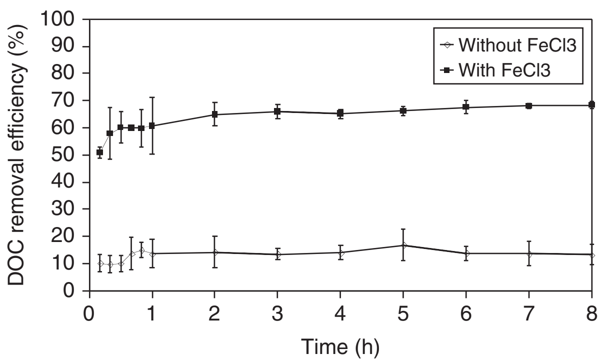


Fig. 8. DOC removal efficiency of DMF treating the type 4 feed.

### 3.3. Effect of organic matter

To examine an effect of organic matter on the DMF performance, feed water with DOC concentration of 10 mg/l (type 4) was fed into DMF. Fig. 7 shows the comparison of turbidity removal efficiencies between the type 4 feed and type 1 feed both with and without coagulation. The turbidity removal performance of DMF filtering the type 4 feed varied depending on coagulation. Without coagulation, the type 4 feed was easier to treat in terms of turbidity removal than the standard seawater even though the difference was not significant. In-line coagulation reversed the results. In-line coagulation improved the turbidity removal performance of DMF filtering the type 1 feed. On the other hand, the turbidity removal performance deteriorated when in-line coagulation was provided to DMF filtering the type 4 feed.

While coagulation deteriorated the turbidity removal performance, it helped the organic removal. As shown in Fig. 8, in-line coagulation increased the DOC removal efficiency of DMF from 17% to 63%. This result indicates that ferric chloride preferably reacted with organics in the feed. The resulting Fe–HA complex was effectively retained by DMF. It seemed that the retained Fe–HA complex then prevented particles initially present in seawater from sitting on the media, as shown in the solid breakthrough (Fig. 7). The breakthrough occurred in filtration of the type 4 feed with coagulation despite the turbidity level of raw seawater was not high. The solid breakthrough was observed shortly (1 h) after filtration started, indicating particle dislodgement from the media. Fe–HA complex could be related to early breakthrough. Fe–HA complex probably coated the media of DMF, while particles are captured by the media. Then, the coating modified the media surface characteristics, which could prevent particles from attaching onto the media. Subsequently, bleeding of captured particles was observed.

Fig. 9 shows the head loss profiles for the standard seawater and the type 4 feed. The type 4 feed initially caused higher head loss than the standard seawater probably due to organic clogging of the media. During the filtration cycle, head loss slowly increased without coagulation. With coagulation, head loss increased gradually with time. Lower head loss development was observed in filtration of the type 4 feed than the standard seawater in consistent with lower turbidity removal.

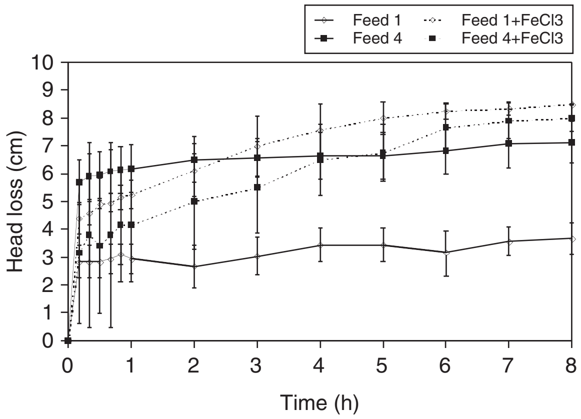


Fig. 9. Head loss development of DMF treating the types 1 and 4 feed with and without coagulation during the filtration cycle.

