Desalination and Water Treatment
www.deswater.com
doi:10.5004/dwt.2017.20861

73 (2017) 121–126
April

Integrated approach for brackish water desalination and distribution: which desalination technology to choose?

K. Minyaoui[a], H. Hchaichi[a], M. Pontie[b], A. Hannachi[a,*]

[a]*GPSI, National Engineering School of Gabes, University of Gabes, Omar Ibn El Khattab Street, 6029 Gabes, Tunisia, Tel. +216 75392100, Fax +216 75392190, email: ahmed.hannachi@enig.rnu.tn*
[b]*GEPEA UMR CNRS 6144/GEIHP EA3142, UFR sciences, University of Angers, 2 Boulevard Lavoisier,49045 Angers cedex, France, Tel. +33666920935, email: maxime.pontie@univ-angers.fr*

Received 1 August 2016; Accepted 9 March 2017

ABSTRACT

In the southern part of Tunisia, brackish water is desalinated and blended with raw water to be delivered to the consumer. The desalination technique used is reverse osmosis (RO). However, it is an energy intensive process compared to other water treatment technologies such as nanofiltration (NF). The latter technique is capable of retaining polyvalent ions and could provide the same distributed water quality with much lower energy consumption. In this work, simulations were conducted in order to compare reverse osmosis and nanofiltration performances in brackish water desalination process within arid regions and to determine the best technique for desalting brackish water for lower energy and water consumptions. For a given distributed water quality, specific energy consumption could be reduced by 40% when nanofiltration is used instead of reverse osmosis. Water consumption when NF is applied is reduced as well. The distributed water quality is not significantly affected by applying NF instead of RO. Besides, these environmental aspects, scaling assessment favored NF as well.

Keywords: Brackish Water; Desalination; Reverse Osmosis; Nanofiltration; Simulation; Energy Consumption; Scaling

1. Introduction

Fresh water is essential for life. Its availability is perhaps one of the most important challenges for human kind to ensure sustainable development. As more people put ever growing demands on decreasing and pollution threatened water resources, the problem of water scarcity is a growing one and is driving towards a rational management and the use of non- conventional water assets [1].

Desalination has become an important alternative for water treatment technology for providing fresh water for all uses. Lately membrane processes gained supremacy over alternative techniques in water desalination market. Mostly reverse osmosis (RO) is used to desalinate seawater and brackish water [2]. However, the energy demand of this membrane technology is still relatively important. There is a continuous effort to reduce energy consumption in desalination [3]. Nanofiltration is a membrane technique placed between reverse osmosis (RO) and ultrafiltration (UF). NF applications are gradually taking over areas reserved to RO especially in the case of water softening [4,5]. In fact, with the development of material sciences NF could evolve to provide many opportunities significantly higher than RO. This technique is able to produce a good fresh water quality in brackish water desalination market, at a low operational pressure and a high retention of multivalent anion salts [6]. NF membranes have shown the ability to retain organic compounds with molecular weight above 300 Da [7,8], also to remove turbidity, microorganisms and hardness [9,10]. Actually, nanofiltration could be a competing membrane process to reverse osmosis for brackish water desalination [11,12].

A major limitation for membrane processes is scaling. Scale formation is due to precipitation of salts present in

*Corresponding author.

Presented at the EDS conference on Desalination for the Environment: Clean Water and Energy, Rome, Italy, 22-26 May 2016

1944-3994 / 1944-3986

saline water. Many mineral species existing naturally in water contribute to the formation of several salts such as: $CaCO_3$ and $CaSO_4$. For calcium carbonate many indices, such as: Langelier Saturation Index (LSI) has been proposed for scaling assessment [13,14]. In membrane based water desalination processes, scaling should be avoided.

