Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2014.959739

55 (2015) 2471–2477
August

Taylor & Francis
Taylor & Francis Group

Techno-economic comparison of reverse osmosis and nanofiltration in desalination of a Moroccan brackish groundwater

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Received 18 July 2014; Accepted 17 August 2014

ABSTRACT

The cost of desalinated water is likely one of the most relevant indicators to characterize and compare the desalination methods with other technical options to supply water for urban, industrial and agricultural purposes. Obviously, costs of producing desalinated water vary from facility to facility due to factors such as location, facility design, plant size and available technology. This work reports on the technical and economical comparison of reverse osmosis (RO) and nanofiltration (NF) in the desalination of the underground brackish water of Moroccan Region. The capital and operating costs for both processes are determined on the basis of a real industrial and economical data. The study was carried out for a production capacity of 3,000 m^3/d corresponding to water consumption for 30,000 capita following the Moroccan considerations (consumption for domestic use of 100 l/per capita per day). Technically and economically, the work shows that in this case, the NF process appears more convenient than the RO.

Keywords: Desalination; Reverse osmosis; Nanofiltration; Comparison; Cost; Performances; Design

1. Introduction

Like many countries in the world, Morocco is facing problems in the supply of water due to an increasing demand and decrease of conventional resources. To solve the problem of water shortage, Morocco proceeded since a long time to use other non-conventional water resources such as wastewater reuse or desalinating brackish water and seawater. Today, the national production capacity by desalination exceeds 50,000 m^3/d and will increase rapidly [1]. However, the majority of desalination plants is based on reverse osmosis (RO) process [2].

Despite the fact that RO is rapidly increasing worldwide thanks to scientific and technological advances, but it still requires an intensive pre-treatment to prevent membrane fouling and higher energy consumption. However, the challenge is in minimizing the high operational costs and energy consumption as well as quality improvement.

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Presented at the Conference on Desalination for the Environment: Clean Water and Energy 11–15 May 2014, Limassol, Cyprus

In this line, several studies have been devoted that the nanofiltration (NF) process can be an alternate to RO for brackish water desalination [2–4]. The principle properties of the NF membranes are due to their remarkable ability, to selectively reject of different dissolved salts with high rejection of low molecular weight and dissolved components. In addition, the NF membranes can provide high water flux at low operating cost and low energy consumption [5,6].

The cost of desalinated water is probably one of the main aspects when the process is applied and selected technically. A literature review indicates that the costs of producing desalinated water vary from facility to facility due to factors such as location, facility design, plant size, available technology, water output quality requirements and environmental constraints. Table 1 shows some information obtained of the literature regarding the process costs of NF and RO vs. the capacity of production.

In this context, this work reports on the technical and economical comparison of RO and NF in desalination of the underground brackish water of a Moroccan Region. The capital and operating costs for both processes are determined on the basis of real industrial and economical data. The study was carried out for a production capacity of 3,000 m^3/d corresponding to water consumption for 30,000 capita following the Moroccan considerations (consumption for domestic use of 100 l/per capita per day).

2. Experimental

2.1. Characteristic of brackish water

The characteristics of brackish water and the required ones, after treatment, following the Moroccan standards of drinking water is shown in Table 2. The water parameters were determined analytically following standard methods [2–15].

2.2. Membranes characteristics

Table 3 gives the characteristics of the used membranes.

3. Results and discussion

3.1. Proposed design

The proposed design for the NF and the RO unit is shown in Fig. 1. The main treatment unit comprises:

- Pre-treatment post
- NF and RO group and
- Post-treatment.

3.1.1. Pre-treatment post

A simple pre-treatment system was carried out; it is composed of sand filters of 5 μm, with capacity of 125 m^3/h filled with sand, to retain the suspended solids that might be present. The speed of filtration of this underground water is 30 m/h. The water undergoes microfiltration on cartridge of polypropylene with 30 m/h of velocity to remove particles larger than 10 μm in order to provide a final protection and to conform the pre-treated water to the NF and RO membranes requirements.

3.1.2. NF and RO group

The calculation of the NF/RO group was carried out on the basis of the results obtained by ROSA

Table 1
Costs of the NF and RO desalination plant

Technologies	Capacity of production (m^3/d)	Cost (m^3)	Authors
NF	100,000	0.214 €/m^3	Costa and de Pinho [7]
	53,000	0.23 €/m^3	Bergman [8]
	20,000	0.24–0.32 €/m^3	Weisner et al.[9]
RO	<20	(4.50–10.33 $)	E. Tzen [10]
	20–1,200	(0.78–1.33 $)	Karagiannis and Soldatos [11]
	40,000–46,000	(0.26–0.54 $)	Afonso et al.[12] and Avlonitis [13]

Table 2
Characteristics of the feed water and Moroccan standard of drinking water

Parameters	brackish water	Normes Marocaines	Normes OMS [5]
T °C	23	–	25
pH	8.08	6.0–9.2	6.5–8.5
TDS ppm	2,690	<1,000	<1,000
Na^+ ppm	**780.12**	**100**	**<200**
Cl^- ppm	**1,325**	**350–750**	**<250**
Mg^{2+} ppm	87.50	100	<50
Ca^{2+} ppm	20	<500	<270
SO_4^{2-} ppm	125.88	200	<200

Note: The bold values in this table show that the water to be treated is characterized by a high content of Na^+ and Cl^- for this reason the treatment is needed.

