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Coupling of membrane processes for brackish water desalination

A. M'nif[a*], S. Bouguecha[b], B. Hamrouni[a], M. Dhahbi[b]

[a]*Laboratoire Eau et Technologies Membranaires, Faculté des Sciences de Tunis, 2092 Manar II, Tunisia*
Tel. +216 (71) 872-600; Fax +216 (71) 885008; email: amin6824@yahoo.fr
[b]*Laboratoire Eau et Technologies Membranaires, Pôle Technologique de Borj-Cédria,*
BP 95, 2050 Hammam-Lif, Tunisia

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Abstract

In the recent years, membrane processes have drawn more attention because of their strong separation capabilities and exhibiting a great potential for the treatment of waters and wastewaters worldwide. However, these membrane separation processes have some problems due to the formation of polarisation films and by-products which may generate bacteria and fouling. These problems may be overcome by combining two or more processes in the desalination units of the treatment process. The specificity of each process makes their integration more efficient. In this work, we report on the concept and the realisation of an experimental pilot plant which is composed of the following compartments: nanofiltration (NF), reverse osmosis (RO), cartridges filter, pump and measuring instruments. Samples of brackish water were filtered through filtrate cartridges in order to get rid of the suspended matter. A pilot plant equipped with composite RO and NF membranes was operated at 6 bar, ambient temperature and neutral pH with relatively good water recovery. This pilot plant shows the ease with which the combination of both processes is carried out. The main objective is to evaluate the effect of NF and RO membranes as well as their coupling on water quality. The effects of divalent and monovalent cations on operating parameters were studied. The recovery (Y) in NF/RO coupling was improved compared to that obtained in RO alone. This may be explained by a decrease in the input osmotic pressure of the RO membrane. This coupling also improves salt rejection and thus leads to a decrease in the salinity of water product. The results show that the coupling is efficient as it highly reduces water salinity.

Keywords: Reverse osmosis; Nanofiltration; Brackish water

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*Corresponding author.

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1. Introduction

To sustain the commercial, agricultural and social development in arid and semi-arid regions like south Tunisia (North Africa), an adequate supply of fresh water is of primary importance. Production of fresh water from seawater and brackish water has proved to be an alternative for these regions. Desalination processes, by distillation or by membrane techniques, are based on the concentration principle [1].

Membrane separation processes have exhibited a great potential for the treatment of waters and wastewaters by complying with the increasingly strict legislation concerning potable water quality and allowable wastewater discharges worldwide. Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) have been progressively used for water and wastewater treatment in order to remove suspended solids and reduce the content of organic and inorganic matters. Many authors have reported the application of NF and RO to highly reduce TDS, salinity, hardness, nitrates, cyanides, fluorides, arsenic, heavy metals, colour and organic compounds, e.g., total organic carbon (TOC), biological oxygen demand (BOD), chemical oxygen demand (COD), total organic halides (TOX), trihalomethanes (THM), THM-forming potential (THMFP), and pesticides, besides the elimination of bacteria, viruses, turbidity and TSS from surface water, groundwater, and seawater [2–5].

Separating the divalent cations (water softening), natural colour, trihalomethanes precursors and reduction of total dissolved solids (TDS) can be achieved by using nanofiltration (NF) [6,8]. In addition to the best removal of TDS and organics compounds [7,9], RO has a potential to remove all classes of pathogens.

The phenomenon of reverse osmosis is based on the permeability of some membranes to the flow of water in such a way that if two compartments are placed in contact with each other separated by a semi-permeable membrane, one with a high salt content and the other with a low content, water passes from the second compartment to the first one until the osmotic pressures of both compartments are equal. To invert the process, pressure is applied superior to the osmotic pressure in such a way that water without salts or with a low salt content is obtained [10].