In Tunisia, especially in the southern part, water scarcity has promoted the use of non-conventional water resources [13]. For this purpose RO desalination unit, run by the National Water Distribution Utility (SONEDE), has been operating since 1995 at 75% conversion rate and a nominal production capacity of 360 m^3/h. The salinity of feed water is about 3 g/L. Because the water needs exceed desalination capacities, SONEDE is delivering a mixture of desalinated and ground waters. The advantageous of replacing RO by NF mainly for reducing overall energy consumption will be investigated. Thus, the present work aims to compare reverse osmosis and nanofiltration performances in this brackish water desalination process for the same delivered water quality. For both cases the membrane desalination unit is supposed to have the same configuration to treat the same feed flow rate of 400 m^3/h. A RO design commercial software was used for calculations. The specific energy consumption and water use will be examined and discussed. The scaling tendency will be also compared for both membrane processes.

2. Case study

The case study considered here is the brackish water desalination plant of Gabes that is supplied with water characterized by a high hardness and sulphate contents. It is a geothermal water extracted from Chott Fejij region before getting cooled to ambient temperature. The water salinity and pH are 3 g/L and 7.8, respectively. The raw brackish water does not contain any harmful contaminants. Its mineral content is shown in Table 1.

The system configuration of the adopted process has two stages allowing treating 400 m^3/h feed flow rate. The first stage contains 42 pressure vessels, the second 24 tubes. Each pressure vessel has 6 modules in series. The concentrate of the first stage feeds the second. The fresh water collected in both stages will be then blended with the raw water to be distributed to the population. The schematic diagram of the system configuration is shown in Fig.1.

Commercial software was used for conducting simulation of the membrane desalination processes. Only cases

Table 1
Feed water mineral contents in ppm [13]

SO_4^{2-}	1175
Cl^-	870
Na^+	370
Ca^{2+}	376
HCO_3^-	100
Mg^{2+}	90
K^+	15
SiO_2	12
Fe	0.08
TDS	2950

where secure operating conditions for membrane modules were retained. This insures that simulation results would match what is expected in real desalination practices.

In this work, RO brackish water and dense NF membranes were considered. For the investigation BW30 Dow Filmtec RO elements and NF90 Dow Filmtec membrane elements were chosen. The selection of NF modules was motivated by their high productivity and ability to provide a high salt rejection rate close to RO element. Calculations were performed with the following assumptions: average water temperature of 25°C and pump efficiency of 80% with the system configuration described earlier in this section.

3. Results and discussion

The results presented in this section are relative to a comparative study between reverse osmosis and nanofiltration membranes. First permeate TDS variation with recovery rate for both membrane technologies is shown in Fig. 2. Dotted lines are relative to hydrodynamic conditions slightly different from what should be imposed in practice with the same desalination unit configuration. This was the case of only NF for relatively high recovery rates exceeding 78.5%. Beyond this limiting value, maximum recommended element permeate flow rate would be exceeded. It is obvious that the permeate TDS increases with the recovery rate. Clearly, salt rejection is considerably higher for RO with the worst permeate TDS of 57 mg/L at 80% conversion rate. For NF the permeate TDS figures are much higher indicating that permeate quality is affected when NF is used.

Typical evolution of specific energy consumption at different recovery rates is shown in Fig. 3. Specific energy consumption is given with respect to the permeate flow rate. Energy needs increase with the recovery rate which is a result of increasing pressure demand. Nanofiltration membranes allow desalination with lower energy consumption (below 0.31 kWh/m^3) for conversion rates not exceeding 80%.

For ion removal, we chose to present rejection rates versus recovery rates for both membrane types. The results are shown in Figs. 4 and 5 for two different monovalent and bivalent cations and anions. These figures indicate that unlike for monovalent ions, in the case of bivalent ions, the difference in rejections between RO and NF is not significant. That is, NF is able to remove water hardness almost as efficiently as RO.

Referring to Fig. 1, a steady state conservation equation allows calculating the needed blending raw water flow rate as follows:

$$Q_M = Q_P \frac{TDS_D - TDS_P}{TDS_F - TDS_D} \quad (1)$$

where Q and TDS are flow rate and total dissolved salts, respectively; the indices F, D, M and P designate the feed, distributed, blending and permeate streams, respectively.

