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The importance of fouling-resistant membrane elements – the FilmTec™ SW30XFR-400/34

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ABSTRACT

Biofouling in reverse osmosis (RO) occurs when bacteria settle in the elements and start building a biofilm. This paper highlights the performance of a new generation of fouling-resistant RO element, the newly developed FilmTec™ SW30XFR-400/34 seawater fouling-resistant membrane element in terms of its biofouling resistance. Additionally, this paper presents a validation of the product at a realistic scenario: the Middle East Red Sea. The validation trials proved the robust performance that this new membrane element shows under harsh biofouling conditions. This membrane element is able to offer 34% lower pressure drop than previous generations with a stable performance in terms of normalized permeate flow and salt rejection. In the validation trials this feature led to a significant reduction of the chemical cleanings (CIP) caused by biofouling; more than 33% reduction of the annual CIP frequency. Additionally, thanks to the membrane chemistry robustness, one of the FilmTec™ brand essence attributes, the product is able to offer advantaged chemical resistance when chemical cleanings are performed. Under the same conditions, where an element from another membrane manufacturer is experiencing 85% increase in salt passage, FilmTec™ SW30XFR-400/34 shows stable performance.

Keywords: Seawater; Reverse osmosis; Fouling-resistant; Membrane; Pressure drop; Biofouling

1. Introduction

Water scarcity is being 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].

Fouling in reverse osmosis elements takes on many forms. These are typically categorized as inorganic scaling, colloidal or particle fouling, organic fouling and biological fouling [4]. The former two are generally solved through advanced pretreatment technologies to soften the water like lime softening, antiscalant dosing or ultrafiltration pretreatment to remove suspended solids. There are also pretreatment technologies to reduce the concentration of dissolved organic material from thousands of ppm down to 40–60 ppm, but reducing the concentration further is less efficient and can be costly [5]. Because of this, the RO systems are expected to share the burden and are often exposed to waters with concentration of organic matter >10 ppm.

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Consequentially, they suffer from organic fouling and biological fouling.

Organic fouling is defined as the accumulation of organic contaminants on the membrane surface [6]. This accumulation creates a drop in the effective membrane permeability, which lowers the membrane flux and increases the energy of operation [7].

Biofouling is defined as the growth and accumulation of micro-organisms and the agglomeration of extracellular materials on the solid–liquid surface within the feed channel of a spiral wound RO module [8]. The extracellular polymeric substances (EPS) films are especially troublesome to clean. The films anchor on surfaces with low shear and form webs within the feed spacer architecture, as it can be seen in Fig. 1. This "web" creates high resistance to water flow through the feed channel of the element and displays as an increase in feed-concentrate pressure drop (dP) across the RO pressure vessel. High dP leads to hydraulic imbalance and can result in module damage. Additionally, like organic fouling, biofilms can affect feed channel transport properties and reduce the effective membrane permeability. Both system dP increase and drop in permeability increase the energy of operation but also lead to frequent cleanings to regain element performance. In total, fouling affects energy consumption, element lifetime, water productivity and cost of water produced [9].

Biofouling is generally the leading issue triggering cleaning in industrial wastewater treatment plants. Although cleaning guidelines recommend performing a CIP when pressure drop increases by 10%–15%, it is observed that some plants clean at the maximum allowed vessel pressure drop of 3.5 bar [10]. This maximum limit is standard for 8-inch reverse osmosis elements in order to avoid irreversible mechanical damage to the elements.

To address this issue, DuPont has designed a novel seawater fouling-resistant membrane element. This novel element is designed to address the most challenging fouling issue limiting industrial and municipal seawater treatment plants: biofouling. The product specifications of the new seawater fouling-resistant membrane element, together with its previous generation, the FilmTec™ SW30HRLE-400, as well as a reverse osmosis element of another manufacturer (Membrane A) can be found in Table 1.

2. Methods

2.1. Single element pilot plant

Prior to the benchmarking of the reverse osmosis elements, an initial assessment of their performance took place in the single element pilot plant. This pre-evaluation was of major importance for the antifouling experiment as it can serve as a reference point for the individual performance of each RO element. The hydraulic tests were performed registering the pressure drop evolution of the elements at increasing feed flow, ranging from 3 to 18 m^3/h at a constant temperature of 25°C. The single element pilot plant is displayed in Fig. 2.