Table 3
Characteristics of the used membranes

Membrane	Area (m^2)	*P* max (bar)	pH	Max temp (°C)	Materials	[Cl_2] tolerance ppm
BW30LE4040 Filmtec)	7.5	41	2 à 11	45	Polyamide	0.1
NF90-4040 (Filmtec)	7.6	41	3 à 10	45	Polyamide	0.1
NF270-4040 (Filmtec)	7.6	41	3 à 10	45	Polyamide	0.1

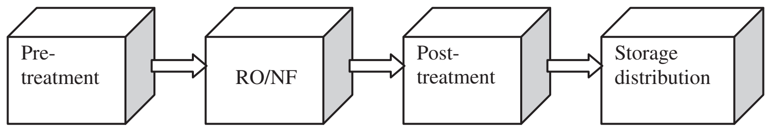

Fig. 1. Proposed design for the NF and RO unit.

software (version 7.2). The programme was elaborated by DOW Chemical Corp. Table 4 gives the results of the design of the NF/OI group. The number of modules and the number of pressure tubes are calculated by the following relation.

3.1.3. Number of modules

$$N = \frac{F_p}{S \times J_W}$$

F_p: flow of permeate (m^3/d), *S*: membrane area per module (m^2), J_w: water flow (l/h/m) and *N*: number of modules.

3.1.4. Number of pressure tubes

$$N_p = \frac{N}{N_e}$$

Table 4
Design of the NF/ OI group

Configuration	Simple pass	
Product capacity	3,000 m^3/d	
Membranes per tube of pressure: Ne		**6**
Number of modules	NF90	**720**
	BW30LE4040	**732**
	NF270	294
Number of pressure tube	NF90	**120**
	BW30LE4040	**122**
	NF270	**49**
Recovery rate (%)	NF90	**84**
	BW30LE4040	**80**
	NF270	**89**

N: number of modules, N_e: Number of modules per tube and N_p: number of pressure tubes.

3.2. Post-treatment

The post-treatment, includes reminéralization by lime using a saturator, suitable to increase the temporary hardness to 1 meq/l (81 mg/l) of calcium bicarbonate in order to decrease the corrosion risks.

3.3. Performances comparison

In this part, the performances of the two technologies in desalination of brackish water were described and compared briefly. The experiments were carried out by three commercial membranes (RO and NF) in simple pass at pressure 10 bars and 30% of recovery rate. The characteristics of the produced water after treatment are presented in Table 5.

The analysis of the results given in Table 5 shows that:

- The obtained permeate quality with the NF90 membrane is satisfactory. However, the produced water by BW30LE4040 is practically demineralized, a remineralization step is needed.
- The achieved permeate quality with the NF270 is not satisfactory in term of TDS, chloride, and

Table 5
Characteristics of the produced water after treatment with RO/NF

Unité	TDS (ppm)	Cl^- (ppm)	Na^+ (ppm)
NF270	1,975.20	1,212.98	642.05
NF90	429.85	250	151
BW30LE4040	132.21	78.36	44.43

sodium, the contents exceed the recommended standards, additional treatment is required before distribution.

3.4. Cost comparison

In this part, the capital and operating cost of NF and RO process are evaluated and compared. The economical analysis was carried out for a production capacity of 3,000 m^3/d corresponding to water consumption for 30.000 capita following the Moroccan considerations in rural medium (consumption for domestic use of 100 l/per capita per day).

3.4.1. Capital costs

The capital cost included the cost of system itself and its foundation on its place. In our case, the total capital costs include

- Cost of construction and building.
- Cost of pre-treatment steep.
- Cost of NF and RO group.
- Cost of post-treatment steep.
- Cost of auxiliary equipment.
- Cost of various services.

These costs are based on real purchase prices and the assumptions given above, and may change as these assumptions change. Fig. 2 summarizes a comparison between the NF/RO membranes of the estimated capital cost.

With the analysis of the results and taking into account the limitations in the calculations that have been indicated, the capital cost of the NF90 is slightly higher than the BW30LE4040 membrane, this differences of the costs between them are due to the cost of cubic meters of the NF membrane, which appears more expensive than the RO membrane.

