Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2020.24882

174 (2020) 46–52
January

Quality of product water by three full-scale seawater reverse osmosis desalination in China

Xiao-Nan Wang[a,*], Ming-Yuan Ma[a], Xian-Hui Pan[a], Jun Hao[a], Chuang-Nian Zhang[b,*]

[a]*The Institute of Seawater Desalination and Multipurpose Utilization, MNR, National Quality Supervision and Inspection Center for Seawater and Brackish Water Utilization Products, Tianjin 300192, China, emails: wangxiaonan0306@sina.com (X.-N. Wang), mark40@qq.com (M.-Y. Ma), xianhuipan@126.com (X.-H. Pan), haojun@126.com (J. Hao)*
[b]*Tianjin Key Laboratory of Biomaterial Research, Institute of Biomedical Engineering, Chinese Academy of Medical Science and Peking Union Medical College, Tianjin, 300192, China, email: cnzhang@mail.nankai.edu.cn*

Received 29 January 2019; Accepted 12 September 2019

ABSTRACT

Quality of product water by seawater reverse osmosis (SWRO) desalination has an impact on consumers' health. In this paper, data of product water were obtained from three full-scale SWRO desalination plants for the benefit of a drinking-water supply system in China. Qualities of this product water were analyzed by 103 items. Moreover, challenges and future research needs of the product water by SWRO desalination were pointed out. The results showed that inorganic chemicals and disinfection by-products accounted for about 42% and 33% of the total measured indicators, respectively.

Keywords: Product water; Seawater reverse osmosis desalination; Water quality

1. Introduction

Water is one of the necessities of life. More than one-third of the world's populations have already suffered from shortages of potable water, with a rise to two-third expected by 2025 [1–5]. Due to the advantages of increasing water supply beyond what is available from the hydrological cycle, product water by seawater reverse osmosis (SWRO) desalination has been becoming a useful technology for man-made freshwater from the vast oceans in recent years. It was widely used in many coastal countries, particularly in the eastern Mediterranean region, the United States, China, Australia and Japan [6,7]. With the continuing depletion of potable water supplied by natural surface water or groundwater resources, the use of product water by SWRO desalination could be increased rapidly in the future.

In China, increased potable water demand is now becoming more challenging. It has been estimated that the potable water crisis exists in more than 400 cities and several islands [8]. SWRO desalination has become the technology of choice to supply potable water. It aims to deliver to each consumer with a new source of safe water for drinking, adequate in quantity and healthy contribution. The numbers of SWRO desalination plants had been more than 110 by the end of the year 2017. These SWRO desalination plants produced 812,600 m^3/d desalted water and accounted for 68.40% of the total production capacity of China's seawater desalination. Capacities of these SWRO desalination plants for potable water were from hundreds of tons, thousands of tons to ten thousand tons, which accounted for 33% of total China's SWRO desalinated water. Most of these plants located in coastal cities, such as Zhejiang, Shandong, Hebei, Liaoning, and Fujian. Furthermore, more and more people rely on

* Corresponding authors.

SWRO desalination to meet their daily freshwater needs. New SWRO seawater desalination plants are being planned in many provinces, such as Shandong, Zhejiang, and Hebei. Therefore, total volumes of SWRO desalination capacity are still increasing in China.

Quality of product water for drinking by SWRO desalination has an impact on health or adversely affect the acceptability of SWRO desalination product water for human consumption from long-term exposure, which heightened concern in the recent year [9–11]. However, there are two striking problems for product water by full-scale SWRO desalination. (i) Available data for the quality of product water by SWRO desalination are limited. (ii) It is necessary to study systematically to learn more about the product water for drinking by SWRO desalination [12–16]. In the previous paper, we had identified 60 priority concerns for the benefit of the drinking-water supply system under the framework of an integrated SWRO stage from source to tap [17].

