Pilot study and modeling for salinity reduction in drinking water in Berjand

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ABSTRACT

The salinity of the ground water in Berjand, the capital of the province of South Khoorasan in Iran, has been a matter of concern since the ground water is the only source of drinking water in the city. Firstly, the authors studied the effects of both nano-filtration (NF) and reverse osmosis (RO) for the reduction of total dissolved solids (TDS) in the north and the south of the city. Secondly, we applied the Reverse Osmosis System Analysis simulator to the pilot study under the same circumstances as the pilot study to investigate the suitability of the software as a predictor of water quality. The results of the pilot study showed that the NF and RO processes have a high percentage of TDS removal at all pressures. The NF and RO membranes showed very high efficiency in the reduction of TDS. The RO system needs more energy than the NF system.

Key words | Brijand, nano-filtration, reverse osmosis, salinity, water treatment

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INTRODUCTION

The high amount of dissolved solids in ground water which are present in the form of cations and anions of different valences makes the water unsuitable for industrial or public use. Nano-filtration (NF) and reverse osmosis (RO) are most commonly used for the reduction of water salinity. Several researchers worked on NF and RO, such as Gagliardo *et al.* (1998), Karakulski *et al.* (2002), Afonso *et al.* (2004), Kumar *et al.* (2006), Walha *et al.* (2007), M'nif (2007), Belkacem *et al.* (2007, 2008) and Subramani *et al.* (2012).

The city of Berjand is situated in the center of the province of South Khorasan in northeastern Iran (Figure A-1, available online at http://www.iwaponline.com/jws/062/037.pdf). The high salinity of the ground water in the city, however, makes it unsuitable for drinking. The reduction of salinity thus holds paramount importance for the sustenance of life in the region.

The first objective of this work, as a pilot study, was to determine the percentage removal of total dissolved solids (TDS) and the water recovery ratio using NF and RO methods. The second aim was to apply a Reverse Osmosis System Analysis (ROSA) 8.0.3 (last version) simulator to the same circumstances as the pilot study to find out the appropriateness of the model.

MATERIAL AND METHODS

In this study, pilot plants comprised of NF and RO were used for the reduction of TDS from ground water in the north and south parts of Berjand in South Khorasan.

The pilot plants were situated beside the reservoir tanks which contained the ground water in the north and south of the city. The TDS and pH of the water before and after treatment were monitored. The treatment was carried out on two different water samples, one for both the NF and RO plants. Since chlorine is added to the tanks for disinfection purposes, samples were collected from the inflow of the tanks. The study was carried out in the summer and early autumn of 2009. The characteristics of the apparatus used in the pilot study are shown in Table A-1 (available online at http://www.iwaponline.com/jws/062/037.pdf).

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The accuracy of the TDS meter, flow meter, thermometer and pressure meter were ±1 mg/L, ±0.1 L/min, ±1 °C and ±0.1 bars, respectively.

The quality parameters of the raw water in both of the tanks were measured (Table A-2, available online at http://www.iwaponline.com/jws/062/037.pdf). Both membranes were installed in a pilot plant. A valve connected and disconnected the two membranes, but each of them worked as an independent pilot plant. Total times of the experiment were 480 h for each part of the city. The TDS of the raw water was monitored and water was subsequently treated every 10 min for the first hour of the experiment and every 15 min in the following hours for each day of the experiment. Operating pressures for RO were 8, 10, 12 and 14 bars, while for nano-filtration the values were 4, 6 and 7 bars. Discharge was also monitored at each pressure value during the operation. The TDS average of the water in the north and south of the city was 1,157 mg/L.

Water quality monitoring was carried out during the summer and early autumn of 2009 in the north and south of Berjand from two tanks. Three samples were selected each time for water quality monitoring. Each sample was monitored by digital TDS meters (28/02-2000 Micro N/C Toc Uerson) and, for the reliability of the results, three samples were also sent to the Science and Technology Park laboratory in South Khorasan. Discharge was measured by an installed gauge on the system. Figure A-2 shows a schematic of the pilot process of NF and RO in this research. Table A-3 shows input information for the pilot study in Birjand. (Figure A-2 and Table A-3 are available online at http://www.iwaponline.com/jws/062/037.pdf.)

Limitations in the pilot study

There were a few limitations which are as follows. First, due to the abstraction of water from the large reservoirs for the pilot study, there was a slight variation of TDS and temperature. However, in order to minimize the error in our experiment, we took the water during the morning between 8 and 12 a.m. when the variation was minimal. Membrane performance for removing TDS of the water is affected by changing TDS and temperature of the influent. Second, slight fouling was observed several times when operating the membrane. When the fouling was observed, we changed the membrane and cartridge filter. Third, the pilots were not operating at lower pressure because the effluent discharge was very low.

Model formulation

The straightforward formula for permeate flow Q through an RO membrane is shown by Equation (1):

$$Q = (A)(S)(\Delta P - \Delta \pi) \tag{1}$$

where S, $(\Delta P - \Delta \pi)$ and A are the wetted surface area, the net driving pressure and the membrane permeability coefficient or A-value, respectively.