The total consumed water flow rate is given by:

$$Q_W = Q_F + Q_M \quad (2)$$

and the distributed water flow rate is:

$$Q_D = Q_P + Q_M \quad (3)$$

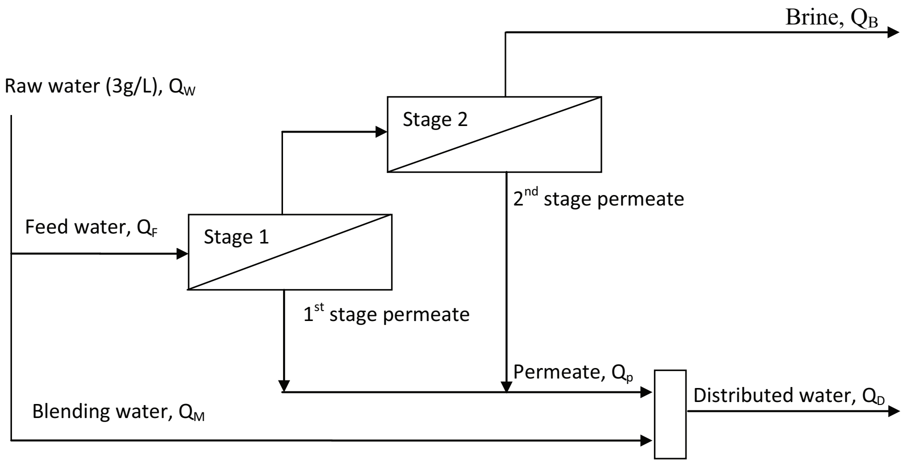

Fig. 1. Distributed water production flow sheet.

For comparing the ability of the two desalination techniques to provide a distributed water flow rate of a given quality, two dimensionless or reduced quantities are defined. These are:

- Water consumption ratio, or the reduced water consumption flow rate, is defined as the ratio of total fresh water flow rate and the membrane unit feed flow rate:

$$WCR = \frac{Q_W}{Q_F} \tag{4}$$

- Water distribution ratio, or the reduced water distribution flow rate, is defined as the ratio of distributed water flow rate and the membrane unit feed flow rate:

$$WDR = \frac{Q_D}{Q_F} \tag{5}$$

The specific energy consumption will be defined with respect to the distributed water flow rate. The national water distribution utility has chosen to distribute water with a TDS

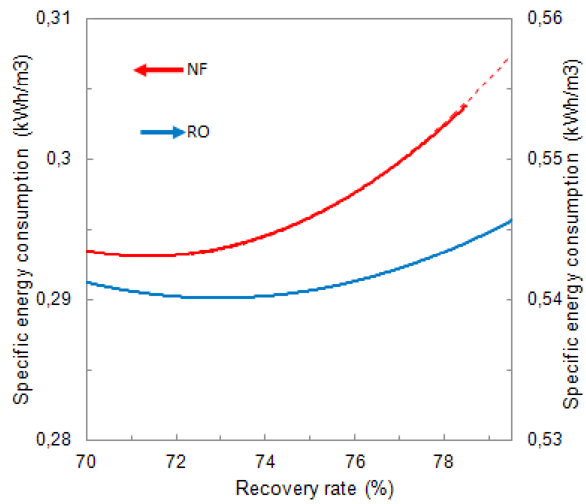

Fig. 3. Specific energy consumption vs. recovery rate.

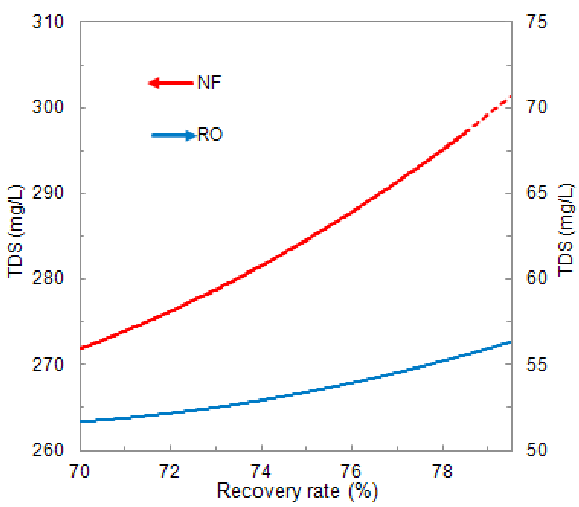

Fig. 2. Permeate TDS vs. recovery rate.

