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Influence of the chosen process parameters on the efficiency of seawater desalination: SWRO pilot plant results at Urla Bay seashore

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ABSTRACT

The most widely used desalination method used in order to produce potable water from seawater is reverse osmosis (RO). In this study, desalination tests were performed at a seashore of Urla Bay, Izmir, Turkey. The tests were carried out at different pressures (55–62 bar) using a single RO module at different feed seawater temperatures (10–15 °C). Variables such as pH, conductivity, TDS, salinity, turbidity, relative rejection of some ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-) and B levels in permeates collected were measured.

Keywords: Boron; Desalination; Reverse osmosis; Seawater; SWRO; Water

1. Introduction

It has become an obligation to produce potable and drinking water from seawater in some regions such as in the Middle East and African countries. The most widely used desalination methods are reverse osmosis (RO) and thermal processes such as multi-stage flash distillation. Although thermal processes still dominate in some Middle Eastern countries, in many countries all around the world RO is preferred because of its low energy consumption. Production of potable water from seawater has been performed successfully by this method for about 20 years [1–3].

RO is a membrane separation process which is based on using a semi-permeable membrane. The membrane used is said to be permeable for water but partially permeable for dissolved substances. By applying a pressure above the level of osmotic pressure of feed water, feed is forced to permeate through the membrane. Applied pressure in seawater desalination is generally in the range from 55 to 68 bar, and the range is 10–15 bar for brackish water desalination [1].

The clear advantage of RO, which is the retaining property of very small dissolved particles, makes it competitive for producing potable water. These small particles may have harmful effects on both human health and on agriculture. Boron, which has gained much attention, is a good example. Although boron is necessary for plant growth as a trace element, it can show detrimental effects at concentrations higher than 0.3 mg/L in irrigation water. Moreover, it has been proved that boron has toxic effects even at low concentrations such as 0.5 mg/L and levels

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above 1.0 mg/L for most plants are considered to be toxic [4,5]. The World Health Organization (WHO) recommends a level of 0.3 mg/L as maximum boron concentration in drinking water. In these circumstances, a RO system should produce water containing boron at concentrations in the range of 0.3–0.5 mg/L from a standard feed of 4–5 mg/L if seawater desalination is considered. However, it is not possible to reduce boron concentration to these levels using a single-stage RO unit because of its chemistry. Boron is usually present in water as boric acid, and its prior dissociation to borate ions proceeds at a pK_a value of 9.14 [6–12].

Boric acid is not effectively rejected by RO membranes. It should dissociate into ions in order to be rejected and this is only possible at high pH values regarding its high pK_a values [13]. Alkali conditions can be obtained in regular seawater but this has some drawbacks such as scaling problems originating from hardness components naturally occurring in seawater. Many seawater desalination plants solved this problem by using a two-stage RO unit. In the first stage, hardness components are removed and salinity is decreased, and in the second stage most of the boron present in seawater is eliminated at improved alkali conditions. Mekorot Water Company in Israel has reached successful boron reduction by splitting the permeate stream from a RO pass and blending it with the product water from the second RO unit and an IEX system [14,15].

Many different boron removal techniques have recently been tried. Kara et al. studied the applicability of the Donnan dialysis technique equipped with different commercial ion-exchange membranes [16]. Sayiner et al. worked with highly concentrated boron solutions such as 100–1000 mg/L and proposed that electrocoagulation using iron and aluminum electrodes is an applicable method with a boron removal capacity up to 95% [17]. There are also some batch mode studies performed by scientists. Bouguerra et al. examined the adsorption technique onto activated alumina and compared the efficiency with the RO they also used [18]. Celik et al. used activated carbon impregnated with salicylic acid [19] and Ma et al. tried cotton cellulose as an alternative adsorbent for boron removal [20].

The purposes of the present work were: (1) to test experimentally the performance of an RO (SWRO) unit established in the Izmir–Urla region in Turkey under different feed water temperatures; (2) to analyse the quality of water produced from this unit in terms of ionic species removal; and (3) to examine the levels of boron concentration in the product water.