For more details relating to the mathematical theory of the RO and the NF, the reader should refer to Paul (2004), Zhao et al. (2005), Sehn (2008), Oh et al. (2009) and Cath et al. (2010).

Computer simulation of the RO and NF process was conducted using ROSA 8.0.3 software by Dow; the package is for the design of systems applying the Filmtec™ range of membranes by Dow. Initially the program was used to duplicate the conducted tests, providing comparative data for the validation process. The study of RO and NF membranes using the simulation package was conducted for TDS reduction of ground water in Brijand.

For simulation and calibration descriptions, readers should refer to ROSA manual (Dow FILIMETEC Reverse Osmosis 2009).

RESULTS

The data in Table A-2 were analyzed by the Science and Technology Park laboratory in South Khorasan province, which monitored it during the pilot study in July 2009. Tables 1 and 2 show the summary of the results from the NF and RO pilot studies in the north and south of the city.

As shown in Tables 1 and 2, there is a direct relationship between the operational pressures and effluent (discharge) in both the RO and NF membranes. An increase of up to 12 and 6 bars in the operating pressure of both RO and NF processes, respectively, results in an increase in the efficiencies and reduction of TDS. When a further increase in the operational pressure in the north of the city using NF membrane resulted in the reduction of efficiency, it could be a result of slight fouling. Consequently, high operating

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Table 1 | The results of pilot and modeling study in the north of Berjand

RO pilot study results in the north of the city

Operation pressures (Bars)	TDS (mg/L)	Discharge recovery (%)	Removal efficiency (%)	Energy consumption (kWh/m^3)
8	97	38	91.62	0.731
10	85	56	92.65	0.618
12	88	73	94.12	0.568
14	87	85	92.48	0.570

RO modeling study results in the north of the city

Operation pressures (Bars)	TDS (mg/L)	Discharge recovery (%)	Removal efficiency (%)	Energy consumption (kWh/m^3)	Concentrate TDS	Permeate flow	Blended TDS (0.07 m^3/h) – energy
8	24.56	53.06	97.94	0.52	2569.75	0.16	390.11–0.36
10	26.32	67.57	97.79	0.51	3701.74	0.19	342.51–0.38
12	30.82	82.54	97.42	0.5	6824.10	0.22	315.43–0.38
14	–	100	–	–	–	–	–

NF pilot study results in the north of the city

Operation pressures (Bars)	TDS (mg/L)	Discharge recovery %	Removal efficiency (%)	Energy consumption (kWh/m^3)
4	151	35	86.95	0.397
6	142	67	87.73	0.31
7	165	86	85.74	0.283

NF modeling study results in the north of the city

Operation pressures (Bars)	TDS (mg/L)	Discharge recovery (%)	Removal efficiency (%)	Energy consumption (kWh/m^3)	Concentrate TDS	Permeate flow	Blended TDS (0.07 m^3/h) – energy
4	120.05	49.25	89.95	0.28	2286.52	0.18	431.78–0.2
6	132.12	78.31	88.94	0.27	5136.85	0.26	364.32–0.21
7	152.55	92.57	87.23	0.26	14453.42	0.28	364.37–0.21
14	–	100	–	–	–	–	–

pressures yielded a greater amount of treated water which causes the water reduction. However, the TDS efficiency reduction in this situation is still satisfactory for drinking.

Energy consumption in both processes was reduced with increased operational pressure. The objective of generating the maximum amount of treated water with minimum energy consumption and acceptable TDS removal was reached at a pressure of 7 bars in the NF process and a pressure of 14 bars in the RO process.

Both NF and RO membranes showed extremely high efficiency in reducing TDS. Both techniques provided acceptable values of TDS in the treated water when compared to the standard TDS values in drinking water. (The WHO standard or the ISIRI (2007) is 500 mg/L.)

An increase in the operational pressure yields more treated water. Energy consumption is also an important factor which must be taken into account. Tables 1 and 2 show energy consumption, removal efficiency and amount of water treated in different operating pressures. As shown, the best operational condition (minimum energy consumption and maximum TDS reduction efficiency) for the pilot study was 12 bars, but raising the pressure to 14 bars results in decreasing energy consumption to a great extent. Hence, the best operating pressure is 14 bars (RO process) when all the

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Table 2 | The results of pilot and modeling study in the south of Berjand

RO pilot study results in the south of the city

Operation pressures (Bar)	TDS (mg/L)	Discharge recovery (%)	Removal efficiency (%)	Energy consumption (kWh/m^3)
8	107	36	91.12	0.772
10	92	55	92.37	0.628
12	72	69	94.37	0.605
14	90	80	92.53	0.604