In this paper, product water by three full-scale SWRO desalination plants located in China was determined by the Standards for Drinking Water Quality (2006) of the People's Republic of China. The water quality index contained 103 comprehensive items which were guided in the Standards for Drinking Water Quality (2006) of the People's Republic of China. These items were characterized in terms of organoleptic parameters, microorganisms, inorganic chemicals, organic chemicals, disinfectants and disinfection by-products (DBPs), and radioactivity, respectively. Challenges and future research needs of the product water by SWRO desalination were also pointed out.

2. Materials and methods

2.1. Sample water

Samples of product water after post-treatment were collected from three full-scale SWRO desalination plants producing above 10,000 m^3/d of drinking water in China, separately. The pretreatment of seawater contained a sand filter, precipitation, flocculation and ultrafiltration (UF) membrane filtration before directed to SWRO modules. UF represented by 0.01–0.02-micron pore size. The SWRO desalination process contained 4–9 groups of polyamide semipermeable membranes. Post-treatment of SWRO desalinated water was accomplished by dissolving sea shells, calcite bed filtration, and lime dissolution. Also, chlorine was used as disinfection to eliminate pathogens. Plant I and Plant II, the product water were pumped directly into the distribution system and then blended with surface water. Plant III, the product water was blended with surface water and then pumped into the distribution system. Samples were handled and stored at 4°C and analyzed in 24 h.

2.2. Analytical methods

Product water samples were determined by three labs which had been authorized by China National Accreditation Service for accuracy and reliability. Analyses were conducted on each sample at least two times. Standards for Drinking Water Quality (2006) of the People's Republic of China in China were used to analyze the samples.

2.3. Instruments

Instruments for 103 items analyzing depended on the methods that were used in the Standard Examination Methods for Drinking Water GB/T 5750.1~5750.13-2006 in China. For example, these included liquid chromatography, gas chromatography, inductively coupled plasma atomic emission spectrometry, graphite furnace atomic absorption spectrophotometer, and spectrophotometer et al.

3. Results and discussion

Seawater is varied due to seasonal and climatic changes, which is characterized by temperature, pH, conductivity, turbidity, total dissolved solids, silt density index, suspended solids, and total organic carbon [18]. However, the quality of the product water depended primarily on the SWRO desalination system design, type of membrane, chemical treatments, and post-treatment. Results of 103 items were compared with the Standards for Drinking Water Quality of the National Standards of the People's Republic of China for further research.

3.1. Organoleptic indicators

Consumers evaluated the quality of the product water by SWRO desalination principally upon organoleptic indicators. Therefore, these parameters were determined for the product water. In this study, organoleptic parameters of the product water consisted of color, odor, and pH were analyzed in full-scale SWRO desalination plants, which caused aesthetic effects in terms of taste, odor and appearance. Table 1 illustrated average organoleptic indicators of the product water by SWRO. It could be seen that color was formed in the product water by SWRO Desalination Plant I which was caused by the post-treatment processes. There were no significant changes in the Odor (Table 1). In full-scale SWRO desalination plants, the pH was adjusted to 7.0~8.5 to condition product water and ensure disinfection efficiency.

3.2. Microorganisms

According to Table 1, microorganisms in the product water of SWRO desalination were minor, including total coliforms (e.g. fecal coliform and *E. coli*), heat-resisting coliform group, *Escherichia coli*, aerobic bacteria count, Giardia, and *Cryptosporidium*. Results show that turbidity was low from Table 1. It was because turbidity was caused by post-treatment, such as reminization by seashells or limestone in the SWRO process. Higher turbidity was associated with higher levels of disease-causing microorganisms, such as viruses, parasites, and some bacteria. It might cause symptoms, such as nausea, cramps, diarrhea and associated headaches.

