Study of Environmentally-friendly Pretreatment Technology for SWRO Desalination Plant

YOSHIAKI ITO[*1] MASAYUKI TABATA[*2]
KATSUNORI MATSUI[*3] KAZUHISA TAKEUCHI[*4]
GAKU KONDO[*5] HIDEO IWAHASHI[*5]

Various chemicals are used in the operation of SWRO desalination plants. The use of chemicals has significant environmental and economic influences, such as increased amounts of waste and plant operational costs. Therefore, a process in which the chemical consumption is reduced or no chemicals are used is highly desired. Mitsubishi Heavy Industries, Ltd. (MHI) has been working on the development of chemical-free pretreatment technology that is both environmentally-friendly and economically efficient. MHI conducted a demonstration experiment in Japan and Qatar, adopting the chemical-free sand filtration technology utilized in the Japanese salt manufacturing industry. As a result, the experiment verified that the operation of RO membranes is possible with stable desalination performance and SWRO differential pressure, proving the applicability of chemical-free sand filtration to SWRO desalination using RO membranes.

1. Introduction

Approximately 97% of the water on earth is seawater, and fresh water only accounts for the remaining 3%. Out of the 3%, the amount of water which is actually available such as river water and groundwater is said to be no more than 0.8%(1). Considering the serious water shortages due to the expected global economic growth and population increase in the future, the role that seawater desalination technology plays will be increasingly important as a means of securing precious water resources.

The major technologies of seawater desalination are the evaporation method and the reverse osmosis method. The reverse osmosis method using RO (Reverse Osmosis) membranes has become increasingly popular in recent years, as it consumes less energy and operation/maintenance is easier compared with the evaporation method(2).

Seawater desalination plants take seawater through the water intake facility, remove any substances that would clog pores of the RO membranes such as suspended solids in seawater in the pretreatment facility before pressurizing the seawater in the pressure booster and supplying it to the RO membranes. The permeate water that desalinates through the RO membranes undergoes post-treatment, such as low-pressure RO treatment or the addition of hardness, depending on the level of water quality required prior to becoming available for industrial use, drinking or other purposes. In seawater desalination plants using RO membranes, various chemicals are used to achieve smooth operation. **Table 1** and **Figure 1** show major chemicals and treatment processes/chemicals, respectively. In some plants, in addition to the chemicals used for normal operations, special chemicals for the periodical chemical cleaning of the membranes and disinfectants for preventing biofouling (fouling of membranes and clogging of membrane pores due to microorganisms) may be used. The use of these chemicals has a significant influence on the operational cost of the plant. Furthermore, there is the concern that they significantly affect the

*1 Chemical Research Department, Research & Innovation Center
*2 Chief Staff Manager, Business Intelligence & Innovation Department, Marketing & Innovation Headquarters
*3 Chief Staff Manager, Plant Engineering Department, Plant Engineering Division, Mitsubishi Hitachi Power Systems, Ltd.
*4 Chief Staff Manager, Chemical Research Department, Research & Innovation Center
*5 Project Division, Engineering Headquarters

environment when they are concentrated and returned to the ocean. Therefore, a desalination process using fewer chemicals or no chemicals at all is highly desirable.

Table 1 Major chemicals used for seawater desalination and their purposes

Chemicals	Purposes of the use of chemicals
Sodium hypochlorite	Preventing screens and pipes used for water intake from becoming clogged by marine organisms including shellfish
Sodium bisulfite	Preventing inflow of chlorine which damages the RO membrane through the reduction reaction
Coagulants (Mainly ferric chloride)	Facilitating removal of substances which cause the fouling of the RO membrane, including silt, suspended solids and organic materials, in the pretreatment
Sulfuric acid	Enhancing the effects of coagulants and preventing the generation of scale on the RO membrane

