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Application of dissolved air flotation as pretreatment of seawater desalination

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ABSTRACT

The performance of dissolved air flotation (DAF) was evaluated for pretreatment of seawater desalination in this study. For this purpose, DAF was compared with dual medial filtration (DMF) for its performance of particle removal and organic reduction through pilot-scale experiments. A pilot-scale DAF plant with capacity of 3.2 m^3/h was installed at southern coast of the East Sea and operated for four months (June–September, 2009). According to this study results, the organic reduction performance of DAF was comparable to that of DMF. Both DAF and DMF removed the same organic fraction. However, DAF could not match DMF in particle removal. The association of DAF and DMF could improve the pretreatment performance and better filtrate quality was obtained in terms of particle removal. The association reduced the clogging head loss and initial turbidity breakthrough.

Keywords: Dissolved air flotation; Dual media filtration; Seawater desalination; Pretreatment

1. Introduction

Dissolved air flotation (DAF) is a process to separate solid particle or liquid from a liquid phase using air bubbles [1]. Unlike sedimentation, which separates solid particle by means of the gravitational force, flotation relies upon the buoyant force. Consequently, flotation has an advantage over sedimentation in separation of relatively light particles such as hydrocarbon, algae, etc. The application of DAF is not limited to freshwater. Both pilot and full-scale application studies of DAF as pretreatment of seawater desalination have been reported in literature. The pilot study was conducted in the Persian Gulf with high and unstable SDI (silt density index) and some hydrocarbons. The association of DAF with double stage direct filtration produces a reliable feed water to reverse osmosis (RO) membrane [2]. DAF is effective for removing hydrocarbons when they are present in suspended matters. A full-scale application was reported by the International Power Mitsui Operation and Maintenance Indonesia [3], who is responsible for the operation of a power plant using steam turbine power generation. In order to satisfy all water needs, they operate a RO system to treat raw seawater. According to their operation results, application of DAF and filter as a pretreatment strategy was successful producing a RO feed water of turbidity less than 0.25 NTU and SDI less than 1.5 on average.

Nonetheless, dedicated researches on the use of DAF as pretreatment of seawater RO desalination system (SWRO system) are still lacking. The objective of this study is to investigate the feasibility of DAF application as pretreatment of SWRO system. The feasibility was evaluated by comparing the particle removal and organic reduction performances of DAF with dual media filtra-

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tion (DMF). Ssince particles and organics are the most important fouling materials of SWRO system, their removal performances were evaluated. DMF was selected because it is a widely adopted separation process for both freshwater and seawater applications. The performance of DAF was evaluated through pilot-scale experiments.

2. Materials and methods

2.1. Raw seawater

Raw seawater was taken from the southern coast of Korea. Characteristics of raw seawater during the study period are summarized in Table 1. According to Table 1, conductivity and the total dissolved solids (TDS) concentration of raw seawater was comparable to typical seawater quality. Rain increased the suspended solids (SS) concentration and turbidity. The highest SS concentration of 52.0 mg/L and turbidity peak of 17.4 NTU were observed during rain. The article count (>2 μm) also increased close to 9,000 particles per mL. The average COD concentration was 3.7 mg/L and its corresponding level of UV-254 was 1.6 m^{-1}. The chlorophyll-*α* concentration remained low.

2.2. Pilot plant

The pilot plant (3.2 m^3/h) has three basins of rapid mixing basin, slow mixing, and flotation basin as shown in Fig. 1. These basins have the same area of 0.8 m^2 (1 m × 0.8 m), but different depths. The water depths of rapid and slow mixing basin are 0.25 m and that of flotation basin is 1.2 m. The overflow rate was 4.0 m/h and flotation time was 18 min. Flocculation time was 4 min. Ferric chloride (38 %) of 20 mg/L was added to raw seawater. Rapid mixing and slow mixing were provided at 250 rpm and 60 rpm respectively.