3.3. Inorganic chemicals

Inorganic chemicals in the product water were very low (Table 1). These included volatile phenol, anion synthetic detergent, cyanide, cyanogen chloride, nitrate, ammonia nitrogen, sulfide, As, Cd, Cr, Pb, Hg, Se, Al, Fe, Mn, Cu, Zn, Sb, Ba, Be, Mo, Ni, Ag, and Tl. These results show that the

Table 1
The average value of the product water quality by three full-scale seawater reverse osmosis desalination in China

			Plant I	Plant II	Plant III
	Organoleptic indicators				
1	Color	/	5	<5	<5
2	Odor	/	0	0	0
3	pH	/	7.89	7.48	8.12
	Microorganisms		Plant I	Plant II	Plant III
4	Aerobic bacteria count	CFU/mL	ND	1	ND
5	*Cryptosporidium*	pcs/10 L	ND	ND	ND
6	*Escherichia coli*	CFU/100 mL	ND	ND	ND
7	Heat resistant coliform group	CFU/100 mL	ND	ND	ND
8	Giardia	pcs/10 L	ND	ND	ND
9	Total coliforms	CFU/100 mL	ND	ND	ND
10	Turbidity	NTU	0.2	<0.5	0.3
	Inorganic chemicals		Plant I	Plant II	Plant III
11	Aluminum	mg/L	<0.05	<0.04	0.069
12	Ammonia nitrogen (counted as N)	mg/L	<0.02	<0.02	0.12
13	Antimony	mg/L	<0.0005	<0.0001	<0.0005
14	Anion synthetic detergent	mg/L	<0.05	<0.05	<0.05
15	Arsenic	mg/L	<0.001	<0.0001	<0.001
16	Barium	mg/L	<0.01	<0.001	0.094
17	Beryllium	mg/L	<0.002	<0.0002	<0.0002
18	Boron	mg/L	0.91	0.22	0.45
19	Cadmium	mg/L	<0.005	<0.0001	<0.0005
20	Chromium (VI)	mg/L	<0.004	<0.004	<0.004
21	Chloride	mg/L	91.4	33.8	47.6
22	Copper	mg/L	<0.01	<0.009	<0.005
23	Cyanide	mg/L	<0.002	<0.002	<0.002
24	Cyanogen chloride (counted as CN)	mg/L	<0.01	<0.01	<0.01
25	Fluoride	mg/L	<0.20	<0.20	<0.20
26	Iron	mg/L	<0.01	<0.004	<0.05
27	Lead	mg/L	<0.0025	<0.001	<0.0025
28	Manganese	mg/L	<0.01	<0.05	<0.05
29	Mercury	mg/L	<0.0001	<0.00005	<0.0001
30	Molybdenum	mg/L	<0.02	<0.008	<0.005
31	Nitrate (counted as N)	mg/L	<0.20	<0.20	<0.20
32	Nickel	mg/L	<0.01	<0.005	<0.005
33	Oxygen consumption (counted as O_2)	mg/L	0.33	0.65	0.44
34	Selenium	mg/L	<0.001	<0.0001	<0.0004
35	Silver	mg/L	<0.02	<0.0001	<0.0025
36	Sodium	mg/L	56.2	16.6	38.1
37	Sulfate	mg/L	3.03	1.63	<0.75
38	Sulfide	mg/L	<0.01	<0.02	<0.02
39	Thallium	mg/L	<0.0001	<0.0001	<0.00001
40	Total hardness (counted as $CaCO_3$)	mg/L	66.0	80.3	<1.0
41	Total dissolved solid	mg/L	213	134	99
42	Volatile phenol (counted as phenol)	mg/L	<0.002	<0.002	<0.002
43	Zinc	mg/L	<0.01	<0.01	<0.05
	Organic chemicals		Plant I	Plant II	Plant III
44	Atrazine	mg/L	<0.0005	<0.0005	<0.0005
45	Benzene hexachloride	mg/L	<0.0002	<0.00001	<0.0002
46	Bentazone	mg/L	<0.00003	<0.0002	<0.00003

(continued)