## 4. Conclusions

Effects of various water quality parameters (TDS, turbidity, DOC) on seawater filtration were evaluated in this study. For this purpose, DMF consisting of anthracite layer and sand layer was operated with and without in-line coagulation. According to this study, high TDS was beneficial in turbidity removal when in-line coagulation was not provided. High ionic strength reduced the electrical repulsion, helping the particle capture by the filter media. However, this beneficial effect of TDS was diminished by in-line coagulation. Addition of turbidity causing particles brought in early solid breakthrough. Backwash with wash water alone was insufficient to clean the media effectively when DMF was filtering highly turbid seawater. Coagulation helped backwash and restored the turbidity removal performance of DMF after backwash. Coagulation also lessened the extent of the solid breakthrough. Coagulation helped the organic removal by DMF, but deteriorated the turbidity removal performance instead.

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## References

[1] J.K. Kaldellis and E.M. Kondili, The water shortage problem in the Aegean archipelago islands: cost-effective desalination prospects, Desalination, 216(1–3) (2007) 123–138.
[2] L. Zhang, L. Xie, H.L. Chen and C.J. Gao, Progress and prospects of seawater desalination in China, Desalination, 182 (1–3) (2005) 13–18.
[3] S.H. Kim, S.H. Lee, J.S. Yoon, S.Y. Moon and C.H. Yoon, Pilot plant demonstration of energy reduction for RO seawater desalination through a recovery increase, Desalination. 203 (2007) 153–159.
[4] D.A. Cline, Filtration options for pretreatment of demineralization, Proceeding of the International Water Conference, Pittsburgh, PA, 2000.
[5] A. Brehant, V. Bonnelye and M. Perez, Comparison of MF/UF pretreatment with conventional filtration prior to RO membranes for surface seawater desalination, Desalination, 144(1–3) (2002) 353–360.
[6] K.T. Chu, M.N.A. Hawlader and A. Malek, Pretreatment of seawater: results of pilot trials in Singapore, Desalination, 159 (2003) 225–243.
[7] J.Y. Shin and C.R. O'Melia, Pretreatment chemistry for dual media filtration: model simulations and experiment studies, Water Sci. Technol., 53(7)(2006) 167–175.
[8] A. Zouboulis, G. Traskas and P. Samaras, Comparison of single and dual media filtration in a full-scale drinking water treatment plant, Desalination, 213(1–3) (2007) 334–342.
[9] S.L. Kim, J. Paul Chen and Y.P. Ting, Study on feed pretreatment for membrane filtration of secondary effluent, Sep. Purif. Technol., 29(2) (2002) 171–179.
[10] S.T. Mitrouli, S.G. Yiantsios, A.J. Karabelas, M. Mitrakas, M. Føllesdal and P.A. Kjolseth, Pretreatment for desalination of seawater from an open intake by dual-media filtration: pilot testing and comparison of two different media, Desalination, 222 (2008) 24–37.
[11] S.T. Mitrouli, A.J. Karabelas, S.G. Yiantsios and P.A. Kjølseth, New granular materials for dual-media filtration of seawater: pilot testing, Sep. Purif. Technol., 65(2) (2009) 147–155.
[12] A.E. Greenberg, L.S. Clescerl and A.D. Eaton, Standard Methods for the Examination of Water and Wastewater, 19th ed., American Public Health Association, Washington DC, 1995.
[13] B. Dobias, Coagulation and Flocculation: Theory and Applications, Marcel Dekker, Inc., New York, 1993.
[14] B. Derjaguin and L. Landau,. Theory of the stability of strongly charged lyophobic sols and of the adhesion of strongly charged particles in solution of electrolytes, Acta Physicochim. URSS, 14 (1941) 633–662.
[15] E.J.W. Verwey and J.T.G. Overbeek, Theory of the Stability of Lyophobic Colloids, Elsevier, Amsterdam, 1948.
[16] J.A. Fitzpartick and L.A. Spielman,. Filtration of aqueous latex suspension through beds of glass spheres, in Ref. [17].
[17] J.S. Chang and S. Vigneswaran, Ionic strength in deep bed filtration, Water Res. 24(11) (1990) 1425–1430.
[18] A.K. Zachary and M. Elimelech, Direct microscopic observation of particle deposition in porous media: role of the secondary energy minimum, Colloids Surf. A., 294 (2007) (2006) 156–162.
[19] B. Koglin and H. Rumpf, Chem. Ing. Tech. 48 (1997) 335, in Ref. [13].