Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2016.1150887

57 (2016) 25331–25336
November

Taylor & Francis
Taylor & Francis Group

The role of desalination in removal of the chemical, physical and biological parameters of drinking water (a case study of Birjand City, Iran)

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Received 10 August 2015; Accepted 31 January 2016

ABSTRACT

One of the important components of public health is providing clean water in communities. According to documentations by international organizations, it is clear that high percentage of illnesses is directly related to water consumption in the society. Considering the fact that large mineral content in water can cause problems for consumers, the use of desalination to remove the minerals solute would therefore be a great idea in Iran. This cross-sectional descriptive study was performed to evaluate the role of six desalination devices (reverse osmosis) in Birjand that can remove chemical and physical parameter inputs such as nitrate, nitrite, total hardness, electrical conductivity (EC), chromium(VI), manganese, total dissolved solids (TDS), and microbial parameters (fecal coliform and total coliform) of water. One hundred and forty-four (144) samples of input and output point's desalination were harvested and analyzed according to standard methods. The results showed that these devices could remove up to 90% chromium(VI), TDS, salinity, nitrite, from input water and 100% in many cases. The concentrations of chemical parameters in treated water were as follows: TDS = 262–369 mg/l, total hardness = 92–200 mg/l as $CaCO_3$, nitrate = 4.31–11 mg/l, nitrite = 0 mg/l, Cr = 0–0.002 mg/l, Ca = 6.4–12.8 mg/l, Mg = 17.3–40.3 mg/l, Mn = 0 mg/l, salinity = 63 mg/l, pH range = 7–7.6, fecal coliform = 0 (MPN/100), total coliform = 0 (MPN/100), EC = 403.4–507.7 μs/cm and membrane flux retention coefficient = 1. Analysis of input and output data using paired *t*-test showed significant differences in these parameters ($p < 0.05$). Thus to remove high levels of mineral from drinking water in Birjand and since heavy metal chromium(VI) in the resource water in that area is higher than the standard requirement, using these systems can achieve good results.

Keywords: Reverse osmosis; Desalination plant; Water quality; Membrane process; Birjand

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1. Introduction

Drinking water is one of the ways necessary minerals can be provided for the body [1,2]. One of the ways epidemic diseases can be contracted is by using polluted water, therefore purification and improvement of water resources can play a great role in reducing such diseases [3]. The high concentration of solids soluble in water makes it salty and reduces the consumers' tendency to use such water [2,4]. Access to adequate water (quantity) and assurance of its safety (quality) are the most significant concerns of health authorities and water industry experts especially in developing countries suffering from the shortage of water [5,6]. The high amount of some physical and chemical parameters such as hardness, total dissolved solids (TDS), nitrate, nitrite, pH, salinity, temperature, chloride, and heavy metals (chromium(VI) and manganese) in water brings about some problems for the consumer [7–9]. Thus, using water desalination devices has become necessary. The membranes used in these devices to remove minerals from water include reverse osmosis (RO), microfiltration (MF), nanofiltration (NF), and ultrafiltration (UF). The membrane separation technology has found its status among the consultant engineer, designers of environment pollution control, and industrial factory engineers [6]. The membrane processes in the USA and EU play an important role in production of drinking water with good quality in which the purpose is to remove Disinfection byproducts (DBPs), turbidity, nitrogen, synthetic organic materials, and protozoan cysts [10,11]. These devices are also effective in the removal of Arsenic from water [12]. To increase the efficacy of RO membranes, MF membranes can be used before such membranes [13]. The membrane filtration method has great ability in preventing *Cryptosporidium* and *Giardia lamblia* cysts from entering water [14]. Regarding the location of Birjand city (hot and desert area) and poverty of the region in terms of groundwater, the only source of water is underground water tables for different urban, agriculture, and industrial applications. The high amount of minerals present in water is an inevitable feature and people easily feel its salty taste. The people in Birjand have long searched for favorable drinking water; an example is the use of storage facilities filled with river and qanat water which had better quality. The interest in desalination of groundwater has increased in areas short on freshwater, such as the South Khorasan Province of Iran. Brackish water sources are often groundwaters and can be naturally saline aquifers or groundwater that has become brackish as a result of seawater intrusion or anthropogenic influences (overuse and irrigation) [15]. Groundwater with low to moderate salinity (1,000–5,000 mg/L TDS) is relatively common. The difference in feed water quality can lead to differences in design and operation, for example, differences in pretreatment, feed pressure, configuration of stages, water recovery, fouling prevention, and waste disposal [16]. Due to the introduction of modern technology in drinking water purification systems, using water desalination devices with RO method became common in Birjand such that there are six water desalination devices (RO) in Birjand operated by private sector which sells the drinking water to the public. Membranes are composed of cellulose acetate (CA) which makes them particularly well suited for desalting high TDS water in these units [15]. Finally, the disposal of concentrate is a significant challenge in the RO system. In these RO plants, the disposal of concentrate led to seepage pit or absorbing well in the distance standard with resource water. Fig. 1 presents a description of the RO process. Since the control of drinking water is of great importance in terms of health, this research was carried out to determine the quality of water entering and exiting water dispensing devices in the Health Faculty of Medical Science of Birjand in 2014.