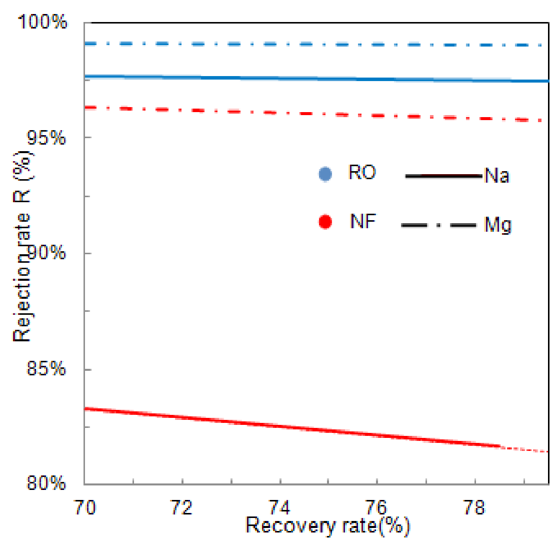

Fig. 4. Cations' Rejection rates vs. recovery rate.

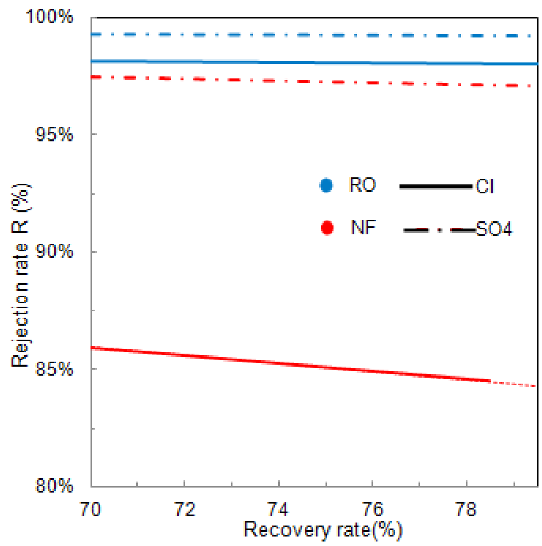

Fig. 5. Anions' rejection rates vs. recovery rate.

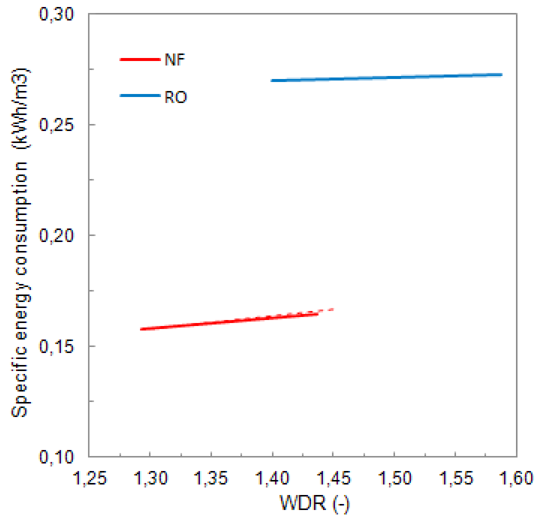

Fig. 6. Specific energy consumption vs. water distribution ratio.

of 1500 mg/L. For this scenario, what is extremely important is that; below a water distribution ratio of 1.46, both techniques deliver the same water quality for much lower energy and water consumptions when NF is used instead of RO. Energy demand is almost reduced by 40%. Moreover, for the same water distribution ratio, water consumption is reduced by about 4.3%. These results are shown in Figs. 6 and 7.

The comparison of NF and RO desalination techniques will be extended to various distributed water salinities. For this purpose a recovery rate of 78.5% is selected for NF. In fact, we chose this recovery rate in order to respect safe design and operating conditions for membrane modules. This value corresponds to limiting nominal operation of the desalination unit without changing the membrane configuration described in section 2. For RO the current recovery, 75%, corresponding to pseudo optimum energy consumption, is considered. Specific energy consumption per cubic meter of distributed water flow rate at different distributed water salinities will be then compared for RO and NF. The results are shown in Fig. 8. Energy consumption is reduces by about 38% when NF membranes are used. As the water salinity decreases the specific energy consumption increases.