Table 1
Characteristics of raw seawater during the study period

Parameter	Concentration
Temperature	17.5–26.0 (23.8)
pH	7.8–8.1 (8.0)
Conductivity, mS/cm	49.6–51.6 (50.6)
Total dissolved solids (TDS), g/L	34.8–37.9 (36.0)
Suspended solids (SS), mg/L	22.0–52.0 (35.6)
Turbidity, NTU	2.0–17.4 (5.8)
Particle count (> 2 μm), #/mL	5,207–8,932 (7,846)
Chemical oxygen demand (COD), mg/L	2.0–8.4 (3.7)
UV-254, 1/m	1.1–2.3 (1.6)
Chlorophyll-α , mg/m^3	1.1–2.8 (1.8)

*Values in parenthesis indicate the average values

The operating pressure affects bubble diameter and the recycle ratio affects bubble volume concentration [4]. Small bubbles have large surface area, thus increasing

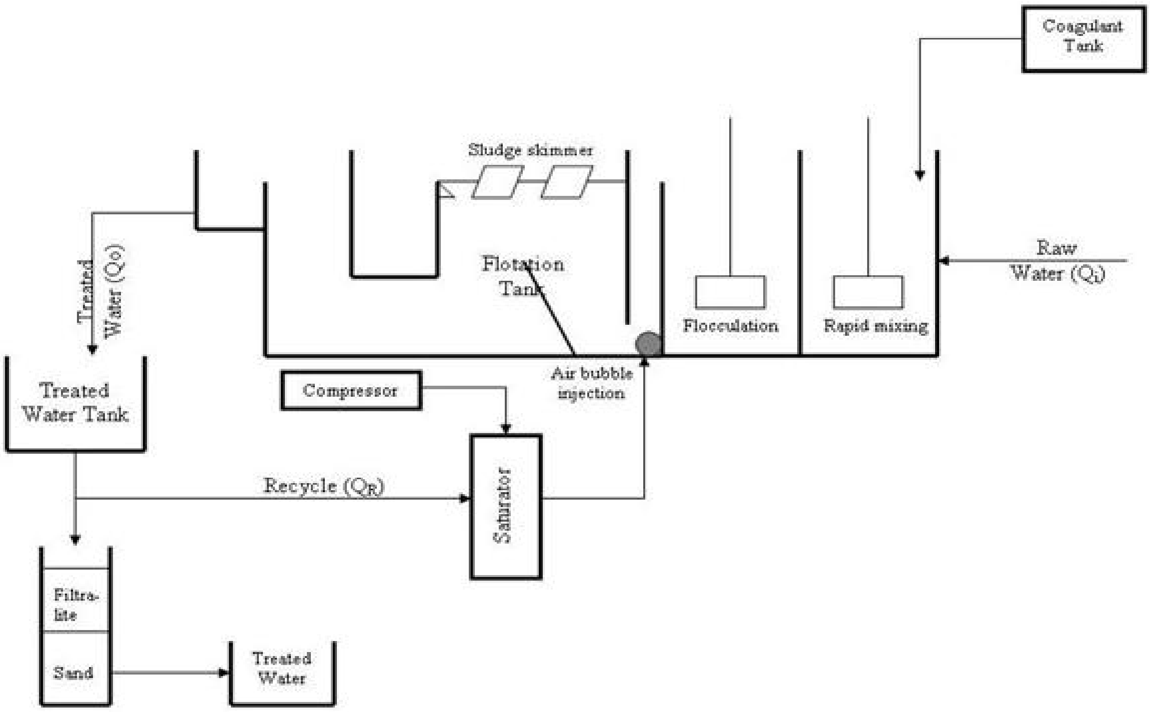

Fig. 1. Schematic diagram of the pilot plant.

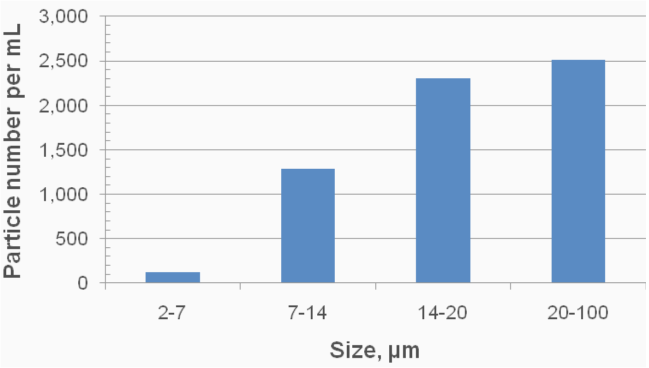

Fig. 2. Size distribution of air bubble formed during DAF operation.

the interfacial area between bubbles and particles to be removed. Large bubble volume concentration ensures more collision opportunities. The operating pressure of 400–600 KPa is generally recommended to ensure formation of small bubbles [4]. Edzwald and Walsh [4] recommended the bubble size of 10–120 μm for DAF operation and a typical design and operation value of the recycle ratio between 6–30%.

