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Sustainability and cost of water savings through new high rejection FilmTec™ BW30XHR PRO-440 membrane for seawater desalination

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ABSTRACT

This study demonstrates the advantages of utilizing new membrane chemistry in reverse osmosis. The newly developed FilmTec™ BW30XHR PRO-440 element is especially effective for second pass operation in seawater desalination, and for producing high-quality permeate water used in a range of industrial applications. The study presented here includes single element experiments with synthetic solutions and continuous operation with River Ebro water. It is shown that the FilmTec™ BW30XHR PRO-440 elements had a 99.8% rejection for sodium and chloride under standard test conditions and synthetic solutions. Rejection vs. standard elements was improved for several individual monovalent and divalent ions, boron, and TOC. For two second pass seawater configurations and one example of industrial application, the value proposition of the new product vs. previous generation products was calculated, showing savings in chemicals by up to 24%, savings in energy by up to 3%, and savings in CAPEX by up to 20%.

Keywords: Reverse osmosis; Second pass; High rejection

1. Introduction

Water scarcity is recognized as one of the main threats that mankind is facing globally [1]. Reverse osmosis (RO) membrane technology has developed as a promising technology to address this problem, holding roughly 44% market share, and growing among all the desalinating technologies [2]. This increase has been driven as materials are improved, and costs dropped [3].

Reverse osmosis is therefore an established technology for various applications that include desalination of seawater, treatment of wastewater and production of drinking water from surface and ground water. For seawater desalination, an effective configuration is a two-pass system, to achieve both high recovery and still excellent permeate quality [4]. In second pass, brackish water type RO membranes are required that offer both high permeability and hence low energy costs and at the same time high rejection. Several industrial applications such as electronics industry require especially high permeate quality.

The innovation presented in this study aims to serve the needs mentioned above. A new membrane chemistry was developed for a brackish water type membrane that combined low energy consumption with higher rejection compared to standard RO brackish water membranes. Compared to former generation elements, this advantage was demonstrated with synthetic solutions and a field trial in continuous operation side-by-side with standard elements and with surface water from the River Ebro as feed water. Additionally, a durability study was performed side-by-side

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vs. two typical competitors from the market. In the durability study, CIPs were done in short intervals to investigate potential changes in membrane performance.

2. Methods

2.1. Test in single-element-configuration

The higher rejection of the new membrane was demonstrated by performing tests under standard conditions in single element configuration with synthetic solutions in recirculation mode. The experiments with synthetic solutions were performed at 15.5 bar pressure, 15% permeate recovery, pH 8 and 25°C. Three different synthetic feed solutions were used:

- 2,000 mg/L NaCl;
- 2,000 mg/L NaCl, 100 mg/L NO_3^-, 1.5 mg/L B, 1.5 mg/L SiO_2, 2 mg/L Isopropyl alcohol (IPA);
- 2,000 mg/L NaCl, 100 mg/L NO_3^-, 1.5 mg/L B, 1.5 mg/L SiO_2, 25 mg/L Isopropyl alcohol (IPA).

The experiments were conducted by recirculating back concentrate and permeate into the feed tank to maintain constant conditions and taking samples of feed and permeate after stabilization.

2.2. Pilot study with river water

A two-month pilot test was performed in continuous, once-through mode using Ebro River feed water The characterization of the Ebro River water is shown in Table 1 and a scheme of the pilot plant used for the experiment is shown in Fig. 1. Six elements of the new type FilmTec™ BW30XHR-440 were operated in parallel with six standard reverse osmosis elements. Both lines had a feed flow of 10 m^3/h at a permeate recovery of 50%. The temperature during the two months of operation was between 11°C and 19°C.

2.3. Economic savings

Potential cost savings are modelled using the cost model developed by Busch [5]. Specific details assumed to perform each one of the three different cost saving scenarios here calculated are presented in this paper. The three different cases assessed are: (1) the savings in chemicals cost that the new FilmTec™ BW30XHR-440 high rejection membrane enables; (2) the savings in energy operating expenses (OPEX); (3) the savings in capital expenses (CAPEX) that can be obtained.

