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Preliminary experiments on UF pretreatment for SWRO

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ABSTRACT

In this study, unlike the previous researches, the pretreatment equipment composed of a 40-μm disk filter and a hollow fiber ultra-filtration (UF) membrane was constructed. The performances of the pretreatment facilities were analyzed on the basis of 5-week-long continuous experiments using sea water. The results confirmed that the newly constructed pretreatment equipment could be used for the pretreatment of sea water reverse osmosis as evidenced by silt density $index_{15}$ values below two for a long period and measured turbidities of about 0.4 NTU. The membrane fouling could be removed by using chemical enhanced backwash. Trans-membrane pressure and the permeability could be returned to the initial conditions. It reveals that UF membrane performances of the pretreatment were dependent on the sea water conditions and operating conditions.

Keywords: Ultra-filtration (UF); Disk filter; Pretreatment; Chemical enhanced backwash (CEB); Silt density index (SDI)

1. Introduction

The sea water reverse osmosis (SWRO) is the most widely used desalination method accounting for 80% of the desalination plants recently installed in the world. This method is simple and low in the investment cost in comparison with other desalination methods. However, the reverse osmosis (RO) plant has the disadvantage of a weakness against fouling [1].

RO membrane fouling has a great influence on the plant performance and it is classified into biofouling, particle fouling, organic fouling, and scaling [2–4]. If RO membrane fouling is not controlled, it shortens the membrane lifetime and the backwashing period. It increases the operating cost due to the low recovery rate. In order to minimize the fouling and extend the membrane lifetime, the feed water to the RO plant should be of high quality. The efficient pretreatment facilities become an essential part of RO desalination plants.

The previous conventional pretreatments basically consist of single or dual media filter, a dissolved air flotation, and a cartridge filter. The technology of coagulating or flocculating contaminants by the chemical

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doses has been applied to these facilities. The previous conventional pretreatments could maintain the Silt density index (SDI) below four and the turbidity below 0.25 for the feed water to the RO plant [5–8].

Recently, microfiltration (MF) and ultrafiltration (UF) have been used more than the previous conventional pretreatments because the MF/UF membranes are more compact and more efficient in protecting the RO membrane from the fouling. The membranes can remove phytoplankton, silica, and organic matter easily. The MF/UF pretreatment has a small footprint and a chemical volume. It can supply high-quality feed water to the RO plant [9,10]. Lately, MF/UF pretreatment facilities operating at low pressure of 2 to 3 bars have been applied [11–17].

Guilibaud et al. [11] tested and compared the performance of UF membrane with polyacrylonitrile (PAN) material and a pore size of 50 kDa, UF membrane with polyethersulfone(PES) material and a pore size of 100 kDa, and MF membrane with polyvinylidene(PVDF) material and a pore size of 0.1 μm. The results showed that the membrane with PVDF material was the most appropriate in the viewpoint of the energy consumption.

Zhang et al. [12] tested the performance of two types of inside-out UF modules with different materials of polyvinyl pyrolidine and PES for the pretreatment of the RO desalination plant with the high turbidity of raw sea water. The experiments were conducted by varying operation parameters such as the flux, the backwash duration, the backwash interval, and the chemical enhanced backwashing (CEB) interval. The test results showed that the two types of pretreatments operated stably and the water qualities also satisfied the conditions for the feed water of the RO plant.

Xu et al. [13] compared the performance of the inside-out and outside-in hollow fiber UF membranes at low temperature (2–7˚C). They reported that at low temperature, the amount of permeate was more for the inside-out membrane than for the outside-in membrane. They also reported that both types of membrane satisfied the conditions of RO feed water and that the hollow fiber UF membrane could be used even at low temperature.

García-Molina et al. [14] tested UF membrane for the pretreatment of 5,500 m^3/day RO desalination plant. They reported that the permeability range of the UF pretreatment was from 120 to 140 LMH/bar and that the trans-membrane pressure (TMP) was about 0.5 bar

To find appropriate operating conditions of the outside-in hollow fiber UF membrane, Riaza et al. [15] conducted the pilot tests by varying the flux from 60 to 110 LMH. They reported that the CEB period decreased a great deal as the flux increased. In addition, they reported that the CEBs could make the system operate stably even at high fluxes.