2. Experimental

All experiments were performed by an RO system which was established in the Izmir–Urla region (Fig. 1). Previously chlorinated raw seawater in the feed tank was transferred to low pressure pump and after that to sand filter and cartridge filter, respectively. Physically and chemically pretreated seawater was transferred to RO membranes via a high pressure pump in order to be desalinated. Two parallel mounted RO membranes were used in the system. The membranes used (spiral-wound FilmTec™ SW30 2540) are produced commercially by Dow with a 2.8 m^2 active area each. Feed seawater was transferred to the RO membranes with high pressure and water permeate was taken as product water. Experiments were performed under different pressures (55, 60, and 62 bar) and at different feed seawater temperatures (9.8, 13.2, 14.2 and 15.4°C). The quality of product water was determined after some measurements such as electrical conductivity (EC), pH, total dissolved solid (TDS), salinity, turbidity, and ions concentration. Azomethine-H method was performed in order to determine boron concentration. Metal ions were measured with AAS.

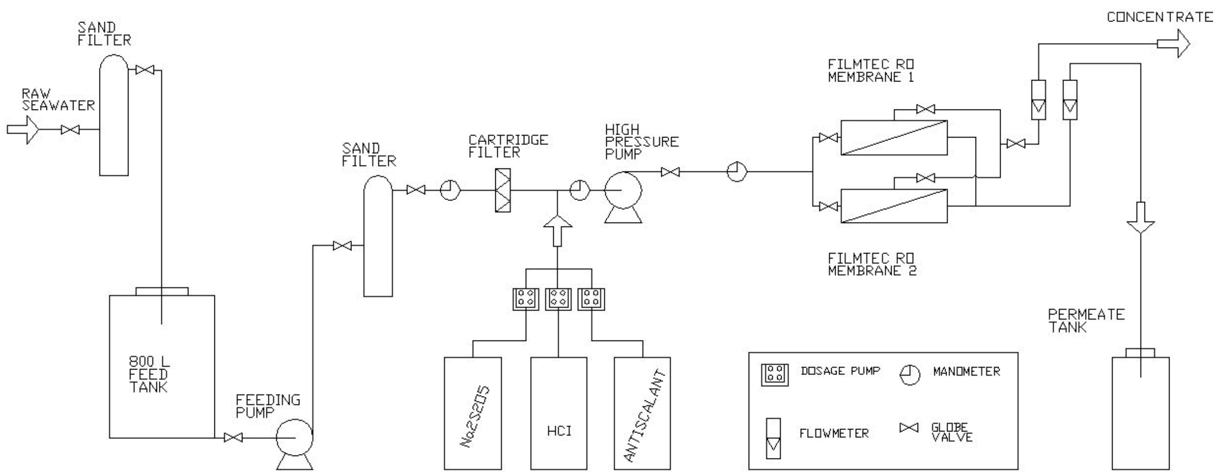

Fig. 1. Flow diagram of the reverse osmosis system.

3. Results and discussion

The RO system employed here could be operated with a single membrane or two membranes for the sake of parallel configuration. In this study, parameters were investigated only for the single membrane operation. The effect of the temperature of the feed seawater on the process parameters for feed and permeate streams is given in Table 1. Similarly, the effect of pressure on the same process parameters is tabulated in Table 2.

The effect of temperature on chemical composition (main constituents) and turbidity levels in feed and permeate streams is given in Table 3, and the effect of applied pressure in Table 4.

Fig. 2 shows average removal percentages of chemical species in the temperature range from 9.8°C to 15.4°C.

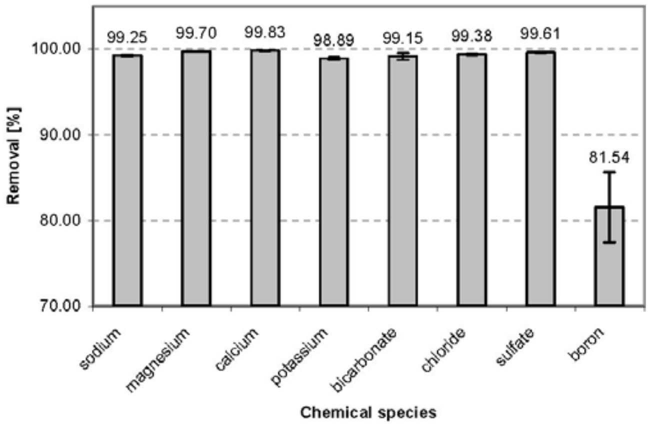

Fig. 2. Removal efficiency (%) of chemical species by a reverse osmosis system at constant applied pressure, 55 bar.