RO modeling study results in the south of the city

Operation pressures (Bar)	TDS (mg/L)	Discharge recovery (%)	Removal efficiency (%)	Energy consumption (kWh/m^3)	Concentrate TDS	Permeate flow	Blended TDS (0.07 m^3/h) – energy
8	22.90	52.74	97.95	0.53	2350.14	0.16	360.81–0.37
10	24.79	68.43	97.78	0.51	3501.55	0.19	317.54–0.37
12	28.27	82.40	97.47	0.51	6242.21	0.22	290.66–0.38
14	–	–	–	–	–	–	–

NF pilot study results in the south of the city

Operation pressures (Bar)	TDS (mg/L)	Discharge recovery (%)	Removal efficiency (%)	Energy consumption (kWh/m^3)
4	141	32	88.3	0.431
6	130	62	87.63	0.336
7	139	63	69.21	0.293

NF modeling study results in the south of the city

Operation pressures (Bar)	TDS (mg/L)	Discharge recovery %	Removal efficiency (%)	Energy consumption (kWh/m^3)	Concentrate TDS	Permeate flow	Blended TDS (0.07 m^3/h) – energy
4	126.31	48.06	88.7	0.29	2045.28	0.18	407.16–0.21
6	135.40	75.93	87.88	0.27	4236.61	0.26	342.55–0.22
7	157.62	91.28	85.9	0.26	11212.24	0.29	345.48–0.21

factors, including (a) scarcity of water in the region, (b) waste removal, (c) TDS efficiency reduction and (d) energy consumption, are taken into account. Nevertheless, comparison of two pilot studies in two different countries with different water quality characteristics is a difficult task. We compared the result of our work with the study of Afonso *et al.* (2004), the water recovery of this study was higher than their work.

As shown in Tables 1 and 2, the results of the pilot study and simulation models are comparable in the RO process, except for 14 bar pressure, and the minimum difference between the previously mentioned results occurred at 12 bar pressure. The ROSA results showed 100% effluent discharge recovery at 14 bar pressure for both the north and south of the city was occurring, which may mean that no treatment occurs for reduction of TDS, however, in practice, water was treated. The changing energy consumption and discharge of the effluent in both the pilot and the simulator while increasing pressure were similar, and decreasing energy consumption and raising the rate of flow up to 12 bar pressure occurred. Therefore, the ROSA simulator may be used to predict the water quality of Berjand.

Tables 1 and 2 have also shown that in the results of the pilot study and simulation models using the NF process, both the consequences were similar, except for the

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7 bar pressure in the north. The results of the study in both the pilot and the model indicated reduction of energy consumption and increasing outlet discharge when the pressure was increased. According to results from the model for RO, when the pressure was increased, the efficiency of removal of TDS was decreased. Figure A-3 (available online at http://www.iwaponline.com/jws/062/037.pdf) illustrates the comparison between the pilot study with the ROSA simulator using the NF process in the south of the city. As indicated in the figure, the results of both are nearly the same, and the correlation coefficient is 0.98. The same consequence was achieved in the north of the city when the RO process for water treatment was used (Figure A-4, available online at http://www.iwaponline.com/jws/062/037.pdf), and $R^2 = 0.99$. The TDS removal efficiency of the RO process was higher than the NF process.

Figure A-5 (available online at http://www.iwaponline.com/jws/062/037.pdf) shows a comparison between the pilot study with the ROSA simulator using the RO process in the south of the city. The results of both are slightly different and the correlation coefficient is 0.91. The same result was reached in the north of the city when the RO process for water treatment was used (Figure A-6, available online at http://www.iwaponline.com/jws/062/037.pdf), and $R^2 = 0.93$.

The differences between the pilot study and ROSA software may be as a result of the following: ROSA software cannot accept accurate physical and chemical characteristics of water; this may affect the results. The inability for complete application of the existing conditions of a pilot study of the ROSA software may be a second reason for the slight differences between the pilot result and the model. Third, the membranes which were used in the pilot study were washed; therefore, the membrane characteristics could have changed. Finally, this difference is due to different characteristics of the individual membrane element, e.g. the membrane permeability for individual elements may vary by ±20%.

However, 91–94% efficiency removal of TDS is not necessary for the water as the TDS of the water for drinking should be reduced to 500 mg/L (ISIRI 2007; WHO 2008). It may be economical to treat part of the water with the NF and dilute it with raw water.

CONCLUSION

Taking into consideration the results of the pilot study and applying the ROSA software in Berjand, the following conclusions can be reached: The NF and RO membranes showed very high efficiency in reducing TDS of the ground water in Berjand for drinking. By increasing pressure, the amount of treated water was augmented; conversely, energy consumption declined for both the pilot and the ROSA model. By boosting pressure up to a certain point, TDS removal increased and then it declined for the experimental study and the model. The energy consumption of the RO membrane was more than that of the NF membrane for both the experiment and the model. The results of the pilot and the ROSA showed the same trends with slight differences; however, these differences were due to different characteristics of the individual membrane element, e.g. the membrane permeability for individual elements may vary by ±20%. The results of this study could be useful for arid climate regions that use ground water for drinking water. Blending part of the feed water to permeate water reduces energy consumption in both NF and RO modeling.

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