Table 1 *continued*

			Plant I	Plant II	Plant III
47	Chlorothalonil	mg/L	<0.00002	<0.00002	<0.0004
48	Chlorpyrifos	mg/L	<0.002	<0.0001	<0.002
49	Deltamethrin	mg/L	<0.0002	<0.0001	<0.0002
50	Dimethoate	mg/L	<0.0001	<0.0001	<0.0001
51	2,4-dichlorophenoxyacetic acid	mg/L	<0.00002	<0.00005	<0.00002
52	Dicophane	mg/L	<0.0002	<0.000005	<0.0002
53	Equigard	mg/L	<0.00005	<0.00005	<0.00005
54	Furadan	mg/L	<0.0001	<0.0001	<0.00025
55	Glyphosate	mg/L	<0.025	<0.025	<0.025
56	Heptachlor	mg/L	<0.0002	<0.00002	<0.0002
57	Hexachlorobenzene	mg/L	0.0008	<0.00002	<0.00002
58	Lindane	mg/L	<0.0001	<0.00001	<0.0001
59	Malathion	mg/L	<0.0001	<0.0001	<0.0001
60	Methyl parathion	mg/L	<0.0001	<0.0001	<0.0001
61	Parathion	mg/L	<0.0001	<0.0001	<0.0001
62	Pentachlorophenol	mg/L	<0.00027	<0.00003	<0.00027
63	Acrylamide	mg/L	<0.00005	<0.00005	<0.00002
64	Benzene	mg/L	<0.0050	<0.00004	<0.0050
65	Benzo(α)pyrene	mg/L	<0.0000014	<0.0000014	<0.0000010
66	Chlorobenzene	mg/L	<0.0050	<0.00004	<0.0050
67	1,1-dichloroethylene	mg/L	<0.0050	<0.00012	<0.0050
68	1,2-dichloroethylene	mg/L	<0.0050	<0.00006	<0.0050
69	1,2-dichlorobenzene	mg/L	<0.0050	<0.00003	<0.0050
70	1,4-dichlorobenzene	mg/L	<0.0050	<0.00003	<0.0050
71	Dibutyl phthalate (2-ethylhexyl) ester	mg/L	0.0028	<0.002	<0.002
72	Epoxy chloropropane	mg/L	<0.0004	<0.0004	<0.00002
73	Ethylbenzene	mg/L	<0.0050	<0.00006	<0.0050
74	Hexachlorobutadiene	mg/L	<0.0005	<0.0001	<0.0005
75	Microcystin-LR	mg/L	<0.00006	<0.00006	<0.000014
76	Styrene	mg/L	<0.0050	<0.00004	<0.0050
77	Tetrachloroethylene	mg/L	0.00038	<0.00014	<0.0012
78	Toluene	mg/L	<0.0050	<0.00011	<0.0050
79	Trichloroethylene	mg/L	<0.0030	<0.00019	<0.0030
80	Trichlorobenzene	mg/L	<0.0075	<0.00004	<0.0075
81	Vinyl chloride	mg/L	<0.0050	<0.00017	<0.0050
82	Xylene	mg/L	<0.0075	<0.00011	<0.0075
	Disinfectants and disinfection by-products		Plant I	Plant II	Plant III
83	Bromate	mg/L	<0.005	<0.005	/
84	Chlorine gas and free chlorine preparation (free chlorine)	mg/L	0.05	0.05	0.5
85	Chlorine dioxide	mg/L	/	0.02	/
86	Chlorate	mg/L	<0.005	<0.005	/
87	Formaldehyde	mg/L	<0.05	<0.05	/
88	Hypochlorite	mg/L	<0.0024	<0.0024	/
89	Chlorodibromomethane	mg/L	<0.00008	<0.00008	<0.003
90	1,2-dichloromethane	mg/L	<0.005	<0.00006	<0.005
91	Dichloroacetic acid	mg/L	<0.002	<0.002	<0.002
92	Dichloromethane	mg/L	<0.005	<0.005	<0.005
93	Mono bromodichloromethane	mg/L	<0.003	<0.00008	<0.003
94	Perchlormethane	mg/L	0.000038	0.00031	<0.0003
95	1,1,1-trichloroethane	mg/L	<0.005	<0.00008	<0.005