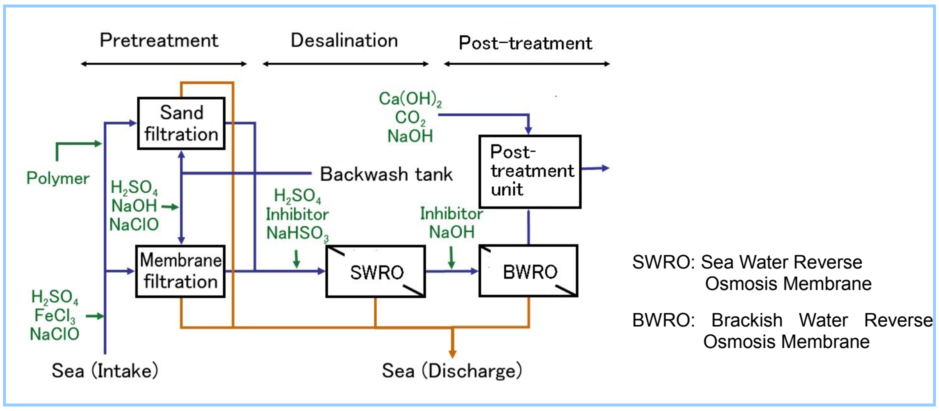

Figure 1 Schematic flow diagram of SWRO desalination plant

2. Advantages of chemical-free pretreatment technology

Introduction of pretreatment technology using no chemicals to SWRO desalination plants will offer numerous benefits.

[Environment]

・No industrial waste

・No influence on the marine ecosystem

[Safety]

・No need to handle dangerous chemicals such as strong acid

[Operation]

・Easier operation with no need for proper handling of chemicals

[Construction costs]

・No facilities for safekeeping/injection of chemicals are necessary.

・No sludge treatment facility is necessary.

[Operational costs]

・Cutting costs for chemicals

・Cutting costs for analyses required for adjusting chemical dosages

・Cutting power use for injecting or churning chemicals

MHI has been working with a continuous effort on the development of chemical-free pretreatment technology for seawater desalination plants. Currently, MHI is carrying out joint research with a client company in Qatar in order to receive the first order for the new-style desalination facilities.

3. Development of chemical-free pretreatment technology

In the Japanese salt manufacturing industry, electrodialysis has been used to make salt for human consumption over the years. The seawater pretreatment applied in this method uses no chemicals including coagulants. The water intake facility is also completely chemical-free with no chlorine, and has been in stable operation at some companies for more than 30 years. The electrodialysis method used in salt production is also a technology utilizing membranes, which has significant applicability to the pretreatment technology in seawater desalination plants[3].

3.1 Demonstration experiment at Naikai Salt Industries Co., Ltd.

MHI conducted a joint survey/research of chemical-free pretreatment technology with Naikai Salt Industries Co., Ltd., which is one of the Japanese leading companies. Naikai Salt Industries applies a two-stage single-layer sand filter in the pretreatment process, where the filtration is operated at a flow rate within the range of regular rapid filtration.

Figure 2 shows the chronological change of the Silt Density Index (SDI) of the filtrate water during the monitoring period. SDI is one of the water quality indices in which the value goes up as the amount of suspended solids in the water increases. As we can see, when the filter restarts after a shutoff, the SDI value goes up first and then down, and returns to a level of water quality similar to what it was before the shutoff after one week. In addition, **Figure 3** shows a profile of Denaturing Gradient Gel Electrophoresis (DGGE) in terms of samples obtained from sand over the same period[4]. The bands indicate the types of bacteria. Therefore, the samples with a band at a different position are considered to have different types of bacteria. From the samples obtained on August 16, immediately after the operation was resumed, a band which had not been identified from the samples taken on August 11, before the shutoff, was observed, in which we can see some changes in the microorganism community. As time passes after the restarting of operation, the band pattern became similar to how it was in the state of the microorganism community before the shutoff. Therefore, we assumed that microorganism community was closely related to the sand filtration performance. Further, from the sand monitoring result shown in **Figure 4**, some substances adhering to the sand were observed. Accordingly, as shown in **Figure 5**, we estimate that, as the clarifying mechanism[5], the biofilm that microorganisms form on the filter catches suspended solids in seawater[6].

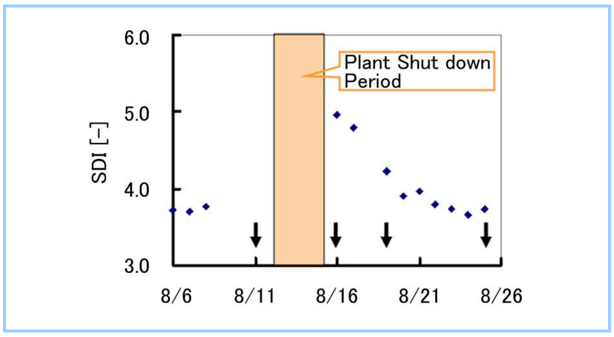

Figure 2 Chronological changes in SDI of filtrate water from chemical-free pretreatment unit