3.4.2. Operating costs

The operating cost covers all expenditure incurred after plant commissioning and during actual operation. These include:

- *The amortization cost*: it was calculated for a reimbursing interest rate is 6,7%. It is obtained by multiplying the capital cost by an amortization factor a, which is given by Atikol and Hikmet [16]:

$$a = \frac{i(i+1)^n}{(1+i)^n - 1}$$

where i is the annual interest rate (%) and n is the life time of the facility.

- *The cost of maintenance*: it was estimated at 3% per year of the capital cost [17].
- *The membrane replacement rate:* it depends largely on raw water quality, the cost of membrane, the replacement rate and the recovery of the process. For this calculation, the replacement rate has been found to be equal to 5% [16–18]. The membranes life was evaluated to 5 years for two processes. This is given by the following relation [19].

$$C_{\text{memb}} = \frac{\lambda \times N_{\text{memb}} \times P_{\text{memb}}}{V_{\text{L}}}$$

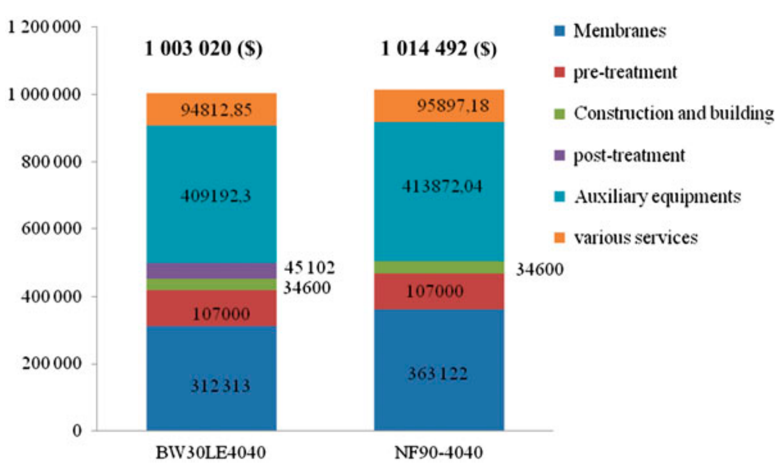

Fig. 2. Capital cost for the two membranes processes RO/NF ($).

- *The energy cost:* to calculate the energy cost, such factors as the working pressure of the high pressure pump, power consumption of the metering pumps and energy prices must be taken into account. In Morocco, the average price of energy is 0.085 €/kWh.

$$C_{\text{energ}} = \frac{E_{\text{pompe}} \times L}{V_{\text{L}}}$$

- *The cost of reagents:* the reagents use depends mainly on feed water quality and degree of pre-/post-treatment and cleaning process. In our case, the feed water quality is good, the major chemicals used for pre-treatment were sulphuric acid for adjusting raw water to pH 6.8 and the antiscalants agents to attenuate the risk of salt precipitations. For the post-treatment the used chemicals were lime and silicates in order to decrease the corrosion risks.

$$C_{\text{Reagents}} = \frac{Q_{\text{alim}} \times \text{CH}_{\text{dose}} \times \text{CH}_{\text{cost}}}{V_{\text{L}}}$$

Table 6 gives the amounts and unit costs of the chemicals used for the two processes in pre-treatment and post-treatment.

- *The unit product water cost*: is the key indicator for evaluating the efficacy of a desalination method; it is equal to the total capital investment, membrane replacement and O&M costs divided by the total amount of produced potable water during the lifetime of the desalination unit. Fig. 3 gives the operating cost and the unit product water cost for the two membranes processes RO/NF.

The analyses of the results reveals that the unit product costs obtained by the NF membrane (NF904040) is slightly lower than that the RO membrane (BW30LE04040). The cost differences between membranes are due to cost of energy requirements and cost of reagents of BW30LE4040, which is more expensive than the NF90. In this case, NF90 is the cheapest membrane.

However, the cost of producing desalted water depend upon many factors that are unique in each case, most important of which are the desalination method, such as pre-/post-treatment requirements,

Table 6
Amounts and unit costs of the chemicals used for the two processes in pre-treatment and post-treatment

Consommables		Dose (g/m^3)	Cost ($/kg)	Cost ($/m^3$)	
Pre-treatment	H_2SO_4 (98%)	40.5	0.325	0.016	0.017
	Antiscalants	0.2	4.68	0.001	
Post-treatment	Lime	59.2	0.17	0.013	0.044
	Silicates	51	0.48	0.031	