96	2,4,6-trichloroacetaldehyde	mg/L	0.00059	<0.00004	<0.00054
97	Tribromomethane	mg/L	0.015	<0.00012	<0.0060
98	Trichloroacetic acid	mg/L	0.0039	<0.001	<0.001
99	Trichloroacetaldehyde	mg/L	<0.001	<0.001	<0.001
100	Trichloromethane	mg/L	0.00049	0.00014	<0.0030
101	Trihalomethanes (Summation of chloroform, chlorodibromomethane, mono bromodichloromethane and bromoform)	mg/L	0.015	0.0038	<0.10
	Radioactivity		Plant I	Plant II	Plant III
102	Total a radioactivity	Bq/L	<0.016	<0.016	<0.01
103	Total b radioactivity	Bq/L	0.118	<0.028	<0.001

SWRO membrane was very efficient at removing inorganic chemicals.

Fig. 1 illustrates the average concentrations of boron, which were 0.22–0.91 mg/L in three full-scale seawater desalination plants producing above 10,000 m^3/d of drinking water in China. The Chinese drinking water standard for boron, as of 2006, was 0.5 mg/L. Thus, boron was not well removed by one of the SWRO desalination plants as compared with the other two plants. The World Health Organization (WHO) regulation had set the maximum concentration of boron at 2.4 mg/L in drinking water in 2011. China's drinking water standard was stricter compared to the present WHO guidelines. The average concentration of boron in seawater was 4.6 mg/L due to the abundance of boron in seawater. Rejection of boron by the SWRO system depended mainly on the recovery and pH of the feed water. Rejection value of boron is between 40%–60% under normal conditions of operation, while the high rejection value of boron is above 96% [19,20]. In China, guidelines of the SWRO product water for drinking are being proposed now. Nowadays, product water by SWRO with this boron concentration was blended with the artificial surface water to ensure the boron level below 0.5 mg/L in the drinking water. It was also helpful to protect public health by blending with source water for mineralization [21]. Meanwhile, alternative technologies have been studied to remove the boron to a relatively low concentration, such as new selective SWRO membrane, a second pass reverse osmosis, electrodeionization and system design [22–27].

To evaluate the impact of essential nutrients, the product water was analyzed by items, such as cadmium and total hardness. Essential nutrients were very efficiently removed by the SWRO desalination. Although drinking-water typically contributed a small proportion to the recommended daily intake of essential elements, with most of through food, these elements needed to be reintroduced to the product water. In this study, reminization of the product water in Plant I and Plant II was accomplished by dissolving seashells or the use of limestone together with carbon dioxide injection. The product water was pumped directly into the distribution system and then blended with surface water within the distribution system. In Plant III, reminization of the product water was accomplished by blending with surface water, where the product water was blended with surface water and then pumped into the distribution system.

3.4. Organic chemicals

Pesticides parameters that existed in the groundwater were at very low concentration in the product water (Table 1). These hazards included heptachlor, malathion, pentachlorophenol, benzene hexachloride, hexachlorobenzene, dimethoate, parathion, bentazone, methyl parathion, chlorothalonil, furadan, lindane, chlorpyrifos, glyphosate, equigard, atrazine, deltamethrin, 2,4-dichlorophenoxyacetic acid, and dicophane. Results indicated that organic chemicals in seawater were different from those in the groundwater. It was because that seawater was characterized by different organic chemicals, which included anthropogenic contamination, oil extraction activity, industrial and shipping activities. Moreover, organic chemicals could be removed by SWRO desalination [28]. In regions of oil production, potential hazards constituent of petroleum hydrocarbons related to volatile substances contamination, including benzene, toluene, ethylbenzene, xylene and solvents (e.g. chloroform, carbon tetrachloride, trichloroethene, and tetrachloroethene). These contaminants caused unacceptable taste and odor in the product water at very low concentrations.