Table 1
Experimental data and calculated values of feed and permeate streams for single membrane operation at 55 bar applied pressure

Feed seawater	*P* (bar)	Temp. (°C)	EC (μS/cm)	pH	TDS (mg/L)	Salinity (‰)	Flow rate, *Q* (L/h)	
	55	9.8	61,000	8.3	40,451	39.6	254.9	
	55	13.2	60,100	8.3	40,451	39.6	258.3	
	55	14.2	58,000	8.2	38,919	38.1	261.7	
	55	15.4	59,600	8.2	40,247	39.4	260.2	
Permeate	*P* (bar)	Recovery (%)	EC (μS/cm)	pH	TDS (mg/L)	Salinity (‰)	*Q* (L/h)	Flux (L/m^{2}h)
	55	14.1	467	7.9	234	0.0	35.9	12.8
	55	15.0	523	7.8	263	0.0	38.9	13.9
	55	15.0	528	7.0	264	0.0	39.2	14.0
	55	15.6	586	7.9	291	0.0	40.7	14.6

Table 2
Experimental data and calculated values of feed and permeate streams for single membrane operation at 14°C feed seawater temperature

Feed seawater	*P* (bar)	Temp. (°C)	EC (μS/cm)	pH	TDS (mg/L)	Salinity (‰)	Flow rate, *Q* (L/h)	
	55	14.2	58,000	8.2	38,919	38.1	261.7	
	60	14.3	59,800	8.3	40,349	39.5	264.9	
	62	13.9	59,900	8.2	40,349	39.5	269.5	
Permeate	*P* (bar)	Recovery (%)	EC (μS/cm)	pH	TDS (mg/L)	Salinity (‰)	*Q* (L/h)	Flux (L/m^{2}h)
	55	15.0	528	7.0	264	0.0	39.2	14.0
	60	18.2	484	7.7	243	0.0	48.3	17.3
	62	19.7	446	7.8	224	0.0	53.2	19.0

Table 3
Chemical composition and turbidity levels in feed and permeate streams for single membrane operation at constant applied pressure, 55 bar (concentrations in mg/L)

	T (°C)	[Na^+]	[Mg^{2+}]	[Ca^{2+}]	[K^+]	[HCO_3^-]	[Cl^-]	[SO_4^{2-}]	[B]
Feed seawater	9.8	10,735	1,318	476	523	136	21,842	2,559	5.2
	13.2	10,545	1,148	427	555	165	20,581	2,787	5.5
	14.2	10,300	1,074	446	527	161	26,494	3,525	5.2
	15.4	10,505	1,137	427	486	165	24,121	3,546	5.2
Permeate	9.8	68.4	3.1	0.7	4.8	0.9	128.6	9.6	0.7
	13.2	79.4	4.0	0.7	6.3	2.1	131.7	11.4	1.1
	14.2	80.3	3.4	0.8	6.3	0.6	132.1	12.2	1.2
	15.4	86.0	3.2	0.8	5.8	1.8	177.6	15.4	0.9

Table 4
Mineral compositions and turbidity levels in feed and permeate streams for single membrane operation at constant feed seawater temperature, 14°C (Concentrations are given in mg/L).

	P (bar)	[Na^+]	[Mg^{2+}]	[Ca^{2+}]	[K^+]	[HCO_3^-]	[Cl^-]	[SO_4^{2-}]	[B]
Feed seawater	55	10,300	1,074	446	527	161	26,494	3,525	5.2
	60	10,830	1,364	437	499	168	25,866	3,891	5.1
	62	10,800	672	444	501	163	21,508	3,018	5.1
Permeate	55	80.3	3.4	0.8	6.3	0.6	132.1	12.2	1.2
	60	71.6	3.2	0.7	4.6	0.7	116.3	23.2	0.7
	62	65.4	3.0	0.6	4.2	0.1	105.6	10.6	0.7

Both anions and cations were quantitatively rejected by the RO membrane (removal efficiency 100%). Among these constituents, boron showed the lowest separation efficiency.

4. Conclusions

RO experiments were performed for different time durations, but flow rate of concentrate was kept constant at 200 L/h. Quality of permeate was highly dependent on feed seawater temperature. As temperature decreased, lower conductivity, lower turbidity but higher mineral rejections were obtained for the permeate stream. In terms of boron removal, higher values of rejection were obtained for decreasing values of temperature. However, boron removal was about 80%, which is the lowest level among the studied species. Permeate flux decreased also with decreasing temperature.