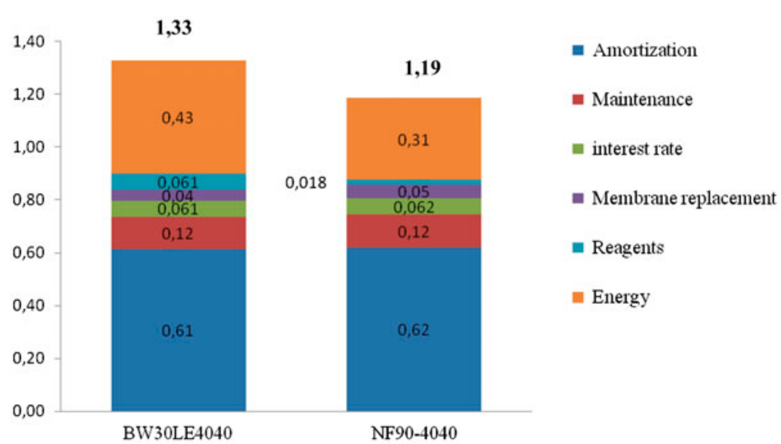

Fig. 3. Operating cost for the two membranes processes RO/NF ($/m^3$).

selected technology, feed water quality, plant location, facility design, plant size, plant life time, membrane life, water output quality requirements and environmental constraints.

Figs. 4 and 5 show the unit product water cost as a function of plant lifetime, and membrane life for the two processes, respectively.

The results show that the unit product cost decreases significantly as function of the plant lifetime. In fact, the expected life of the different elements in a desalination plant and their duration depends on a correct maintenance programme. Due to the high quality and corrosion resistant materials used for membrane desalination systems, it looks that considering longer lifetimes for such plants does not seem unrealistic.

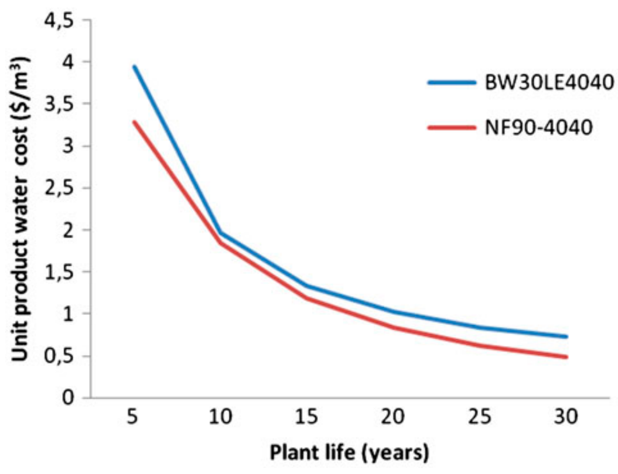

Fig. 4. Unit product water cost as a function of plant lifetime of NF/RO processes.

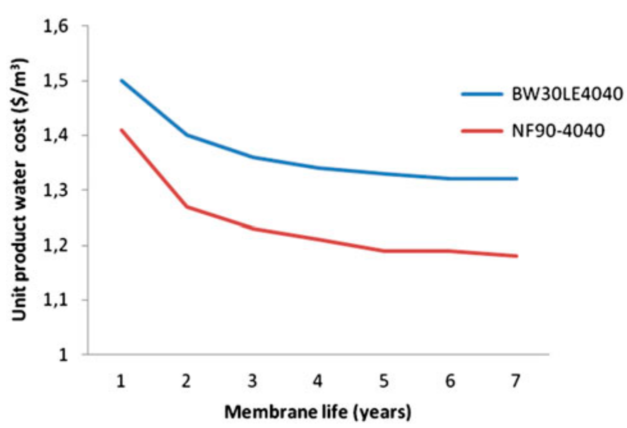

Fig. 5. Unit product water cost as a function of membrane life of NF/RO processes.

The results show that the unit product water cost decreases significantly with the increase in the membrane lifetime. Based on the above results, it is concluded that to reduce the water production cost it is necessary to increase the reliability of the membranes by periodic maintenance.

4. Conclusion

The goal of this study is to compare the technical performances and the economic costs of both technologies NF and RO membrane in brackish water desalination. The economical analysis was carried out for a production capacity of 3,000 m^3/d corresponding to water consumption for 30,000 capita following the Moroccan considerations in rural medium (consumption for domestic use of 100 l/per capita per day).

However, the comparative analysis of NF90 and BW30LE4040 demonstrated that NF90 has higher production efficiency and capital cost and lower operating costs when compared to BW30LE4040.

According to these cost calculations NF can be better suited for the desalination water for the following reasons:

- Low energy consumption.
- Post-treatment limited to chlorination.
- Less membranes, so less clutter.

In addition the results indicate reliably the effect of the operating parameters such as plant lifetime and membrane life on the unit product water cost. It was found that increasing the reliability of the membrane lifetime and the plant lifetime could reduce the cost of the produced water significantly.

Acknowledgements

This work was supported by TIA Company, France. The authors express their thanks for their support.

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