To find out the influence of seawater contaminants on the product water, compounds included benzene, toluene, ethylbenzene, xylene, chlorobenzene, trichloroethene, and tetrachloroethene were analyzed. Other potential hazards included 1,1-dichloroethylene, 1,2-dichloroethylene, 1,2-dichlorobenzene, 1,4-dichlorobenzene, trichlorobenzene,

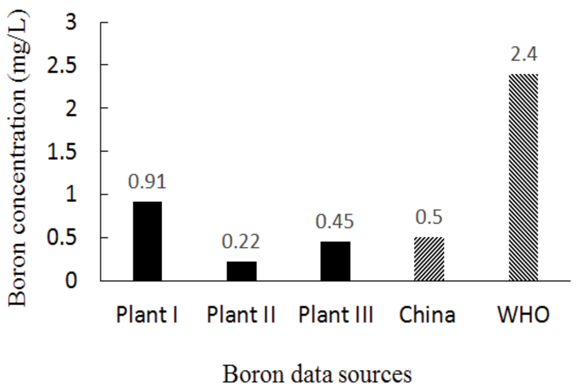

Fig. 1. Concentrations of boron in the product water by seawater reverse osmosis desalination.

hexachlorobutadiene, acrylamide, dibutyl phthalate (2-ethylhexyl) ester, epoxy chloropropane, styrene, microcystin-LR, benzo(α)pyrene, vinyl chloride were also determined due to their health influence on the public health. As shown in Table 1, all of these compounds were removed by the SWRO desalination processes which were below the limit of detection.

3.5. Disinfectants and DBPs

In these three SWRO desalination plants, chlorine was used as a disinfection for the product water by SWRO desalination to eliminate microbes. Meanwhile, residual chlorine was maintained to control microbes, which could cause eye/nose irritation or stomach discomfort at high concentration. DBPs formation and speciation were different, which depended on the content of disinfectant dose, contact time, pH, temperature, and the characteristics of natural organic matter [29,30]. Due to the high removal efficiency of the SWRO membrane, most of the DBPs precursors in the SWRO desalination plants were well removed. Therefore, the concentration of DBPs was analyzed at very low concentrations. These DBPs included trichloromethane, perchlormethane, chlorodibromomethane, mono bromodichloromethane, dichloroacetic acid, 1,2-dichloromethane, dichloromethane, trihalomethanes, 1,1,1-trichloroethane, trichloroacetic acid, trichloroacetaldehyde, 2,4,6-trichloroacetaldehyde, and tribromomethane.

3.6. Radioactivity indicators

Because most radionuclides in seawater were nonvolatile, SWRO membranes could remove most nuclides in the product water. Health risks associated with the presence of naturally occurring radionuclides in the product water were very low under normal circumstances. However, it should be noted that changes in the seawater, or emergencies arising from accidental releases of radioactive substances into the sea, the product water by SWRO should be determined radioactivity indicators.

4. Future research needs

We focused on the quality of product water by SWRO desalination which was analyzed by 103 items. Except for boron, all the analyzed items meet the Standards for Drinking Water Quality of the National Standards of the People's Republic of China. Although the SWRO desalination process removed significant amounts of test parameters, it can be seen from Fig. 2 that inorganic chemicals and disinfectants & DBPs accounted for about 42% and 33% of the total measured indicators, respectively. Consequently, it triggered two more specialized types of research. One is to adjust inorganic chemicals to address the required quality of the product water from SWRO desalination plants. The other is to further reduce the concentration of disinfectants and DBPs.

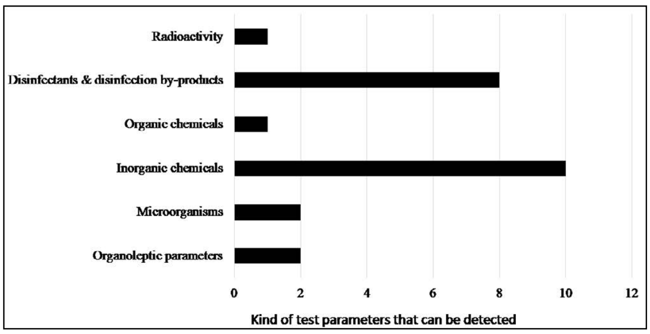

Fig. 2. Distribution of items detected in the product water by seawater reverse osmosis desalination plants.