2. Materials and methods

This cross-sectional study was carried out on six desalination water facilities (RO) in Birjand, the east Iranian provincial capital of South Khorasan, Iran. In total, 144 samples were randomly collected from each facility in 2014. The sampling points in the entering and exiting points of the desalination facilities from every two microbial and chemical samples were collected. The collected samples were sent to Health Faculty lab for physical tests (temperature, total dissolved solid (TDS), electrical conductivity (EC)), and chemical tests (hardness, pH, nitrate, nitrite, chromium(VI), manganese) and microbial tests in standard conditions. To measure heavy metals, Cr, Mn, nitrate, and nitrite were measured with the following methods: standard method of 10157 Standard Institute based on calorimeter method, standard method of 10157 of Standard Institute based on spectrophotometry [17], standard method of 2351 of Standard Institute based on Brucine method with spectrophotometer device [18], standard method of 4500 of Standard Institute based on diazotization method with spectrophotometer device of Perkin model manufactured by the USA, respectively. To assess the microbial contamination,

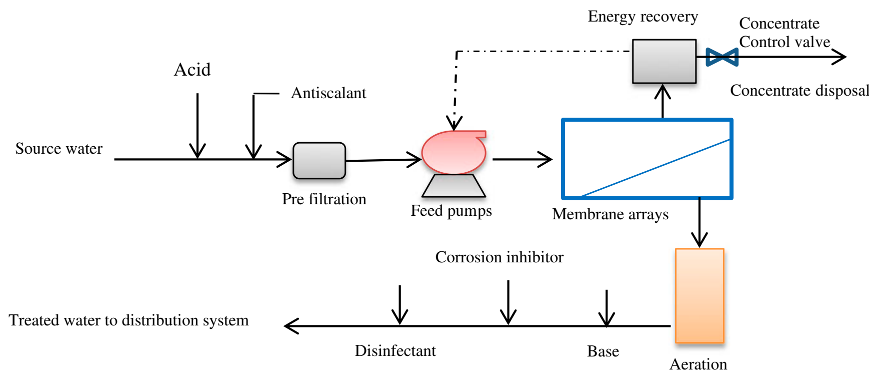

Fig. 1. Schematic of typical RO facility.

multiple tube fermentation of standard no. 3759 of Standard Institute was applied [19]. The measurement of hardness was carried out by titration method with EDTA based on standard method 2340 of Standard Institute with titrimetric method and EC measurement was carried out with EC-meter (manufactured by WTW company, Germany) while pH was measured with pH-meter of knick from Germany. The measurement of calcium hardness was done through titrimetric method of Standard Institute. It is worth mentioning that to collect chemical and microbial samples, 2-L vessels of clean polyethylene and glass sterile vessels were used, respectively. Finally, the data were analyzed by statistical package for the social science (SPSS) software, V.16.0 (Mean ± SE). p-value was calculated using analytical paired t-test and value less than 0.05 was considered as significant. The values of each parameter were compared to standard regulations of drinking water.