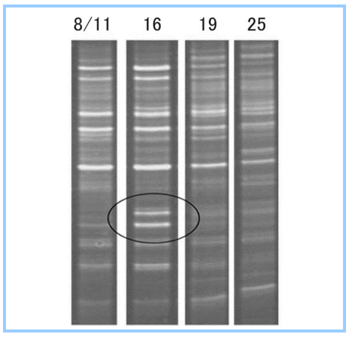

Figure 3 DGGE profile

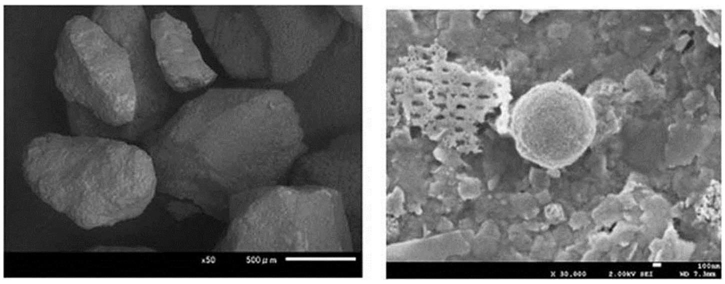

Figure 4 SEM microphotograph of sand media filter

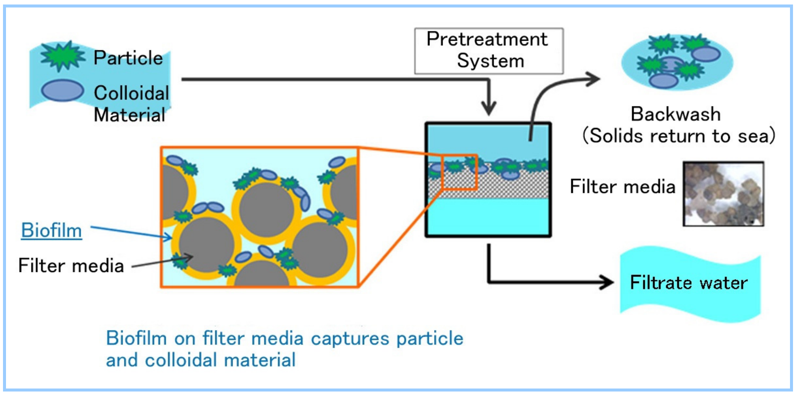

Figure 5 Presumed chemical-free sand filtration mechanism

To verify the presumed mechanism in Figure 5, a laboratory-scale experiment was carried out. The sand media filters used at Naikai Salt Industries were added to Kaolin suspension (a simulated suspended matter) and stirred for 2 minutes. After leaving it to stand for 6 minutes, the absorbance of the suspension (660nm) was measured in order to compare 4 types of sand treatment. **Figure 6** shows the overview and results of the laboratory-scale experiment. The absorbance of the Kaolin suspension, in which the sand used for the chemical-free pretreatment was added, decreased immediately after stopping the stirring (Red line in Figure 6). On the other hand, the green line in Figure 6, representing the suspension with the sand used for the chemical-free pretreatment which was then chlorinated, and the blue line, representing the one in which the sand has undergone ultrasonic treatment, both indicate a gradual decrease in the absorbance. The chlorine treatment and ultrasonic treatment are conducted for the purpose of removing a biofilm formed on the sand media surface. The sand media from which the biofilm had been removed was confirmed to show the similar trend as the sand which was not used for the pretreatment (Brown line in Figure 6). This outcome proves the hypothesis that suspended solids in water are removed by the biofilm formed on the sand media surface at the time of the pretreatment.