The operating pressure of the pilot-scale DAF plant was adjusted to 500 KPa since increasing pressure above 500 KPa has a small effect on bubble size [5]. The recycle ratio was adjusted to 20%. Then, the bubble size was measured using a particle counter. According to Fig. 2, most bubbles formed were in the range of 7–100 μm. This result indicates that the selected pressure was appropriate for DAF operation.

2.3. Experimental method

During the pilot-scale experiments, DAF was operated in parallel with DMF so that the performances of particle removal and organic reduction could be compared. The performances were evaluated by means of the treated water qualities. DMF with anthracite at upper layer and sand at bottom layer was run at the filtration rate of 5 m/h. Ferric chloride of 4 mg/L was added just before DMF for in-line coagulation. DMF was backwashed every 24 h by simultaneous air scouring and sub-fluidized water wash. Later, when the feasibility of the filtration rate increase was tested, anthracite was replaced by Filtralite® and DMF was operated at 10 m/h. Two DMFs were run in parallel: one with DAF and the other without DAF. Their performances were compared by the filtrate quality, head loss, and initial turbidity breakthrough.

2.4. Analysis

Water quality parameters used for evaluation of the particle removal performance include turbidity, particle count and fouling index values, while those for the organic reduction performance include COD concentration and UV-254 level. The fouling index of SDI and MFI (modified fouling index) were measured using 0.45 μm filter paper (Advantec, Japan). Turbidity was measured by HACH 2100N turbidimeter. The particle count was measured by Chemtrac Systems PC 2400PS. The COD concentration was measured using an oxidant of $KMnO_4$. The UV-254 level was measured by Shimadzu UV-1201 UV-VIS spectrophotometer. All analysis was conducted in accordance with the Standard Methods [6] and the Korean Water Analysis Methods [7].

When necessary, high pressure size exclusion chromatography (HPSEC, Shimadzu Corp., Japan) with SEC column (Protein-pak 125, Waters, Milford, USA) was used to determine molecular weight distribution (MWD) of organic matter in raw seawater. A UV detector was used at 254 nm. Calibration was conducted with the standard solution of polystyrene sulfonates with known MW (210, 1,800, 4,600, 8,000, 18,000 Da).

3. Results and discussion

3.1. Particle removal

In order to compare the DAF and DMF performance for particle removal and organic reduction, treated water qualities of DAF and DMF obtained during the pilot plant operation were examined. From comparison of treated water qualities shown in Table 2 with raw water qualities in Table 1, it is clear that the particle removal performance of DAF was unable to match that of DMF. Based on average value, DAF reduced raw water turbidity from 5.8 NTU to 2.2 NTU (62% removal), while DMF reduced to 0.31 NTU (95% removal). Similar results were obtained in particle count. The particle number was marginally reduced by DAF (from 7,846 to 5,712), while it was effectively reduced by DMF. The average particle count of the DMF filtrate was almost one magnitude lower (629) than that of the DAF treated. The low particle removal performance was reflected in the fouling index measurements.

Table 2
Summary of various water quality data during the pilot plant operation

Parameter	DAF treated	DMF filtrate
Turbidity, NTU	1.0–4.2 (2.2)	0.17–0.39 (0.31)
Particle count (> 2 μm), number/mL	2,833–6,970 (5,712)	341–850 (629)
SDI	—	3.1–6.1 (4.9)
MFI, L/s^2	—	11.7–33.1 (18.4)
COD, mg/L	0.8–3.2 (2.3)	0.9–3.2 (2.1)
UV-254, m^{-1}	0.8–1.8 (1.3)	0.9–1.5 (1.3)
Chlorophyll-α , mg/m^3	0.4–1.6 (1.0)	0.7–1.3 (1.0)

The SDI of the DMF filtrate was in the range of 3.1–6.1 with average of 4.9 and the corresponding MFI was in the range of 11.7–33.1 with average of 18.4. However, the SDI of the DAF treated could not be measured when the filtration interval of 15 min was adopted.