3. Results

3.1. Test in single-element-configuration

Fig. 2 shows the results of the experiments with synthetic solutions. It was observed that the new membrane type FilmTec™ BW30XHR-440 had a 99.8% rejection for sodium and chloride ions under standard test conditions in comparison to a 99.7% rejection for the standard reverse osmosis element. The passage of isopropyl alcohol (IPA) as TOC surrogate remained similar to standard elements. A clearly lower passage and hence higher rejection was demonstrated for nitrate and boron.

3.2. Pilot study with river water

Fig. 3 shows the rejection of several solutes during the continuous operation with Ebro River water. A clear rejection improvement was observed with the new membrane type FilmTec™ BW30XHR-440 compared with the standard reverse osmosis element. Both for ions chloride, sodium, and nitrate, FilmTec™ BW30XHR-440 showed higher rejection. For the TOC present in the surface water, the new membrane type demonstrated an improvement in rejection.

3.3. Value proposition

The value proposition of the new product FilmTec™ BW30XHR PRO-440 was calculated for several scenarios vs. configurations with previous generation products.

Table 1
Ebro River water, feed water of continuous experiment

	Average (mg/L)	Standard deviation (mg/L)
Cations:		
Li	0.0331	0.01624
Potassium (K)	4.47	1.997
Sodium (Na)	154	71.75
Magnesium (Mg)	34.9	12.62
Calcium (Ca)	127	18.44
Strontium (Sr)	2.36	1.047
Barium (Ba)	0.0777	0.1399
Iron	0.00224	0.00078
Anions:		
Nitrate (NO_3^-)	10.5	0.9765
Chloride (Cl^-)	173	50
Sulfate (SO_4^{2-})	246	40.80
Br^-	0.290	0.0121
HCO_3^-, mg/L	203	7.562
CO_3^{2-}, mg/L	1.59	0.2847
Others		
SiO_2	7.66	5.623
pH	7.92	0.07346
Conductivity	1230	126.5
TDS	965	173.8
TOC	1.73	0.6096

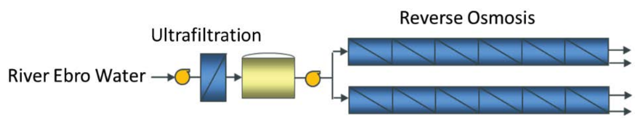

Fig. 1. Scheme of the pilot plant used doe the demonstration trial.