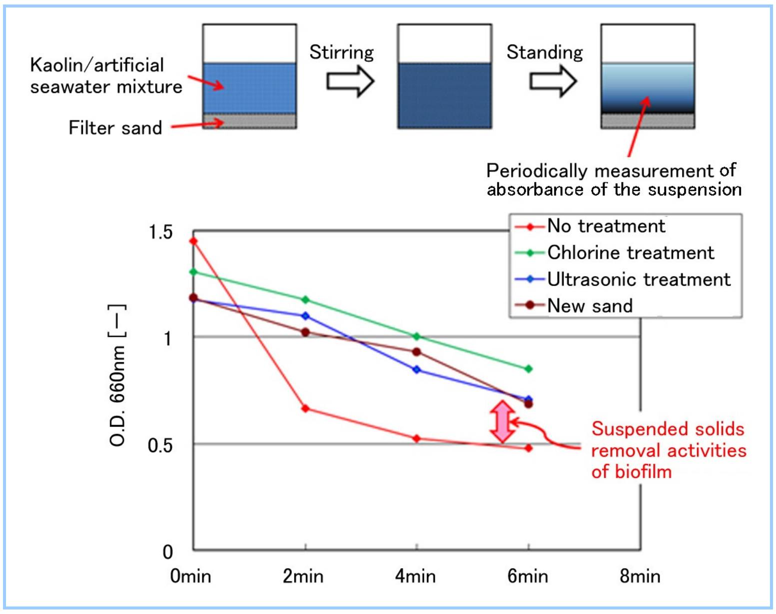

Figure 6 Overview of laboratory-scale experiment and results of absorbance measurements

In addition, chemical-free pretreatment water is supplied to a 4-inch RO membrane unit shown in **Figure 7** in order to obtain various operational data. **Figure 8** shows the feed pressure, SWRO differential pressure and chronological change in water temperature. **Figure 9** shows A Value and B Value. A Value and B Value are coefficients indicating the permeability of the water supplied to RO membranes and that of the solute, respectively. In the experiment, the SWRO differential pressure, A Value and B Value were all stable, producing positive operational results. Accordingly, chemical-free sand filtration was confirmed to be applicable as a pretreatment technology in SWRO desalination plants(7).

Figure 7 Exterior of 4-inch RO membrane unit

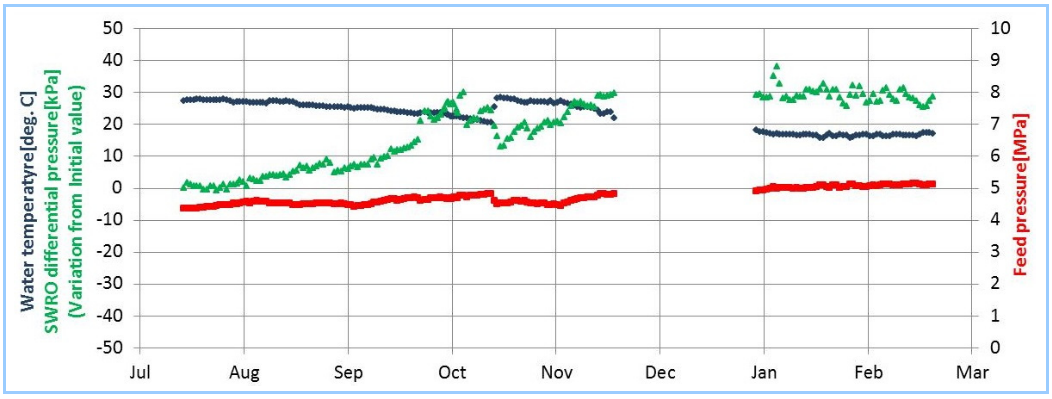

Figure 8 Chronological changes in feed pressure, SWRO differential pressure and water temperature

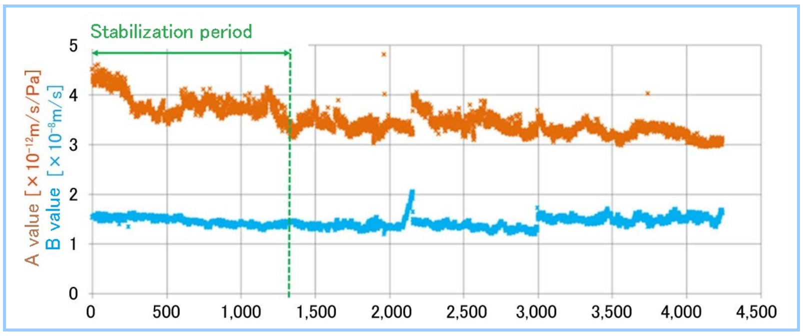

Figure 9 Chronological changes in Values A and B

3.2 Demonstration experiment in Qatar

MHI has been working on a joint experiment since 2012 with the Qatar National Food Security Programme (QNFSP), receiving strong support from Ras Laffan Industrial City (RLIC). The concept of the experiment is shown in **Figure 10**.