Brehant et al. [16] applied both the UF membrane pretreatment and the dual media filter (DMF) conventional pretreatment and compared the performance of the two pretreatments. They showed that SDI could not be decreased below 2.5 in the case of DMF pretreatment but it could be reduced below one. They reported that the UF pretreatment was more stable and could provide the better quality permeate to the RO plant.

Chua et al. [17] tested the performances of both the UF/MF membrane pretreatments and the conventional methods. They reported that permeate SDI of the conventional pretreatment ranged from 2.8 to 3.8 and went up to 6.3, while it remained constant below 3 in the membrane pretreatment. They concluded that the membrane pretreatments were more appropriate to the RO plant.

In this study, unlike the previous pretreatment methods, the pretreatment was composed with a 40- μm disk filter and a hollow fiber UF membrane. The pretreatment was stabilized by the continuous operation. Attempts were made to find the basic parameters required for system operations, such as the TMP recoveries by the CEB and the backwashing. The pretreatment system and SWRO were installed at the island campus of Korea Maritime University in Busan located in the southeast part of Korean peninsula. The experiment has been conducted since 19 September. In this study, the 5-week experimental results were analyzed.

2. Materials and methods

2.1. UF pilot system and intake system

The experimental facility consists of two parts, the sea water intake system and the disk filter/UF membrane pretreatment as shown in Fig. 1. The sea water intake system that drives the raw sea water into the laboratory is composed of an intake pump within a vacuum tank and the pipe connecting between the sea and the feed tank. The level difference between the laboratory floor and the average sea level is about 3 m. The intake pump within the vacuum tank is located 2 m below the ground to prevent the cavitation of the pump. Sea water is forced to flow from the sea into the tank by the vacuum pressure induced by the pump (siphon effect). A tray with a mesh screen was installed inside the vacuum tank which removes the foreign material such as sea weeds and sand.