Water consumption ratio vs. distributed water salinity is reported in Fig. 9. Water consumption is almost reduced by 6% when NF is used instead of RO. That confirms previous results regarding water consumption, presented in the first part of this section. Water savings, when NF is used instead of RO, depend mainly on raw water quality. This is an interesting result especially for regions where water resources are limited. However this water reduction is met with a slight decrease of the distributed water flow rate of about 5% with respect to RO as shown in Fig. 10.

In order to compare the distributed water quality for both membrane technologies, we chose to present the total hardness vs. the distributed water TDS. The results are shown in Fig. 11. On the same figure water qualities of the available commercial bottled water in Tunisia were also presented. For low distributed water salinities RO provides water characteristics very close to bottled water qualities but slightly poorer in calcium and magnesium. Distributed

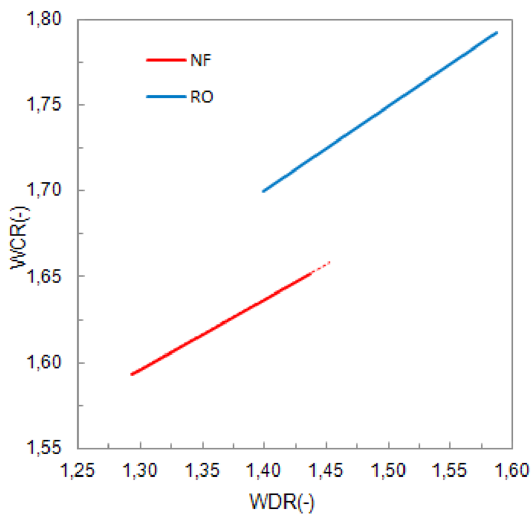

Fig. 7. Water consumption ratio vs. water distribution ratio.

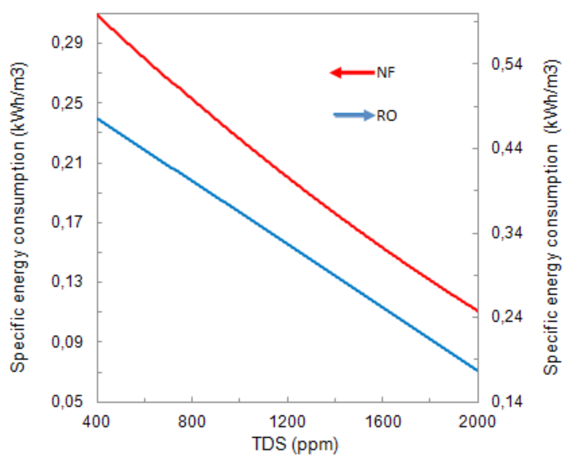

Fig. 8. Specific energy consumption vs. distributed water TDS.

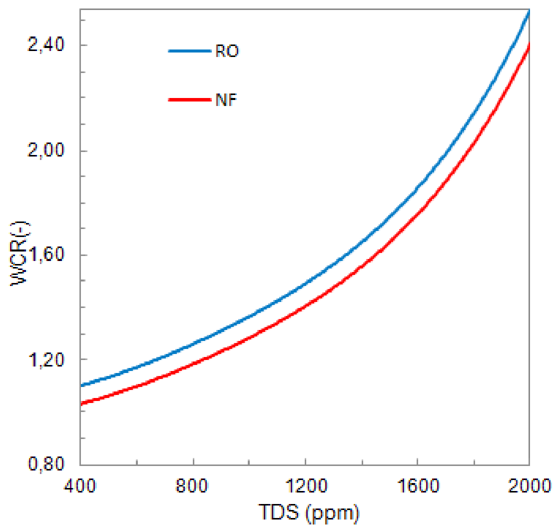

Fig. 9. Water consumption ratio vs. distributed water TDS.