3. Results

Tables 1 and 2 show the mean parameters in the study for entering and exiting water desalination facilities. The minimum and maximum EC was 1,800.3 and 1,935.3 µs/cm for entering water which reached 549.9 and 403.4 µs/cm in the exiting water, respectively. The TDS were 1,170–1,257 mg/l in the entering, reaching 350–262 mg/l in the exiting water. The total hardness in the entering water before purification was 400–560 mg/l as $CaCO_3$ and 92–120 mg/l as $CaCO_3$ in the exiting water. In the entering section of all facilities, the parameter values of nitrate, nitrite, chromium, manganese, fecal coliforms, total coliforms, and pH were compatible with drinking water standards. Table 3 shows p-value using analytical paired t-test and the values of each parameter that were compared to standard regulations of drinking water.

4. Discussion

There are different methods for purifying drinking water so that the consumers can have safe and healthy water. In all stages of production and distribution of drinking water, there must be quality control tests. Regarding the increasing use of desalination water facilities across Birjand, it is necessary to qualitatively control the entering and exiting water of these facilities. In the samples collected from the exiting water of these facilities, TDS, calcium, magnesium, chromium, manganese, and nitrite parameters were at the range of safe drinking water but the hardness was not in the favorable standard range at 2.7% of samples, which is likely from the high hardness of entering water from groundwater resources. In the study of Miran Zadeh et al. [20] on chemical quality of entering and exiting water of desalination water facilities in Kashan, it was shown that exiting concentration of total hardness, calcium and magnesium hardness, alkalinity and nitrate in the exiting section of these facilities were consistent with the results obtained in this study. For pH of entering water into the facility, it was at 7.5–7.9 which was very suitable but it decreased in exiting water reaching 7–7.6 showing that using RO process led to pH reduction. The results of this research show that in exiting water of desalination water facilities, pH decreased in exiting water but it did not reach the drinking water standard which is consistence with those of Miran Zadeh et al. [20] on the desalination facilities in Kashan. In the research carried out in Qum [21], pH of exiting water of all facilities was less than the favorable value (6.5) and reached less than six

Table 1
Analysis of physical and chemical parameters in water desalination input and output Birjand devices

Number	EC (μs/cm)		TDS (mg/l)		Total hardness (mg/l) as $CaCO_3$		Ca (mg/l)		Mg (mg/l)		Nitrate (mg/l)		Nitrite (mg/l)	
	In[a]	Out[b]	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
1	1,858.2	519.5	1,200	330	560	120	56.0	8.0	100.8	24.0	15.7	11.0	0.001	0.000
2	1,800.3	549.9	1,170	350	500	132	40.0	6.4	96.0	27.8	19.2	8.2	0.001	0.000
3	1,935.3	403.4	1,257	262	400	92	44.8	8.0	69.1	17.3	17.0	9.4	0.002	0.000
4	1,926.2	567.7	1,252	369	500	200	40.0	12.8	96.0	40.3	21.2	4.3	0.001	0.000
5	1,894.0	553.1	1,230	359	460	160	38.4	8.0	87.3	33.6	19.4	9.2	0.000	0.000
6	1,916.4	504.3	1,245	320	400	112	44.8	11.2	69.1	20.1	19.5	4.4	0.002	0.000
Acceptable[c] level	NAS[d]		1,000		500		200		150		50		3	

[a]In = influent.
[b]Out = effluent.
[c]WHO guideline (2011).
[d]No standard available.

Table 2
Analysis of microbial and chemical parameters in water desalination input and output Birjand devices

Number	pH		Cr (mg/l)		Mn (mg/l)		Salinity		Total coliform (MPN/100)		Fecal coliform (MPN/100)	
	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
1	7.7	7.5	0.078	0.034	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
2	7.8	7.6	0.106	0.000	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
3	7.7	7.0	0.044	0.000	0.1	0.0	0.8	0.0	0.0	0.0	0.0	0.0
4	7.6	7.7	0.084	0.000	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
5	7.5	7.3	0.061	0.004	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
6	7.9	7.0	0.047	0.002	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0
Acceptable level	6.5–8.5		0.05		0.1		NSA[a]		<1/100 ml		<1/100 ml	

[a]No standard available.