Nanofiltration membranes are often used in the pre-treatment of seawater for desalination, groundwater treatment and removal of natural organic matter. Groundwater is becoming scarce or expensive, and lower quality sources, such as surface water and effluents of wastewater treatment plants, become attractive for production of process water. Today, the main module geometries used are spiral-wound or tubular modules. The advantages of spiral modules are the large surface area of the membrane per m^3 and the low cost of the module. On the other hand, they are extremely susceptible to floating matter, have high energy losses caused by friction in the spacers and it is not possible to reverse flush them [11,12].

During the operation of an NF/RO plant system, the conditions, such as pressure, temperature and feed water quality, can vary causing variations in productivity and product water quality. Integrated membrane systems share a common focus on a process which ultimately results in cheaper and sustainable technologies [13]. Drioli et al. coupled three different membrane units in order to achieve the total recovery of desalted water combined to solid salts production [14].

In this paper, we analyse the performance of coupling both NF and RO membrane units followed by an inversed RO–NF coupling for a better desalination of brackish water with salinities varying from 3 to 10 g/L.

2. Experimental set-up

The experiments were performed on the pilot plant equipped with NF and RO modules. The RO and NF tests were carried out with the use of Osmonics spiral module equipped with AG 2514 TF and HL 2514 T membranes, respectively. The operating pressure ranged between 1 and 6 bar. The set-up is shown in Fig. 1.

The brackish water was prepared from distilled water to which different quantities of NaCl or $MgSO_4$ were added. NF and RO membranes used had an active membrane area of 0.6 m^2 and nominal permeate flow rates of 0.83 and 0.68 m^3/d at 3.10^{-2} bar respectively.

This pilot plant built in our laboratory allows two different coupling of RO and NF processes.

3. Results and discussion

3.1. Performances of RO and NF membranes

The characterization of RO/NF modules was done under the following conditions for the feed water:

- Salinity: 5 g/L
- Temperature: 14°
- Applied pressure: from 1 to 6 bar.

3.1.1. Influence of monovalent ions

As shown in Fig. 2, the rejection rate (TR %) increases for the reverse osmosis membrane and decreases for the nanofiltration one according to the recovery factor (*Y* %). This means a good rejection of the monovalent ions for the reverse osmosis membrane.

3.1.2. Influence of divalent ions

In the two cases high rejection rates were obtained for RO and NF (Fig. 2). However, the value of the RO rejection rate is higher and can reach 98%.

NF rejection rates for bivalent ions are higher than those of monovalent ions.

3.2. Performance of RO-NF coupling

The first coupling mixes the NF module permeates with the feed water and pass it then through the RO module (RO–NF parallel coupling with