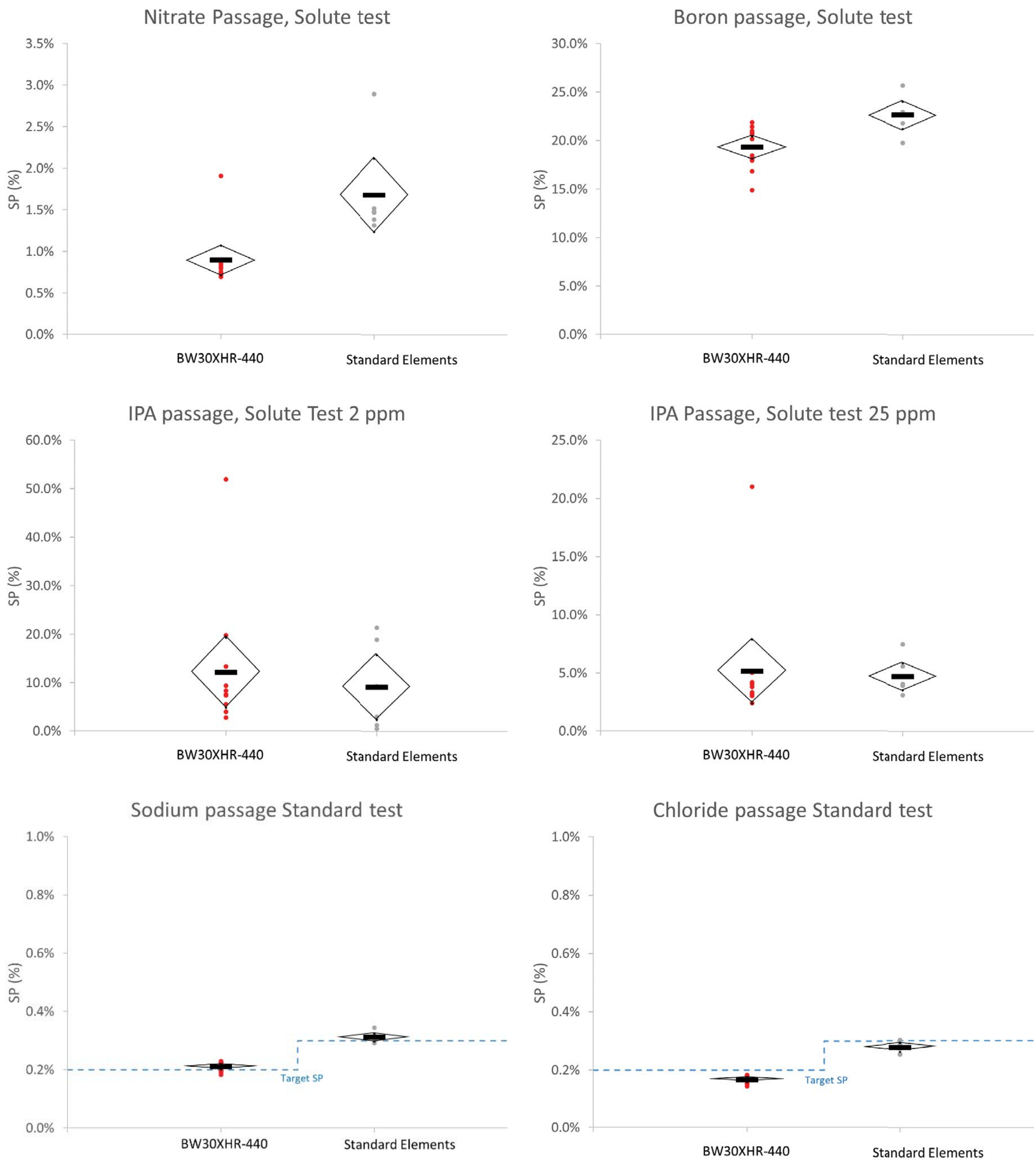

Fig. 2. Passage measured for FilmTec™ BW30XHR-440 elements in comparison with standard elements for synthetic solutions under standard test conditions.

The first scenario focuses on energy savings, the second on chemical savings, and the third on CAPEX savings.

3.3.1. Value proposition based on energy savings

Because of the higher rejection of FilmTec™ BW30XHR PRO-440, it is possible to reduce energy consumption by up to 3%. Having a higher rejection element in the second pass enables the use of a lower energy membrane in the first pass, as shown in Fig. 4.

In terms of OPEX economical savings, this might represent savings of up to \$246,000/y; in terms of potential CO_2 emissions reduction, this might represent a reduction of up to 1,950 metric tons CO_2/y.

This assessment has been generated at conditions of feed TDS 41,100 mg/L, 100,000 m^3/d plant, temperature 30ºC, first pass recovery 45%, flux at 13,5 LMH and second pass recovery 90% and flux 30,3 LMH; flow factor 1, WAVE 1.82M; seawater elements 8,400; brackish water elements 3,360, energy price 0.15 \$/kWh, energy to carbon ratio of 0.71 kg CO_2/kWh.