being different from those of Birjand and Kashan on exiting samples due to different quality of entering the facility, membrane materials, and their utility along with difference in percentage of raw water and desalinated water. In addition, the results of a research on quality of water extracted from desalination facilities in cities and villages of Iran showed that pH of exiting water of these facilities tended toward acidity and corrosion. The water without hardness or with low hardness is suitable for industrial applications but not for drinking. Therefore, hardness concentration must be over 100 mg/l as $CaCO_3$ at 100 to 150 mg/l as $CaCO_3$ in the exiting water of desalination facilities. The results showed that in most facilities, the hardness concentration was less than this value and it must be combined with tap water to be drunk as long-term consumption can cause some problems as confirmed by Yari et al. study [21] in Qum and Miran Zadeh [20] in Kashan. One of the features of RO membranes is the removal of pathogenic factors, TDS, and heavy metals [5]. Since Chromium in the water of Birjand and entering water of desalination water facilities was higher than that of drinking water standard and all filters used in Birjand are of RO type, applying these facilities can remove 100% of these metals. The results of microbial tests showed that none of the samples had coliform contamination, while in similar research on desalination facilities of Qum, 15 samples (6%) had coliform contamination of *Eschershia coli* [21]. This can be due to the formation of microbial film on the

Table 3
Comparison of the mean values of the input and output parameters analysis Birjand desalination devices

Variable	In[a] (N = 30) Mean	SD	SE	Out[b] (N = 30) Mean	SD	SE	Acceptable level[c]	Paired t-test p-value
EC (μ_{moh}/cm)	1,888.40	51.22	20.91	516.310	60.04	24.51	NAS[d]	<0.001
TDS (mg/l)	1,225.66	34.13	13.93	331.660	38.65	15.77	1,000	<0.001
Salinity (mg/l)	0.80	0.00	0.00	0.000	0.00	0.00	NAS[d]	NC[e]
Total hardness (mg/lcaco$_3$)	470.00	62.92	25.69	136.00	38.61	15.76	500	<0.001
Ca (mg/l)	44.00	6.45	2.63	9.060	2.40	0.98	200	<0.001
Mg (mg/l)	86.38	14.07	5.74	27.180	8.62	3.52	150	<0.001
Cr (mg/l)	0.07	0.02	0.01	0.006	0.01	0.005	0.05	0.002
Mn (mg/l)	0.01	0.04	0.01	0.000	0.00	0.00	0.10	0.363
NO_3 (mg/l)	18.66	1.97	0.80	7.750	2.78	1.13	50	0.002
NO_2 (mg/l)	0.00	0.00	0.00	0.000	0.00	0.00	3	0.013
Total coliform (MPN/100)	0.00	0.00	0.00	0.000	0.00	0.00	<1.100 ml	NC[e]
Fecal coliform (MPN/100)	0.00	0.00	0.00	0.000	0.00	0.00	<1.100 ml	NC[e]
PH	7.70	0.14	0.05	7.350	0.30	0.12	6.5–8.5	0.07

[a]In = influent.
[b]Out = effluent.
[c]WHO guideline (2011).
[d]No standard available.
[e]Not computed: the correlation and t cannot be computed because the standard error of the difference is 0.

membranes after a while from the ground water resources. In the study of Schwartz et al. [22] on the biofilm formed on the membranes, the bacteria which were resistant to antibiotics and resistant genes were separated. In a study on the relationship between the gastrointestinal effects of water consumption generated from household RO membranes after 7–9 months of installation, it was shown that these units were contaminated with heterotrophic plate count (HPC) bacteria at a higher value than the standard requirement (HPC = 500 cfu/ml). The species identified were Gram-positive and negative *Cocci*, *Pseudomonas* and *Alcaligenes faecalis*. When using filtered water, it must be noted that in most cases [23], the content of Fe exiting from these facilities is less than the standard requirement [10,20,21]. Consequently, individuals should not use desalination facilities permanently; water intake should be alternated using filtered water and tap water. Data analysis using paired t-test on entering and exiting parameters showed that these facilities are able to remove most parameters. Table 3 shows the p-value of less than 0.05 calculated using paired t-test was obtained for all parameters except for manganese and pH. High standard deviation implies the difference between high concentrations of input and output. This illustrated that RO is effective to reduce the input concentrations.

5. Conclusion

Based on the results of desalinated water, all parameters were in accordance to the standard concentration for drinking water. Although, the pH of the outlet water was relatively decreased with respect to the raw water, none complied with drinking water standards. To balance the mineral concentration in the final purified water, it is better to mix the facility's exiting water with raw water, as water of low minerals is not suitable for health.

Acknowledgment

This research has been technically and financially supported by Birjand University of Medical Sciences, Department of Environmental Health Engineering.

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