Then, the particle size distribution was examined in order to determine the particle size susceptible to be removed by these processes. Fig. 3 clearly shows that DMF is superior to DAF in particle removal. DAF was effective in removal of large particles, but ineffective for removal of small particles (2–4 μm). As the particle size increased, the removal efficiency gradually improved. It was 42% for particles of 4–7 μm, 59% for 7–14 μm, and 68% for >14 μm. Similar trend was observed for DMF. The removal efficiency improved with increasing particle size. Overall, DMF was significantly more effective than DAF for particle removal. DMF even removed substantial amount (90%) of small particles (2–4 μm).

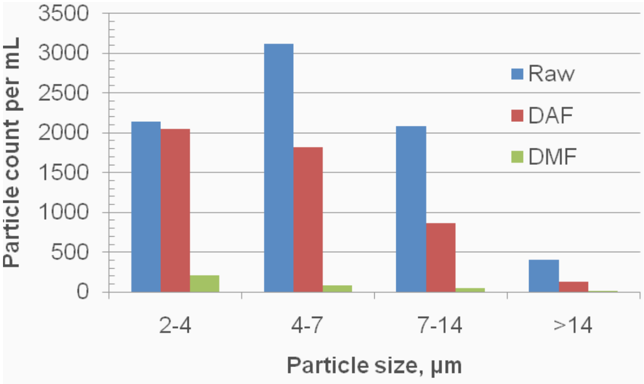

Fig. 3. Particle size distribution of the DAF treated and the DMF filtrate.

3.2. Organics reduction

Unlike particle removal, DAF was effective in organics reduction. According to Table 2, average COD concentration of the DAF treated was 2.3 mg/L (38% reduction) and that of the DMF filtrate was 2.1 mg/L (43% reduction). Average UV-254 of the DAF treated (1.3 m^{-1}) was the same as that of the DMF filtrate. These results indicate that the organics reduction performance of DAF is comparable to that of DMF. DAF also demonstrated the effective removal performance of algae. Average chlorophyll-α concentration of the DAF treated and the DMF filtrate was the same (1.0 mg/m^3).

In order to determine the organic fraction susceptible to be reduced by these processes, MWD analysis was conducted. According to Fig. 4, there were three peaks (180 Da, 800 Da, and 28,000 Da) in raw seawater and the highest peak was recorded at 180 Da. According to Fig. 4, MW fractions of organics reduced by DAF were identical to those by DMF. Both DAF and DMF were very effective in reduction of high MW organic fraction (28,000 Da). As the MW fraction became smaller, the reduction efficiency deteriorated. Nonetheless, they were still able to reduce