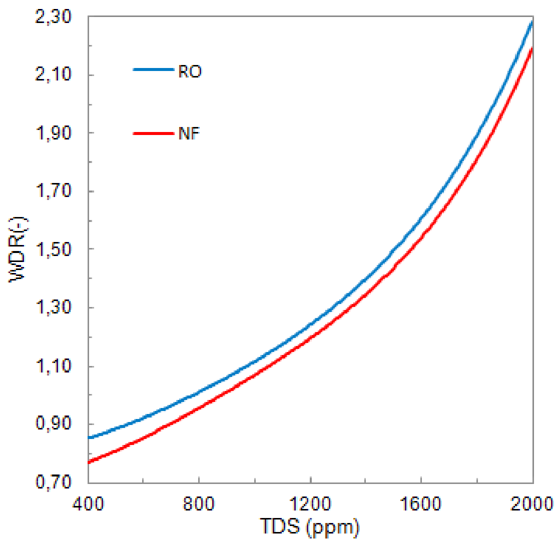

Fig. 10. Water distribution ratio vs. distributed water TDS.

water with NF has lower hardness contents than in the case of RO. The distributed water quality, with respect to mineral contents, was compared to the World Health Organization (WHO) standards [15]. For all mineral species in water, the distributed water respected WHO specifications for both desalination techniques. However, the distributed water chloride contents were higher than the WHO value beyond which chlorides could be detected by taste. As shown in Table 2, for distributed water TDS of 1000 mg/L, the limiting chlorides WHO values were exceeded by 8% and 20% for RO and NF, respectively. This is due to the high chloride content in raw water. This would not constitute a health problem in drinking water as emphasized by WHO that did not specify a health-based guideline value for chloride in drinking water [15].

Both techniques where compared with respect to a major issue hindering desalination processes. Scaling limits the yield and the life span of membranes. It also increases desalination costs. Fig. 12 shows the scaling character of

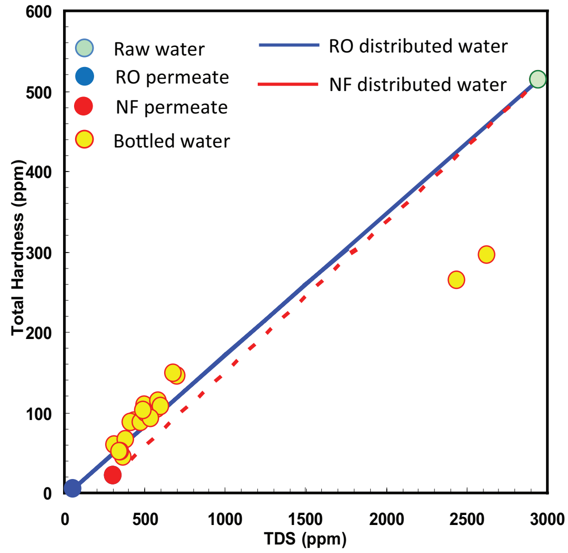

Fig. 11. Total hardness vs. distributed water TDS.

Table 2
Mineral contents in ppm for distributed water of 1000 ppm TDS

	WHO guidelines	Water quality with RO	Water quality with NF
K^+	–	7.9	12.1
Na^+	200	139.7	162.9
Mg^{2+}	200	33.0	29.3
Ca^{2+}	–	138.2	122.3
SO_4^{2-}	500	357.2	307.8
CO_3^{2-}	–	0.20	0.16
HCO_3^-	–	31.4	29.6
Cl^-	250	270.7	302.3
SiO_2	–	4.4	4.5

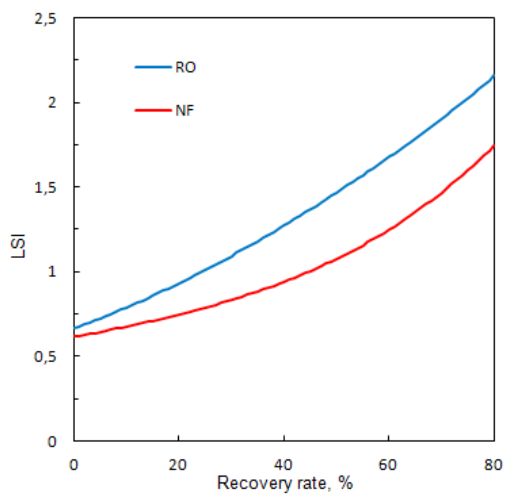

Fig. 12. Variation of LSI with recovery rates.

brines for NF and RO techniques. The scaling assessment was performed using the same approach described in Hchaichi's work [13]. LSI values clearly indicate that for the same recovery rate, NF brine has a much lower scaling tendency than in the case of RO. This process issue favors the use of NF for water desalination with high recovery rates.