2.2. Synthetic seawater recirculation experiment

The experiment presented in the current section was undertaken in the Global Water Technology Center located in Tarragona, Spain (GWTC). This trial was run at constant conditions, feeding 9.5 m^3/h of a synthetic seawater solution based on NaCl, with a recovery of 20.6% and a system permeate flux of 17.4 L/(m^2/h). This plant has 2 parallel 8-inch pressure vessels with 3 elements in each

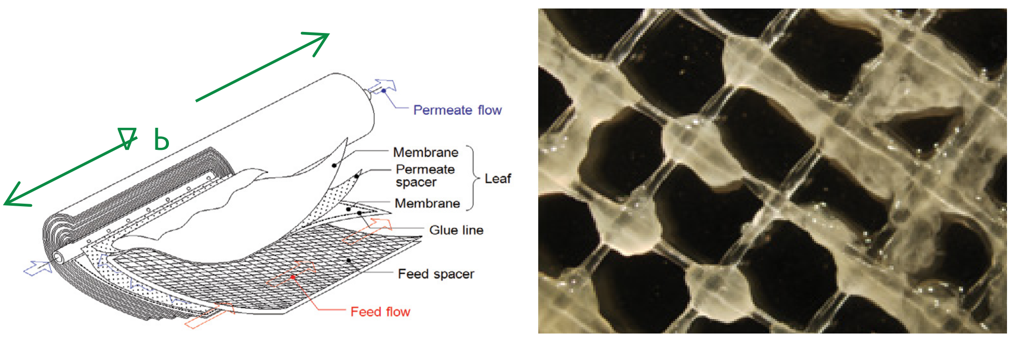

Fig. 1. Reverse osmosis element configuration (a) and biofouled feed spacer (b).

Table 1
FilmTec™ seawater fouling-resistant reverse osmosis element specifications[a]

Product	Active area (ft^2)	Permeate flow (gpd)	Stabilized salt rejection
FilmTec™ SW30XFR-400/34	400	7,500	99.8%
FilmTec™ SW30HRLE-400	400	7,500	99.8%
Membrane A	400	9,000	99.8%

[a]Permeate flow and salt (NaCl) rejection is based on the following standard test conditions: 32,000 ppm NaCl, 55 bar, 25°C, pH 8 and 8% recovery.

pressure vessel. Pipping and pressure vessels are made of super duplex stainless steel, in order to prevent corrosion or pitting of the steel. Additionally, a high pressure pump is responsible of delivering seawater at the adequate pressure into the plant. Finally, permeate and filtrate water is collected into a tank, where it is recirculated using the high pressure pump into the membranes. The plant is fully automated through a programmable logic controller (PLC), which records all the signals into a data logger. Feed flow and permeate flow are recorded using accurate flow indicator transmitters. Also, temperature, feed conductivity and permeate conductivity are recorded with their respective automatic indicator transmitter instruments. Finally, feed, concentrate and permeate pressure is also automatically monitored and recorded. In this test, a pilot provided with two lines were tested in parallel, one containing FilmTec™ SW30HRLE-400, while in the other, the newest seawater antifouling membrane element was loaded, FilmTec™ SW30XFR-400/34. Each line contained a total of 3 elements of each type, respectively. A high level scheme of the pilot were the experiment was carried out is depicted in Fig. 3. Additionally, a picture of the plant is shown in Fig. 4.

The water type used corresponds to synthetic seawater based on 32,000 mg/L of sodium chloride and 5 mg/L of boron added to SWRO permeate. Specific composition of this water can be found in Table 2.

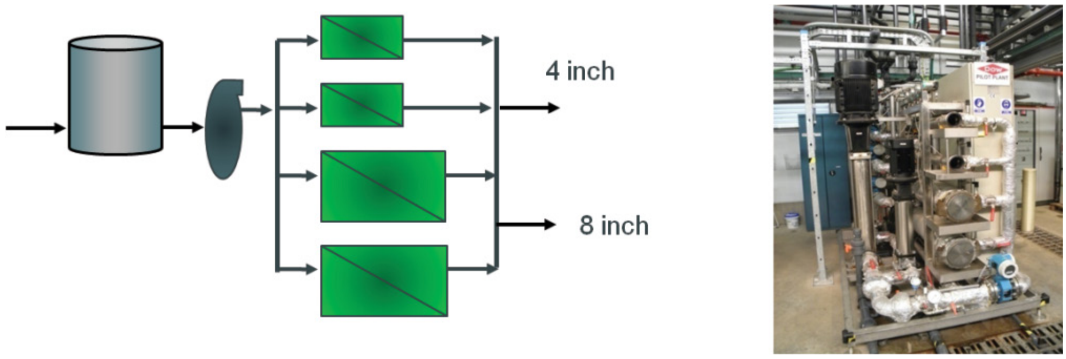

Fig. 2. Diagram and picture of the single element testing plant.