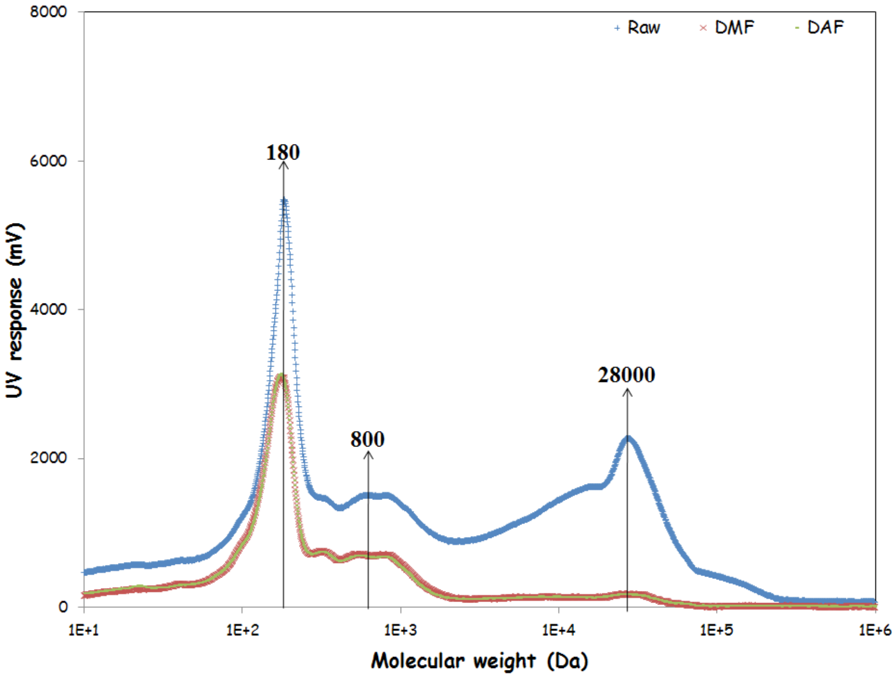

Fig. 4. MWD analysis of the DAF treated and the DMF filtrate obtained during the pilot plant experiments.

some portion of low MW fractions. The MWD analysis confirms that the organic reduction performance of DAF is comparable to that of DMF.

3.3. Association of DAF with DMF

The above results suggest that DAF could not be used alone as pretreatment in seawater desalination due to limited particle removal performance. Subsequently, DAF was associated with DMF to improve the pretreatment performance. It was anticipated that the association of DAF with DMF could not improve the filtrate quality of DMF because the polishing step of DMF could remove whatever DAF removes. As shown above, small particles which DAF was unable to remove, were almost completely removed by DMF. The organic fractions, which were effectively reduced by DAF, could be also removed by DMF.

Nonetheless, the association of DAF with DMF is expected to increase the filtration rate due to reduced contaminant loading. DAF could reduce the contaminant loading to the succeeding DMF. Therefore, the filtration rate was increased to 10 m/h from 5 m/h. As mentioned above, the filter media of upper layer was changed from anthracite to Filtralite® because use of Filtralite® resulted in lower head loss development [8]. Then, the performance of DMF associated with DAF was compared with that of DMF alone.

The association improved the particle removal performance. According to Fig. 5, the association of DAF with DMF reduced the SDI of the filtrate better than DMF alone. Similarly, the association decreased MFI values from 26.4–33.3 s/L^2 to 8.5–10.5 s/L^2. Although data are not shown here, turbidity and particle count also decreased. This result indicates that the association of DAF with DMF can improve the particle removal performance of DMF.

Different results were obtained for organic reduction. The association of DAF with DMF could not improve the organic reduction performance of DMF. There was no significant difference between the COD concentration and UV-254 of the filtrates with and without DAF. This is understandable because the organic fractions reduced by DAF and DMF were identical. Both DAF and DMF removed the same amount of organic matter, but DMF could not remove organic matter after DAF treatment. The association slightly improved the chlorophyll-α removal.

Since head loss of a filter is proportional to the filtration rate, head loss development during filtration was examined while operating DMF with and without DAF. The examination revealed that the clean bed head loss of DMF with Filtralite® and sand at 10 m/h was 0.2 m of water. After 24 h, head loss reached 1.0 m of water without DAF, while it was 0.9 m of water with DAF. Consequently, the one day operation of DMF at 10 m/h resulted in 0.8 m of the clogging head loss while the association of DAF with DMF saved 0.1 m of head loss. Reduced contaminant loading could be responsible for the decreased clogging head loss. As solids are deposited within the void spaces of filter media the porosity decreases which causes clogging head loss development, since most contaminants were previously removed by DAF. Smaller amounts of solids could deposit within the filter media when it was associated with DAF, since a filter is generally provided with the available head loss of 2.4–3.0 m of water [9]. The clogging head loss less than 1 m during filtration of 24 h can be acceptable. This result indicates that DMF with Filtralite® and sand could be operated at 10 m/h for this raw seawater.