5. Conclusions

In this study, product water by SWRO desalination plants for the benefit of the drinking-water supply system in China was studied in detail by 103 items. According to this determination, the product water was acceptable for drinking in China. Furthermore, it demonstrated that the product water by SWRO desalination could be used as a favorable and sustainable freshwater supply option to alleviate water scarcity from the perspective of its quality.

Acknowledgments

This work was supported by a research grant (K-JBYWF-2016-T15) from the State Oceanic Administration People's Republic of China. This work was financially supported by the National Natural Science Foundation of China (21604095), the Natural Science Foundation of Tianjin (18JCQNJC14500) and Program for Innovative Research Team in Peking Union Medical College, CAMS Initiative for Innovative Medicine (2017-I2M-3-022).

However, the manuscript has not been subjected to peer and policy review of the agency and therefore does not necessarily reflect its views.

References

[1] B.E. Logan, The global challenge of sustainable seawater desalination, Environ. Sci. Technol. Lett., 4 (2017) 197.

[2] M. Elimelech, W.A. Phillip, The future of seawater desalination: energy, technology, and the environment, Science, 333 (2011) 712–717.

[3] B.I. Escher, M. Lawrence, M. Macova, J.F. Mueller, Y. Poussade, C. Robillot, A. Roux, W. Gernjak, Evaluation of contaminant removal of reverse osmosis and advanced oxidation in full-scale operation by combining passive sampling with chemical analysis and bioanalytical tools, Environ. Sci. Technol., 45 (2011) 5387–5394.

[4] C.-L. de O. Manes, C. Barbe, N.J. West, S. Rapenne, P. Lebaron, Impact of seawater-quality and water treatment procedures on the active bacterial assemblages at two desalination sites, Environ. Sci. Technol., 45 (2011) 5943–5951.

[5] L.F. Greenlee, D.F. Lawler, B.D. Freeman, B. Marrot, P. Moulin, Reverse osmosis desalination: water sources, technology, and today's challenges, Water Res., 43 (2009) 2317–2348.

[6] J. Zhou, V.W.-C. Chang, A.G. Fane, Life cycle assessment for desalination: a review on methodology feasibility and reliability, Water Res., 61 (2014) 210–223.

[7] X. Zheng, D. Chen, Q. Wang, Z.X. Zhang, Seawater desalination in China: retrospect and prospect, Chem. Eng. J., 242 (2014) 404–413.

[8] Q.R. Zou, X.L. Liu, Economic effects analysis of seawater desalination in China with input–output technology, Desalination, 380 (2016) 18–28.

[9] Y.S. Ovadia, D. Gefel, D. Aharoni, S. Turkot, S. Fytlovich, A.M. Troen, Can desalinated seawater contribute to iodine-deficiency disorders? An observation and hypothesis, Public Health Nutr., 19 (2016) 2808–2817.

[10] O. Lahav, B.H. Liat, Quality criteria for desalinated water following post-treatment, Desalination, 207 (2007) 286–303.

[11] M. Shlezinger, Y. Amitai, I. Goldenberg, M. Shechter, Desalinated seawater supply and all-cause mortality in hospitalized acute myocardial infarction patients from the Acute Coronary Syndrome Israeli Survey 2002–2013, Int. J. Cardiol., 220 (2016) 544–550.

[12] A. Belila, J. El-Chakhtoura, N. Otaibi, G. Muyzer, G. Gonzalez-Gil, P.E. Saikaly, M.C.M. van Loosdrecht, J.S. Vrouwenvelder, Bacterial community structure and variation in a full-scale seawater desalination plant for drinking water production, Water Res., 94 (2016) 62–72.