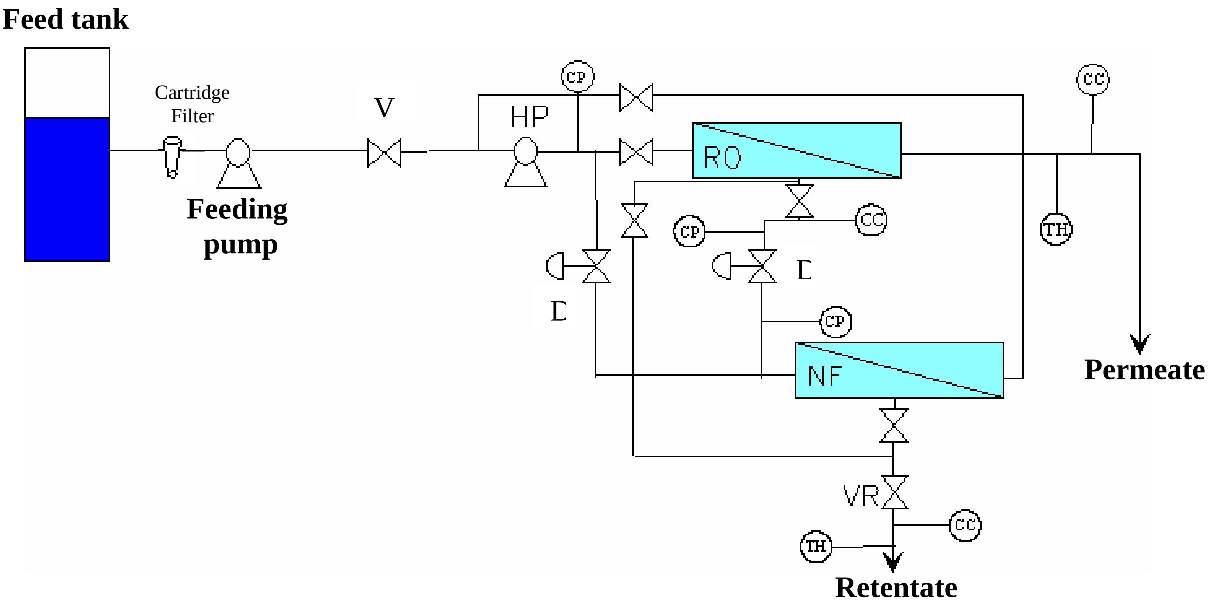

Fig. 1. Experimental set-up. V: valve; VR: reject valve; D: pressure regulator; HP: high-pressure pump; RO: RO module; NF: NF module; CP: pressure vessel; CC: conductivity vessel; TH: temperature vessel.

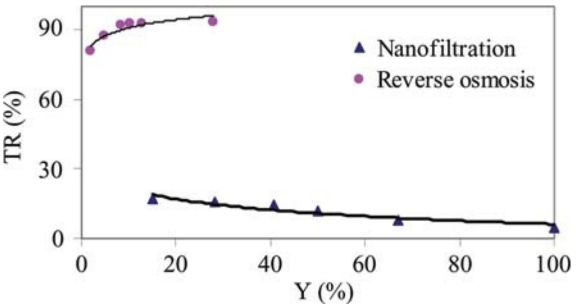

Fig. 2. The rejection rate as a function of the recovery factor for monovalent ions.

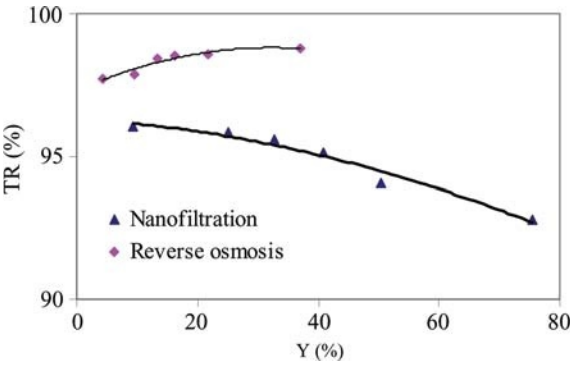

Fig. 3. The rejection rate as a function of the recovery factor ofr divalent ions.

recirculation). The second coupling allows the RO module retentate to pass through the NF module (RO–NF serial coupling).

3.2.1. RO–NF serial coupling

The following design permits to treat the brine rejection of RO module by NF membrane. As shown in Fig. 4, this configuration gives better recovery factor which pass from 37% to 85%. This kind of RO–NF coupling allows recuperating RO reject brine water energy and increasing the quantity of produced water.

RO–NF serial configuration has highly increased the recovery factor (Fig. 5). This rate did not exceed 40% in RO and 80% in the coupled RO–NF. The latter gives an acceptable rejection rate around 94%.

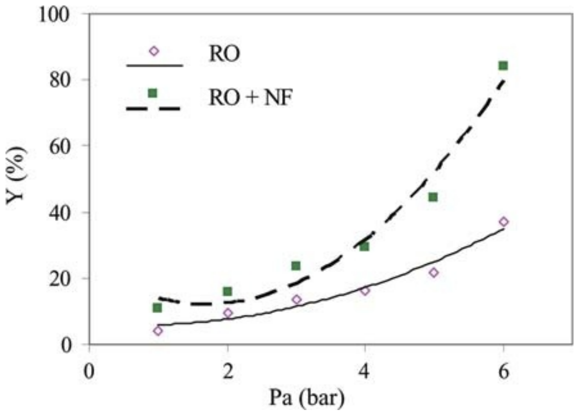

Fig. 4. The recovery factor vs. pressure for RO/NF serial coupling.