The effect of pressure was investigated at constant feed seawater temperature (14°C). Lower conductivity, mineral compositions and turbidity values were obtained at higher applied pressures. Increasing applied pressure also facilitates removal of boron from feed seawater. In addition, permeate flux increased with increasing pressure.

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References

[1] M. Busch and W.E. Mickols, Reducing energy consumption in seawater desalination, Desalination, 165 (2004) 299–312.
[2] C. Fritzmann, J. Löwenberg, T. Wintgens and T. Melin, State-of-the-art of reverse osmosis desalination, Desalination, 216 (2007) 1–76.
[3] N. Kabay, S. Sarp, M. Yuksel, M. Kitis, H. Koseoglu, O. Arar, M. Bryjak and R. Semiat, Removal of boron from SWRO permeate by boron selective ion exchange resins containing containing N-methyl glucamine groups, Desalination, 223 (2008) 49–56.
[4] N. Nadav, M. Priel and P. Glueckstern, Boron removal from the permeate of a large SWRO plant in Eilat, Desalination, 185 (2005) 121–129.

[5] G. Georghiou and I. Pashalidis, Boron in groundwaters of Nicosia (Cyprus) and its treatment by reverse osmosis, Desalination, 215 (2007) 104–110.
[6] J. Redondo, M. Busch and J.P. De Witte, Boron removal from seawater using FILMTEC™ high rejection SWRO membranes, Desalination, 156 (2003) 229–238.
[7] N. Kabay, I. Yilmaz, S. Yamac, S. Samatya, M. Yuksel, U. Yuksel, M Arda, M. Saglam, T. Iwanaga and K. Hirowatari, Removal and recovery of boron from geothermal wastewater by selective ion exchange resins. I. Laboratory tests, Reactive Func. Polym., 60 (2004) 163–170.
[8] N. Kabay, I. Yilmaz, S. Yamac, M. Yuksel, N. Yildirim, O. Aydogdu, T. Iwanaga and K. Hirowatari, Removal and recovery of boron from geothermal wastewater by selective ion exchange resins. II. Field studies, Desalination, 167 (2004) 427–438.
[9] N. Kabay, S. Sarp, M. Yuksel, O. Arar and M. Bryjak, Removal of boron from seawater by ion exchange resins, Reactive Func. Polym., 67(12) (2007) 1643–1650.
[10] N. Nadav, Boron removal from seawater reverse osmosis permeate utilizing selective ion exchange resin, Desalination, 124 (1999) 131–135.
[11] H. Koseoglu, N. Kabay and M. Kitis, Effects of operation conditions and membrane type on removal of boron from water, Symp., Environmental Pollution in Turkey, Gebze-Kocaeli, 2006, pp. 98–103.
[12] N. Kabay, I. Yilmaz, M. Bryjak and M. Yuksel, Removal of boron from aqueous solutions by ion exchange-membrane hybrid process, Desalination, 198 (2006) 74–81.
[13] F. Macedonio and E. Drioli, Pressure-driven membrane operations and membrane distillation technology integration for water purification, Desalination, 223 (2008) 396–409.
[14] P. Glueckstern and M. Priel, Optimization of boron removal in old and new SWRO systems, Desalination, 156 (2003) 219–228.
[15] P. Glueckstern, M. Priel and E. Kotzer, Blending brackish water with desalted seawater as an alterative to brackish water desalination, Desalination, 178 (2005) 227–232.
[16] H.F. Ayyildiz and H. Kara, Boron removal by ion exchange membranes, Desalination, 180 (2005) 99–108.
[17] G. Sayiner, F. Kandemirli and A. Dimoglo, Evaluation of boron removal by electrocoagulation using iron and aluminum electrodes, Desalination, 230 (2008) 205–212.
[18] W. Bouguerra, A. Mnif, B. Hamrouni and M. Dhahbi, Boron removal by adsorption onto activated alumina and by reverse osmosis, Desalination, 223 (2008) 31–37.
[19] Z.C. Celik, B.Z. Can and M.M. Kocakerim, Boron removal from aqueous solutions by activated carbon impregnated with salicylic acid, J. Haz. Mat., 152 (2008) 415–422.
[20] R. Liu, W. Ma, C. Jia, L. Wang and H. Li, Effect of pH on biosorption of boron onto cotton cellulose, Desalination, 207 (2007) 257–267.