The association of DAF with DMF was also beneficial for initial turbidity breakthrough. Fig. 6 shows initial turbidity breakthrough behavior of DMF with and without DAF. Initial turbidity peak just after backwash was 0.17 NTU when DMF was associated with DAF, while it was about 0.25 NTU without DAF. Reduced contaminant loading resulting from DAF pretreatment could decrease the initial turbidity breakthrough. Initial turbidity breakthrough occurs due to backwash remnants, since smaller amounts of solids remained within the filter media after

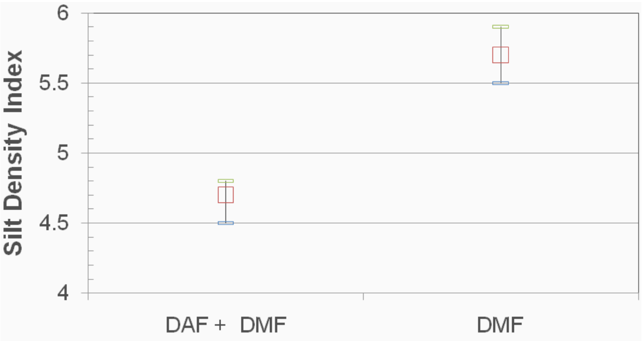

Fig. 5. SDI comparison between DAF+DMF and DMF.

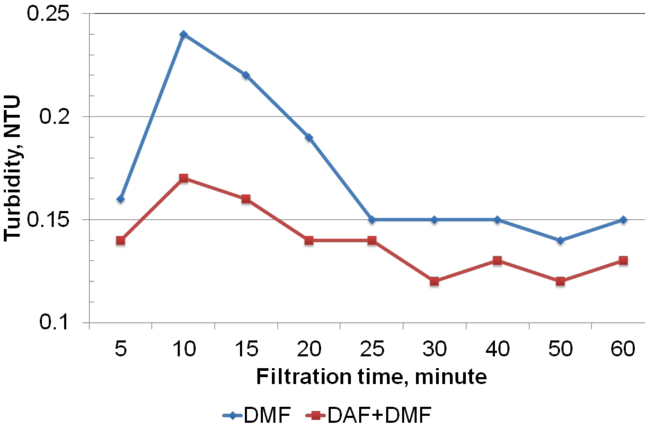

Fig. 6. Comparison of initial turbidity breakthrough between DAF+DMF and DMF.

backwash when DMF was associated with DAF, initial turbidity peak decreased.

4. Conclusions

The performance of dissolved air flotation (DAF) was evaluated for pretreatment of seawater desalination in this study. For this purpose, the performance of DAF was compared with that of DMF for its particle removal and organic reduction from raw seawater using a pilot plant. The examination of water quality data showed that the organic reduction performance of DAF was comparable to that of DMF. The subsequent MWD analysis confirmed that both DAF and DMF removed the same organic fraction. Unlike organic reduction, DAF could not match DMF in particle removal. This result indicates that DAF could not be used alone as pretreatment of seawater desalination. The augmentation of DMF by DAF improved the particle removal performance of DMF, although it could not improve the organic reduction. The association decreased the clogging head loss and initial turbidity breakthrough.

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References

[1] Metcalf and Eddy Inc., Wastewater Engineering: Treatment, Disposal and Reuse. 4th ed., New York, McGraw-Hill, 2003.

[2] V. Bonnelye, M.A. Sanz, J.O. Durand, L. Plasse, F. Guenguen and P.Mazounie, Reverse osmosis on open intake seawater: pretreatment strategy, Desalination, 167 (2004) 191–200.

[3] E. Yulianto, Pretreatment performance monitoring to enhance RO production reliability, PT. International Power Mitsui Operation and Maintenance Indonesia – Operational Experience, 2007.

[4] J.K. Edzwald and J.P. Walsh, Dissolved Air Flotation: Laboratory and Pilot Plant Investigation. AWWA Research Foundation, Denver, Co., 1992.

[5] J. Rubio, M.L., Souza and R.W. Smith, Overview of flotation as a wastewater treatment technique. Minerals Eng., 15 (2002) 139–155.

[6] APHA, AWWA, WEF, Standard Methods for Examination of Water and Wastewater, 19th ed., Washington DC, 1995.

[7] Ministry of Environment, Korean Water Analysis Methods, 2004.

[8] S.H. Kim, J.S Yoon and S. Lee, Comparison of the filtration by different media in pretreatment of seawater desalination by reverse osmosis, J. Korean Soc. Water Wastewater, 23(2) (2009) 215–222 (in Korean).

[9] J.L. Cleasby and G.S. Logsdon, Granular bed and precoat filtration, in R.D. Letterman, ed., Water Quality and Treatment, 5th ed., McGraw-Hill, Inc, New York, 1999.