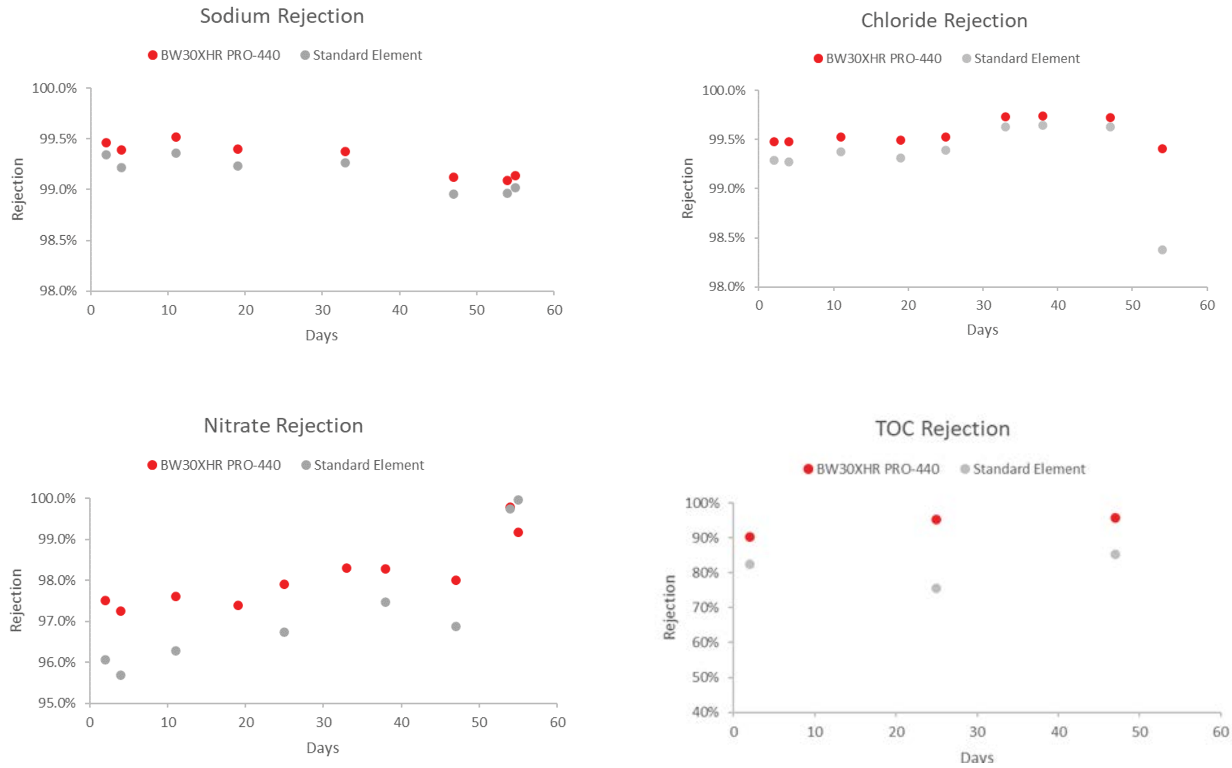

Fig. 3. Rejection measured during continuous operation of the new FilmTec™ BW30XHR-440 elements in parallel with standard elements operated with Ebro River water.

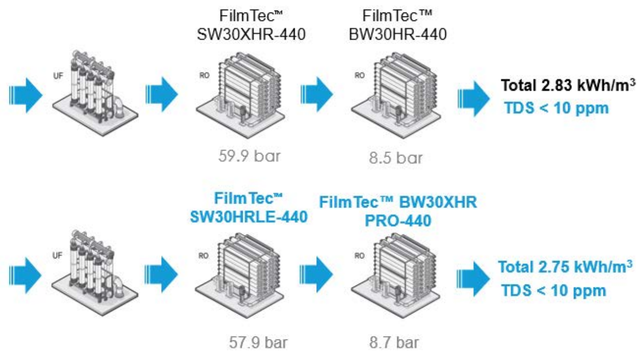

Fig. 4. Value proposition based on energy savings.

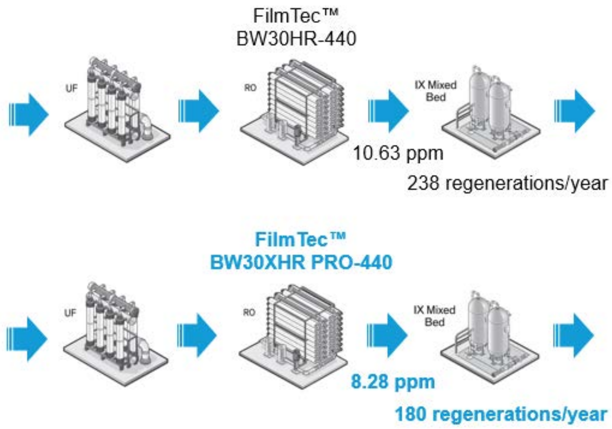

Fig. 5. Value proposition based on chemicals savings.