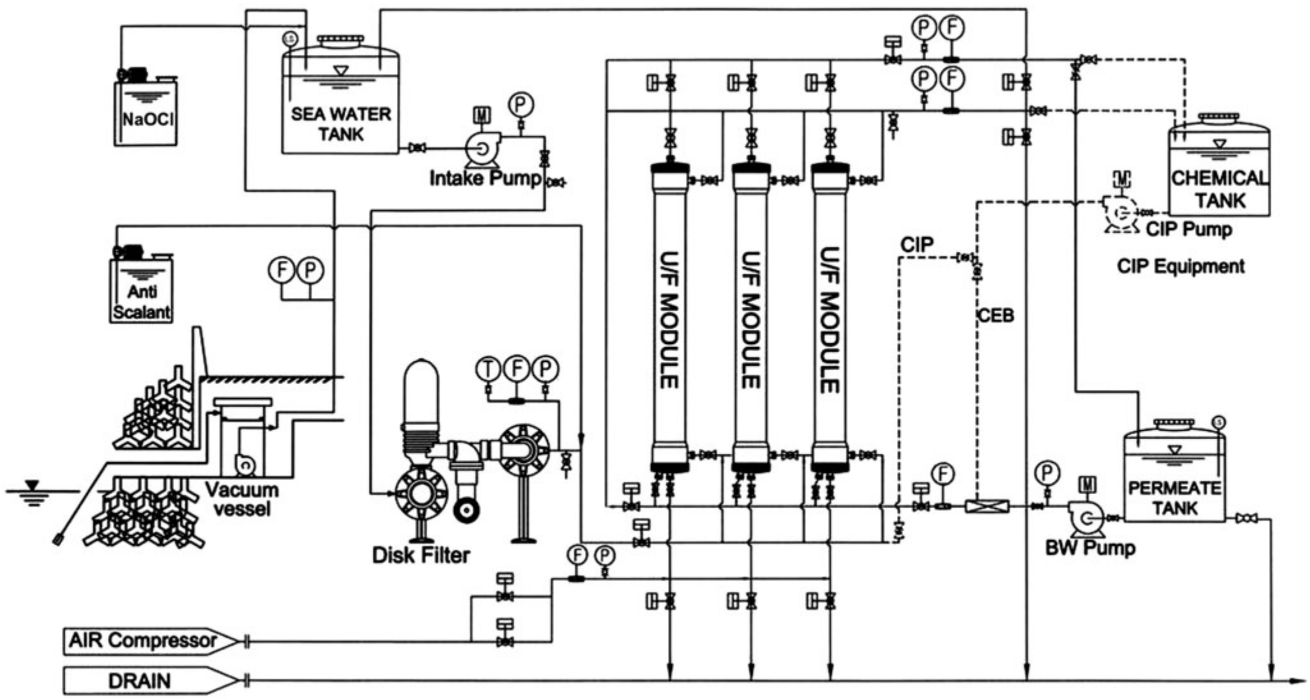

Fig. 1. Schematics of UF pretreatment and intake systems.

Table 1
Specifications of UF membrane

General features	UF
Membrane material	PVDF
Membrane area	60 m^2 (646 ft^2)
Molecular weight cut off	400,000 (Daltons)
Housing construction	ABS, MC nylon
Seal	Polyurethane
Filtration type	Dead-end/Cross flow
Filtration method	Pressure driven filtration

The pretreatment equipment is composed of the hollow fiber UF vessels and the 40 μm disk filter. The disk filter is 2´´ Spin Klin of ARKAL Filtration Systems Ltd. The UF membrane used in these experiments is CSM HFTC 7,090 of Woongjin Chemical Co. Ltd. The detailed specifications of the membrane are given in Table 1. The contaminants attached to the UF membrane were removed by air scouring, backwashing physically and by CEB and clean in place (CIP) chemically. The auxiliary facilities to get rid of the fouling also appear in Fig. 1.

2.2. Experimental methods

In the commission period, the pretreatment facilities were operated intermittently to confirm the functions and the performance verifications of the pretreatment system. During the shutdown period, CEB was conducted and the membrane was soaked by filling NaOCl solution inside the UF vessel. After the typhoon period between August and early September, the system was operated. NaOCl was continuously dosed to the intake tank to maintain its concentration at 2 ppm. An antiscalant was continuously injected between the disk filter and the UF to prevent scale formation on the UF membrane.

The UF operation procedures and the duration time of each process are given in detail in Table 2. The UF membrane was scoured by compressed air and then washed by the mixture of air and the permeate and then by the permeate only. The disk filter removes the suspended solids larger than 40 μm with the options of 30 min backwashing period or 1 bar

Table 2
Processes of UF system and duration times

Processes	Time
Filtration	20 min
1. Air scouring	30 s
2. Air + water washing	30 s
3. Water washing	30 s
Drain	60 s
Flushing	80 s

Table 3
Chemicals and concentrations for CEB and CIP

Chemicals	CEB (mg/L)	CIP (mg/L)
NaOCl	500	2,000
NaOH	500	10,000
H_2SO_4	500	10,000

pressure difference. Almost every time, the disk filter backwashes at 30 min backwash period. Water used for the backwashing of the UF membrane and the disk filter was discharged through a drain pipe.

The chemicals used for CEB and CIP of the UF membrane and the concentration thereof are given in Table 3. During CEB, after circulating an alkaline solution through the UF membrane for 20 min, it was soaked for 40 min. Then, it was rinsed with the permeate and the same process was repeated with an acidic solution. The flow rates of the raw sea water, the permeate and the drain, the inlet temperature, the static pressures at each points, and the turbidities of the raw sea water and the permeate were measured every 10 s.

SDIs of raw sea water and the permeate were measured using OSMONICS AUTOSDI product of GE Infrastructure Water and Technologies Ltd. Samples were forced to flow through the 0.45 μm membrane filter to measure SDI_5 for the raw sea water and SDI_{15} for the permeate. The turbidities of the raw sea water and the permeate were measured with HF Micro TOL of HF Scientific Ltd. The measurement range was 0–100 NTU, and in order to supply samples continuously into the turbidity meters even for the backwashing processes of the disk filter and UF membrane, small tanks were installed between seawater sampling ports and the turbidity meters. The TMP was determined by the pressure difference between the feed raw sea water and the permeate with the hydrostatic pressure taken into consideration.