[13] D.Y. Kim, G.L. Amy, T. Karanfil, Disinfection by-product formation during seawater desalination: a review, Water Res., 81 (2015) 343–355.

[14] J.K. Edzwald, J. Haarhoff, Seawater pretreatment for reverse osmosis: chemistry, contaminants, and coagulation, Water Res., 45 (2011) 5428–5440.

[15] M. Rygaard, E. Arvin, P.J. Binning, The valuation of water quality: effects of mixing different drinking water qualities, Water Res., 43 (2009) 1207–1218.

[16] J. Radjenović, M. Petrović, F. Ventura, D. Barceló, Rejection of pharmaceuticals in nanofiltration and reverse osmosis membrane drinking water treatment, Water Res., 42 (2008) 3601–3610.

[17] X.-N. Wang, Y. Liu, X.-H. Pan, J.-X. Han, J. Hao, Parameters for seawater reverse osmosis product water: a review, Exposure Health, 9 (2017) 157–168.

[18] Q.F. Yang, Y.Q. Liu, Y.J. Li, Humic acid fouling mitigation by antiscalant in reverse osmosis system, Environ. Sci. Technol., 44 (2010) 5153–5158.

[19] D. Prats, M.F. Chillon-Arias, M. Rodriguez-Pastor, Analysis of the influence of pH and pressure on the elimination of boron in reverse osmosis, Desalination, 128 (2000) 269–273.

[20] B. Teychene, G. Collet, H. Gallard, J.-P. Croue, A comparative study of boron and arsenic (III) rejection from brackish water by reverse osmosis membranes, Desalination, 310 (2013) 109–114.

[21] N. Avni, M. Eben-Chaime, G. Oron, Optimizing desalinated sea water blending with other sources to meet magnesium requirements for potable and irrigation waters, Water Res., 47 (2013) 2164–2176.

[22] I.G. Wenten, Khoiruddin, Reverse osmosis applications: prospect and challenges, Desalination, 391 (2016) 112–125.

[23] J.R. Werber, A. Deshmukh, M. Elimelech, The critical need for increased selectivity, not increased water permeability, for desalination membranes, Environ. Sci. Technol. Lett., 3 (2016) 1–29.

[24] K.L. Tu, T. Fujioka, S.J. Khan, Y. Poussade, A. Roux, J.E. Drewes, A.R. Chivas, L.D. Nghiem, Boron as a surrogate for N-nitrosodimethylamine rejection by reverse osmosis membranes in potable water reuse applications, Environ. Sci. Technol., 47 (2013) 6425–6430.

[25] B. Peñate, L. García-Rodríguez, Current trends and future prospects in the design of seawater reverse osmosis desalination technology, Desalination, 284 (2012) 1–8.

[26] K. Rahmawati, N. Ghaffour, C. Aubry, G.L. Amy, Boron removal efficiency from Red Sea water using different SWRO/BWRO membranes, J. Membr. Sci., 423–424 (2012) 522–529.

[27] A. Alpatova, A. Alsaadi, N. Ghaffour, Boron evaporation in thermally-driven seawater desalination: effect of temperature and operating conditions, J. Hazard. Mater., 351 (2018) 224–231.

[28] S. Jeong, G. Naidu, R. Vollprecht, T. Leiknes, S. Vigneswaran, In-depth analyses of organic matters in a full-scale seawater desalination plant and an autopsy of reverse osmosis membrane, Sep. Purif. Technol., 162 (2016) 171–179.

[29] H.-W. Yu, S.-G. Oh, I.S. Kim, I. Pepper, S. Snyder, A. Jang, Formation and speciation of haloacetic acids in seawater desalination using chlorine dioxide as disinfectant, J. Ind. Eng. Chem., 26 (2015) 193–201.

[30] E. Agus, N. Voutchkov, D.L. Sedlak, Disinfection by-products and their potential impact on the quality of water produced by desalination systems: a literature review, Desalination, 237 (2009) 214–237.