Feasibility of two-pass reverse osmosis system in the design of desalination plant to improve boron removal efficiency

Phan Vu Xuan Hung, Seung-Hee Cho, Sang-Don Han, Min-Kyoung Hong, Hong-Joo Lee, Seung-Hyeon Moon
Department of Environmental Science and Engineering, Gwangju Institute of Science and Technology(GIST)

1. Introduction

In recent years, seawater reverse osmosis (SWRO) desalination technology has been used reliably to desalinate seawater as well as brackish waters from saline aquifers and rivers. RO membranes have high rejection for most of solutes in seawater. However, the removal of some micro toxicants including boron is not effective. Boron exists in seawater almost in boric acid form whose molecules are very small, uncharged and non-polar. Therefore, boron rejection in conventional SWROplants is achieved only around 43-78%.

Boron is known as an essential element for plants as trace element, but excess boron is toxic for living organisms. In seawater desalination field, the WHO requires boron concentration in drinking water to be below 0.5mg/L. However, with low boron rejection as mentioned above, it is impossible for conventional plants to reduce boron concentration from 5 mg/L in seawater to 0.5 mg/L in product water. Improving boron rejection has been recognized as one of the vital task of desalination plant recently. In this study, the two pass RO system, which consists of SWRO-BWRO (Brackish water RO), was evaluated to improve boron removal efficiency.

2. Experimental

A lab-scale cross-flow flat-sheet configuration membrane unit (SEPA CF II, Osmonics) was used for all reverse osmosis experiments. The membrane unit contained 19 × 14 cm flat sheet RO membrane provided by Saehan Company that arranged in a stack gave 140 cm^2 of effective membrane area. The desalination of seawater was conducted by simulated two pass RO system, SWRO and BWRO. In SWRO experiments, the RO unit was operated with SR membranes under the pressure of 800psi; feed solution was synthetic seawater. In the next step, the SWRO-permeate-simulated solution was used as feed solution for BWRO experiments in which the RO unit was operated with BE or FRM3 membranes under the pressure of 400psi. Temperature of feed solution was kept constant at 25.0±1.0°C by JISICO cooling circulation path. Retentate flowrate was kept constant at 500ml/min for all experiments.

Synthetic seawater was prepared from NaCl, $MgCl_2.6H_2O$, $MgSO_4$, $CaCl_2.2H_2O$, and KCl so that the concentration of six most abundant components was similar to that proposed in most of references. Boric acid stock solution was then added to synthetic seawater from to obtain the concentration of 5mg/l as boron. The feed solution of BWRO (brackish water) was prepared from same chemicals by simulating the SWRO permeate. The composition of synthetic seawater and brackish water was given in table 1.

Table 1. Composition of synthetic seawater and brackish water

Species	Seawater		Brackish water	
	mol/L	mg/L	mol/L	mg/L
Cl	0.5332	18,904	0.0136	481
Na	0.4532	10,419	0.0109	251
SO4	0.0272	2,615	0.0006	61.9
Mg	0.0522	1,269	0.0015	37.0
Ca	0.0100	400	0.0003	12.8
K	0.0100	392	0.0003	10.1
B		5.0		1.5
TDS		34,000		855

#Cationic species and boron of reservoir and permeate were analyzed by ICP-OES; anionic species were analyzed by ion chromatography.

3. Result and discussion

SWRO experiments were conducted at pH 7.5 and 8.5. Boron rejection showed the difference at two pH values. However, there was no significant difference of salt rejection at two pH values. The permeate concentration and rejection of boron and TDS were demonstrated in table 2.

Table 2. SWRO performance

	Boron permeate (mg/l)	Boron rejection (%)	TDS permeate (mg/l)	Salt rejection (%)
pH=7.5	1.5 ± 0.1	68.5 ± 1.0	850 ±150	97.5 ± 0.4
pH=8.5	1.3 ± 0.1	74.0 ± 2.0		

The boron concentration in permeate was higher than the recommended value of WHO guideline, 0.5mg/l. Therefore, one more post treatment should be added to satisfy this requirement. In this study, BWRO unit was chosen with the use of low pressure, high recovery RO membranes.

In BWRO experiments, two types of RO membrane (BE and FRM3) was operated with varying pH from 6 to 10. Both BE and FRM3 membranes showed the similar performance demonstrated in figure 1.

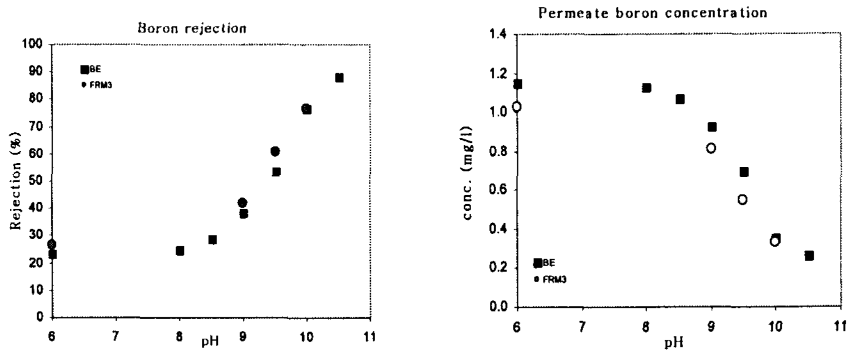

Figure 1. Boron rejection and permeate concentration in BWRO unit

As expected, boron rejection increased remarkably as pH increased from around 8.5. The condition of high pH enhances the dissociation of boric acid to borate ion which is negatively charged so that it is more significantly rejected by RO membranes. The target 0.5mg/l of boron in permeate was achieved as pH of feed solution reached the value of 10. At higher pH value, the remarkable decline of permeate flowrate was observed. This was attributed to the precipitation of magnesium hydroxide on the surface of membrane (precipitative fouling). Therefore, the performance of BWRO unit at pH 10 was selected to design the two pass system. The salt rejection of BWRO is

90.0±1.0% and almost independent on pH. The results obtained form separate experiments of SWRO and BWRO unit were used to design the two pass system in which the permeate of SWRO is divided into two streams; one is treated further by BWRO, one is bypass and blend with BWRO permeate to get product water. In this design, the BWRO unit treated at least 87% of SWRO permeate to achieve the desired boron content in final product. The final product contained TDS below 200ppm and boron concentration below 0.5ppm.

4. Concluding remarks

The two pass system can be applied as themodification of conventional desalination plant to enhance the removal of boron. With the adjustment of pH, the boron concentration in final product was below 0.5mg/l. In this study, the scale formation was negligible. However, in real system, the risk of scale formation when operating at high pH is also high. In this case, antiscalants should be added to maintain the performance of the system.

Acknowldgements

This research was partly supported by a grant (code#C106A1520001-06A085600222) from Plant Technology Advancement Program funded by Ministry of Construction & Transportation of Korean government.

Reference

1. Mark Wiff, "The guide book to Membrane Desalination Technology", Balaban Desalination Publications (2007).

2. Y. Magara, A. Tabata, M. Kohki, M. Kawasaki and M. Hirose, "Development of boron reduction system for sea water desalination", *Desalination*, 118, 25-33 (1998).

3. Y. Magara, T. Aizawa, S. Kunikane, M. Itoh, M. Kohki, M. Kawasaki and H. Takeuti, "The behavior of inorganic constituents and disinfection by products in reverse osmosis water desalination process", *Wat. Sci. Tech*, 34, 141-148 (1996).

4. Boron in Drinking-water. WHO/SDE/WSH/03.04/54