3. Results and discussions

Experimental results were taken during the period of 5 weeks from 19 September to 22 October. Fig. 2 shows the TMP and the permeability of the UF membrane for 12 h on a typical day. In Fig. 2, the symbols mean the data obtained at every 10 s, and TMP was not corrected for temperature. The part connected by the symbols means the UF filtration process, and the part without the symbols means the processes of the air scouring, back washing, the drain and the flushing. This figure shows that TMP abruptly decreases due to the fact that the contaminant attached to the membrane was removed by the air scouring and the back washing and that then the contaminant attached again to the membrane during the filtration process. Recovered TMP by the backwashing was about 0.028 bar on this period. It also shows that the TMP of the membrane continues to increase due to irreversible fouling as the operation continues.

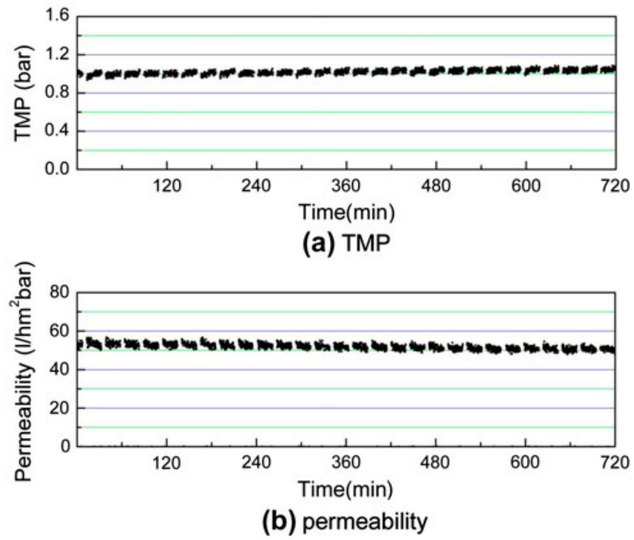

Fig. 2. Variation of TMP and permeability during 6 h operation on a typical day.

In this experiment, the permeate flow rate was almost constant by 9.5 ton/h. The decrease in the permeate flux due to the membrane fouling was insignificant. The variation of the permeability (the permeate flux divided by TMP) is shown in Fig. 2(b). This figure shows that the permeability decreases as much as the TMP increases.

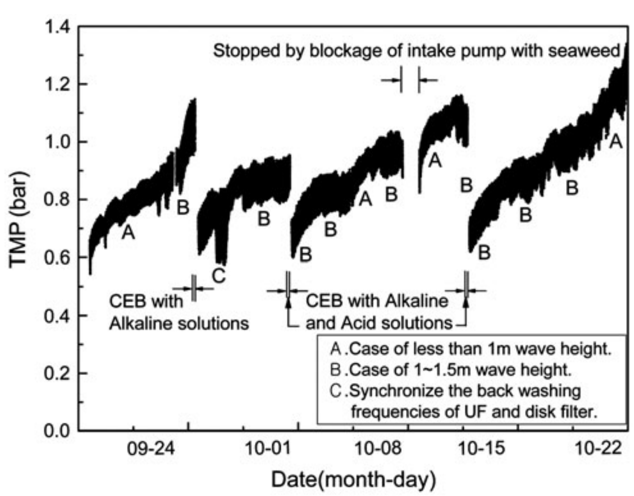

Fig. 3. Impacts of operation time, sea water condition and system operation on TMP.

Fig. 3 shows the change of TMP for 5 weeks. During this period, CEB was conducted three times. In the first CEB, only the alkaline solution was circulated to soak the UF membrane. In the second and third CEB's, after the alkaline solution was circulated to soak the membrane, it was rinsed with the permeate and then the same circulation/soak process was repeated with the acidic solution. Judging from the recovery degree of TMP, it could be confirmed that the alkaline solution was more effective than the acidic one. However, the TMP recovery by the acid solution could not be neglected, and afterwards CEB was conducted using both alkaline and acidic solutions. It reveals that TMP increases on the average by 0.065 bar per day. TMP increased more rapidly within 2 or 3 days after CEB than the remaining period.