3.3.2. *Value proposition based on chemicals savings*

Thanks to the higher rejection of FilmTec™ BW30XHR PRO-440, industrial users can benefit from up to 24% chemical savings because fewer regeneration are cycles required in the downstream mixed bed as shown in Fig. 5.

In terms of OPEX economical savings, this might represent savings of up to 74,000 kg/y of chemicals, resulting in up to 24,500 $/y savings. In terms of potential CO_2 emissions reduction, this might represent a reduction of up to 17 metric tons of CO_2/y.

This assessment has been done at conditions of feed TDS 600 mg/L, UF flux 80 LMH; 5,000 m³/d plant, temperature: 15ºC, recovery 75%, flux of 24 LMH, 6 elements/pressure vessel, 2:1 array, 216 brackish water elements, flow factor of 0.85, WAVE 1.82M, Mix bed with AmberLite™ HPR 1200 H and AmberLite™ HPR 4100 Cl at 20 BV/h assuming 120 kg NaOH per m³ resin and per regeneration and 90 kg HCl per m³ resin and per regeneration, energy price 0.15 $/kWh, energy to carbon ratio of 0.71 kg CO_2/kWh.

3.3.3. *Value proposition based on CAPEX savings*

Because of the higher rejection of FilmTec™ BW30XHR PRO-440 elements, it is possible to have CAPEX savings in a second pass by by-passing a fraction of permeate from the first pass. This enables saving up to 20% fewer elements in the second pass, as shown in Fig. 6.

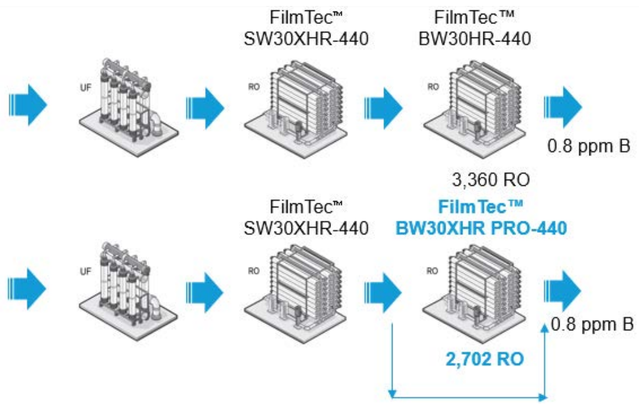

Fig. 6. Value proposition based on CAPEX savings.

In terms of CAPEX economical savings, this might represent savings up to $1,840,000, resulting in up to 24,500 $/y savings. Due to the by-passing, the volume of water that is entering the 2nd pass RO, is smaller, which means that a lower volume flow is pressurized through the pump and hence less energy is consumed. This energy saving leads to CO_2 emissions reduction, which might represent a reduction of up to 3,200 metric tons of CO_2/y.

This assessment has been produced at conditions of feed TDS: 41,100 mg/L; 100,000 m^3/d plant, temperature: 30ºC, first pass recovery 45% and flux 13.5 LMH, and second pass recovery 90% and flux 30.3 LMH; flow factor 1, WAVE 1.82M; seawater elements 8,400; scenario FilmTec™ BW30HR-440: brackish water elements 3,360; scenario FilmTec™ BW30XHR PRO-440: 2,702 brackish water elements, energy price 0.15 $/kWh, energy to carbon ratio of 0.71 kg CO_2/kWh.

4. Conclusions

The new FilmTec™ BW30XHR PRO-440 element offers an extra high salt rejection of 99.8%. It helps customers to reduce the total cost of water by lowering the cost of treatment chemicals used by 24%, saving up to 3% of processing energy, or reducing CAPEX by up to 20%.

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