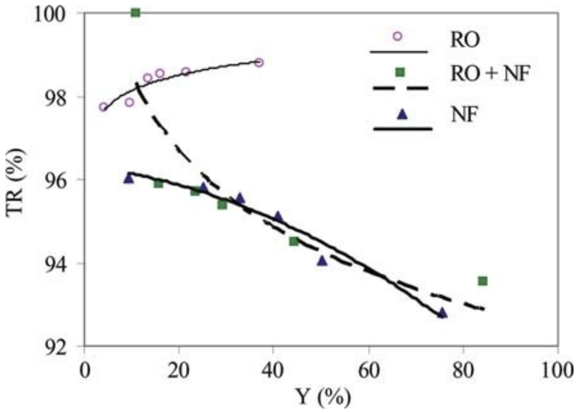

Fig. 5. The rejection rate vs. recovery factor for RO/NF serial coupling.

3.2.2. RO-NF parallel coupling with recirculation

The RO–NF parallel coupling with recir-culation is based on the re-injection of NF permeates in feed RO water. Experiments were realized under the following conditions: range of feed pressure 1–6 bar, feed water temperature 14°C and the salinity 5 g/L.

The results in Figs. 6 and 7 show a substantial improvement of the RO permeate flux. In fact,

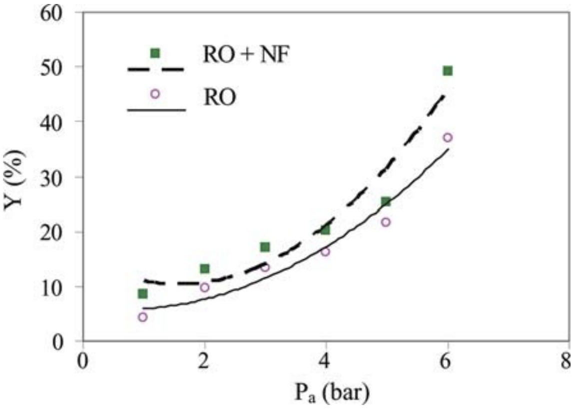

Fig. 6. Recovery factor vs. pressure for RO/NF parallel coupling with recirculation.

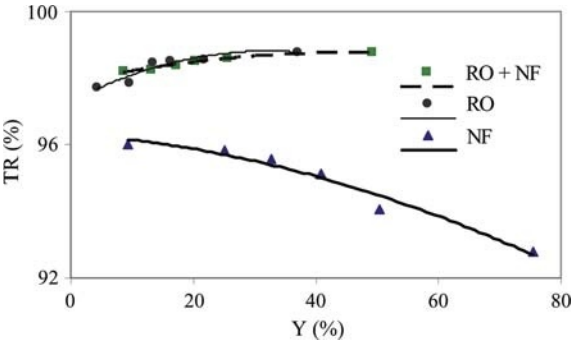

Fig. 7. Rejection rate vs. recovery factor for RO/NF parallel coupling with recirculation.

the recirculation of NF permeates permits to decrease the osmotic pressure of feed water. According to the transfer mechanism of RO the flux increases linearly. This coupling improved also the recovery factor compared to RO alone.

4. Conclusion

Preliminary results obtained on the experimental set-up built in our laboratory led us to some observations for the two kinds of coupling studied.

The first coupling, RO–NF serial configuration, substantially improved the conversion rate which reduced the energy consumption and brine rate. This configuration may present a promising solution to brackish water desalination.

The second coupling, RO–NF parallel configuration with recirculation, may present a promising way for desalinating brackish waters rich in bivalent ions. The recirculation of NF permeates, with low bivalent ions concentration, carried out to reduce the osmotic pressure of the feed water. Consequentially RO permeate flow and conversion rate increase.

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