4. Conclusion

The aim of the present work was to compare performances of nanofiltration (NF) and reverse osmosis (RO) in brackish water desalination processes when permeate is blended with raw water. This scenario is only possible if the raw brackish water is free of any harmful species. Simulation was used to estimate specific energy consumption, water consumption for both membrane desalination techniques. It was concluded that NF allows desalination with nearly 40% and 4.3% lower energy and water consumptions respectively. For the same distributed water salinities the adopted approach suggests that with respect to several issues including environmental, technical and cost, NF could be favored for brackish water desalination. The water quality was not significantly affected when NF is used instead of RO.

References

[1] H. Hchaichi, A. Hannachi, Co-precipitation in multiple-effect distillers at nonconventional temperatures, Desal. Water Treat., 55(12) (2015) 3277–3284.

[2] B. Van Der Bruggen, C. Vandecasteele, Removal of pollutants from surface water and groundwater by nanofiltration: Overview of possible applications in the drinking water industry, Environ. Pollut., 122(3) (2003) 435–445.

[3] N. Mazlan, D. Peshev, A. Livingston, Energy consumption for desalination - a comparison of forward osmosis with reverse osmosis, and the potential for perfect membranes, Desalination, 377 (2014) 138–151.

[4] J. Bohdziewicz, M. Bodzek, E. Wąsik, The application of reverse osmosis and nanofiltration to the removal of nitrates from groundwater, Desalination, 121(2) (1999) 139–147.

[5] R. Rautenbach, T. Linn, L. Eilers, Treatment of severely contaminated waste water by a combination of RO, high-pressure RO and NF - Potential and limits of the process, J. Membr. Sci., 174 (2000) 231–241.

[6] M. Pontié, A. Lhassani, C.K. Diawara, A. Elana, C. Innocent, D. Aureaua, Rumeauf, J.P. Croueg, H. Buissonh, P. Hemerye, Seawater nanofiltration for the elaboration of usable salty waters, Desalination, 167 (2004) 347–355.

[7] H. Kelewou, A. Lhassani, M. Merzouki, P. Drogui, B. Sellamuthu, Salts retention by nanofiltration membranes: Physicochemical and hydrodynamic approaches and modeling, Desalination, 277 (2011) 106–112.

[8] M. Pontié, H. Dach, J. Leparc, M. Hafsi, A. Lhassani, Novel approach combining physico-chemical characterizations and mass transfer modelling of nanofiltration and low pressure reverse osmosis membranes for brackish water desalination intensification, Desalination, 221 (2008) 174–191.

[9] S. Zhao, L. Zou, D. Mulcahy, Brackish water desalination by a hybrid forward osmosis–nanofiltration system using divalent draw solute, Desalination, 284 (2012) 175–181.

[10] A.H. Bannoud, Elimination of hardness and sulfate contained in the water by nanofiltration, Desalination, 137 (2001) 133–139.

[11] H. Dach, Comparison of nanofiltration and reverse osmosis operations for Selective desalination of brackish water: laboratory scale to industrial pilot, PhD thesis, university of Angers, France,2008.

[12] N.E.L. Harrak, F. Elazhar, S. Belhamidi, M. Elazhar, J. Touir, A. Elmidaoui, Performances comparison of two membranes processes: Nanofiltration and reverse osmosis in brackish water desalination, Environ Sci., 6 (2015) 383–390.

[13] H. Hchaichi, H. Elfil, P. Guichardon, A. Hannachi, Scaling tendency assessment in reverse osmosis modules, Desal. Water Treat., 51 (2013) 892–898.

[14] R. Sheikholeslami, Assessment of the scaling potential for sparingly soluble salts in RO and NF units, Desalination, 167 (2004) 274–256.

[15] World Health Organization, Guidelines for Drinking-water Quality, 4th ed., 2011.