As shown in Fig. 3, the TMP change due to the conditions of the sea water and the system operation method was also illustrated. In this figure, period A means the case with a wave height less than 1 m. Period B means the case with a wave height between 1 and 1.5 m. The wave height was determined by eye observation. The change width of TMP during the operation periods closely related with the sea water conditions. The change width of case A, where the sea was quiet, is narrower than case B where the sea was not quiet. Case C represents the change width of TMP during the period when the UF backwashing and the disk filter backwashing are synchronized. TMP change of the membrane for case C was very severe.

Fig. 4 shows the trend of the permeability change for 5 weeks of operation. This figure shows that the permeability returns to the same condition if CEB is conducted in accordance with the TMP change except the first CEB.

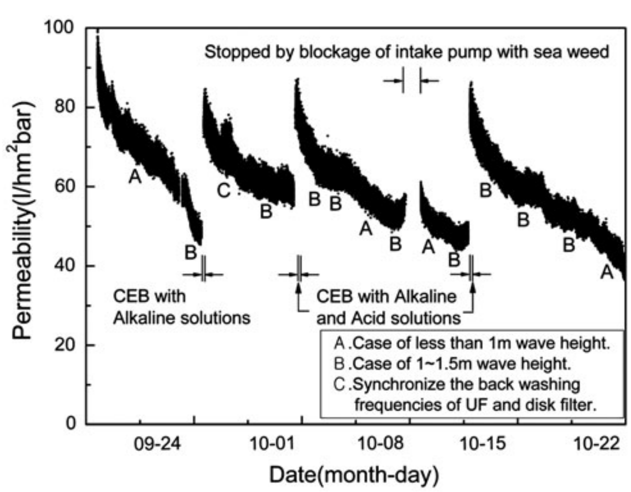

Fig. 4. Trends of permeability during the experiments.

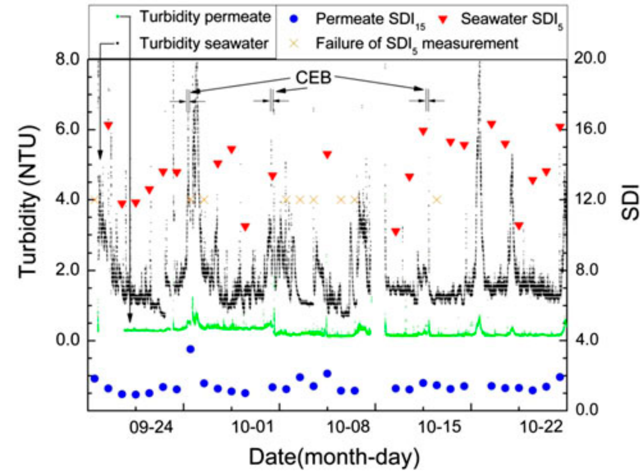

Fig. 5. Trends of turbidity and silt density index.

Fig. 5 shows the turbidity and SDIs of the sea water and permeate measured during the operating period. SDIs were measured for the raw sea water and the permeate once a day. Though the use of SDI as an index for pretreatment performance may be a problem because the effect of the fouling material smaller than 0.45 μmis not considered, it was found in this research that SDI maintained around two during the long period of time. Meanwhile, the turbidity is sometimes used as an index for UF pretreatment, and the results of this research indicate that the measured turbidity maintained below 0.4 NTU during the long period. This figure shows that SDI_{15} of the permeate depends on the turbidities of the permeate and the raw sea water, from which it is conjectured that both the particle fouling and the organic fouling are dominant.

4. Conclusions

The following conclusions were made from the results for 5-week continuous operation of the sea water pretreatment composed of a disk filter and hollow fiber UF membrane:

(1) The system of the present research can be used as the pretreatment of SWRO, since it maintains the SDI_{15} values below 2 for most of the period of 5- week operation and satisfies the high- quality permeate for RO.
(2) The change width of the TMP depends on the system operating conditions and the sea water conditions.
(3) It was found in this experiment that the use of an alkaline solution in CEB was more effective than that of an acidic solution in the present experiments.

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