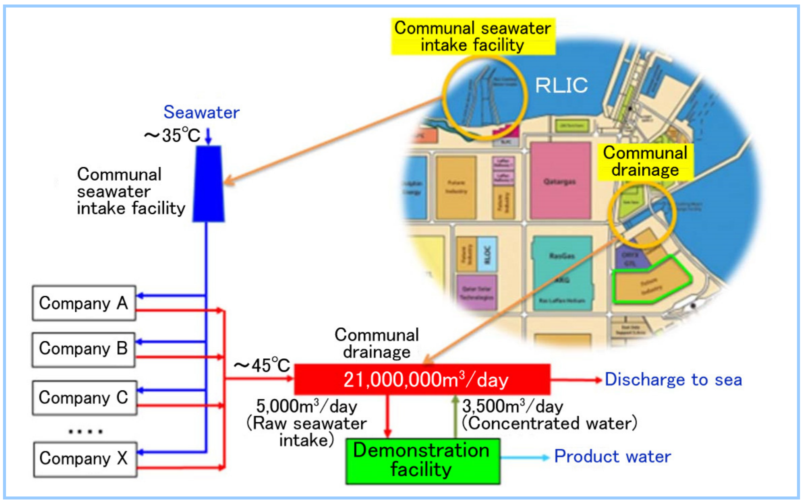

Figure 10 Experiment concept

In the RLIC district, there are communal seawater intake facilities where seawater is taken in so that local companies can use it as cooling water, and communal drainage through which used seawater is discharged. The evaporation method which is the major desalination technique utilized in Qatar and the existing SWRO desalination plants would require marine construction work in order to build water intake/discharge facilities. On the contrary, the new method developed by MHI is designed to reuse the cooling seawater (high-temperature discharged seawater has a maximum temperature of approximately 45°C, whereas regular seawater has a maximum temperature of 35°C to 40°C), which was raw seawater used at power-generating facilities of individual companies located in the local industrial district and which requires no marine construction. Therefore, no work for selecting a location for water intake facilities or the construction of the facilities themselves would be necessary, significantly reducing the cost for plant construction. Furthermore, there is no engineering work for water intake, which would contribute to the preservation of the marine environment. The concentrated waste water resulting from desalination could be returned to the existing communal drainage, thereby eliminating marine construction work for drain facilities. The product water obtained from the used high-temperature discharged seawater is expected to serve as irrigation water.

In the demonstration experiment, seawater was taken through the communal drainage, which is used as raw seawater in chemical-free pretreatment utilizing 4-inch RO membranes. This experiment confirmed the stable operation of the chemical-free pretreatment using seawater from the Arabian Gulf, water that has high turbidity and organic matter concentration. Regarding the operation of RO membranes, the desalination performance and SWRO differential pressure were both confirmed stable, indicating the applicability of chemical-free sand filtration as the RO membrane pretreatment(7).

4. Conclusion

MHI has been working on the development of a chemical-free pretreatment technology for SWRO desalination that is both environmentally-friendly and economically efficient. Demonstration experiments were conducted both in Japan and Qatar, where the chemical-free sand filtration used in the Japanese salt manufacturing industry was adopted. Stable operation has been confirmed in terms of the desalination performance and SWRO differential pressure, which verifies the applicability of chemical-free sand filtration to the pretreatment process of SWRO desalination. MHI intends to accumulate operational data in order to extend the scope of the application of this new technology.

References

1. The Website of Water Reuse Promotion Center http://www.wrpc.jp/annai/an04.htm
2. International Water Association, Desalination-Past, present, future（2016） http://www.iwa-network.org/desalination-past-present-future/
3. Matsui, K. et al., The performance of pressure sand filter for seawater, Bull. Soc. Sea Water Sci., Jpn. 66 (3), 124 (2012)
4. Takeuchi, K. et al., Chemical free seawater pretreatment, Bull. Soc. Sea Water Sci., Jpn. 67（5）, 279-282（2013）
5. Goda, Y, Present state of sea water filtration process in salt manufacturing plant, Bull. Soc. Sea Water Sci., Jpn. 63（6）（2009）
6. Tabata, M. et al., Bench-scale test for the study for the chemical-free pretreatment system of SWRO desalination plant, Proceedings of IDA World Congress, TIAN13-344
7. Takeuchi, K. et al., The study of environmentally friendly pretreatment system, Desalination and Water Treatment 364, 1-7（2012）