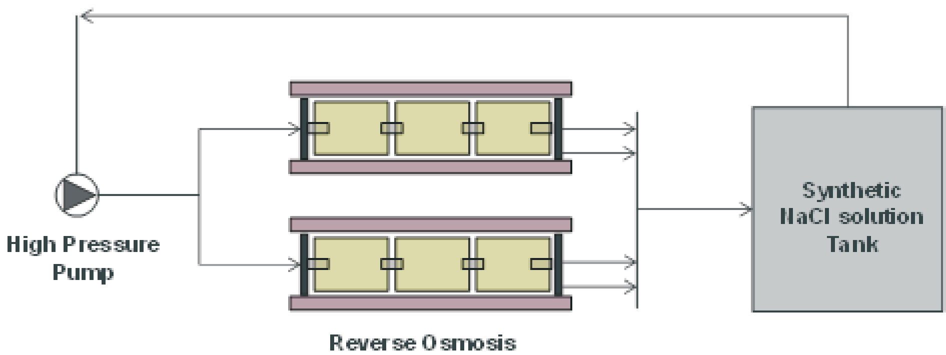

Fig. 3. Synthetic seawater pilot plant schematic.

Fig. 4. Synthetic seawater pilot plant photo.

2.3. Field trials with Red Seawater

This experiment was carried out in the DuPont's Middle East Innovation Center (MEIC), located at the premises of the King Abdullah University of Science and Technology (KAUST) in the Kingdom of Saudi Arabia (KSA). The testing asset consists of ultrafiltration and reverse osmosis and is fed by Red Seawater. The RO section consists of 2 parallel 8-inch pressure vessels for up to 8 elements in each pressure vessel. Pipping and pressure vessels are made of super duplex stainless steel, in order to prevent corrosion or pitting of the steel. The plant is fully automated through a PLC, which records all the signals into a data logger. Feed flow and permeate flow are recorded using accurate flow indicator transmitters. Also temperature, feed conductivity and permeate conductivity are recorded. Finally, feed, concentrate and permeate pressure and feed-concentrate differential pressure are also automatically monitored and recorded. A schematic of the plant can be seen in Fig. 5. Additionally, a picture of the plant is shown in Fig. 6. For this study, water was pretreated by DuPont's Ultrafiltration modules, and in each RO vessel, 6 elements were installed. Feed flow to each RO vessel was 7.25 m^3/h, and the recovery was set to 40% which results in an average permeate flux of 12.5 $L/(m^2h)$.

This study was carried out using water from to the Red Sea that KAUST has natural access to. The water composition can be found in Table 3.

2.4. Durability study

A durability study consisting of multiple cycles (7) of caustic (pH 12, 35°C) and acid (pH 2, 25°C) cleaning-in-place (CIP) was performed side-by-side, comparing the newly developed FilmTec™ seawater antifouling membrane element against a fouling-resistant membrane element from another membrane manufacturer. Before and after each cleaning, each element was tested in recirculation under standard test conditions, in or order to assess the effect that each cleaning cycle has on its standard test performance. This experiment was done in the Red Seawater Pilot Plant that DuPont has in MEIC at the KAUST in the KSA. Fig. 7 shows a schematic of this plant.

Table 2
Synthetic water composition

Compound	Concentration (mg/L)
Boron (B)	5.0
Chloride (Cl)	19,412
pH	8.0
Sodium (Na)	12,588
Total dissolved solids (TDS)	32,005

Fig. 6. RO section of the MEIC testing asset, used for the Red Seawater field trials.

Table 3
Red Seawater composition

Compound	Concentration (mg/L)
Ammonium (NH_4)	0.1
Barium (Ba)	0.01
Bicarbonates (HCO_3)	124
Boron (B)	3.4
Calcium (Ca)	425
Carbon dioxide (CO_2)	0.29
Carbonates (CO_3)	43
Chloride (Cl)	22,515
Fluoride (F)	1.41
Magnesium (Mg)	1,329
pH	8.1
Potassium (K)	511
Silica (SiO_2)	1
Sodium (Na)	12,833
Strontium (Sr)	6.2
Sulfate (SO_4)	3,038
Total dissolved solids (TDS)	40,845

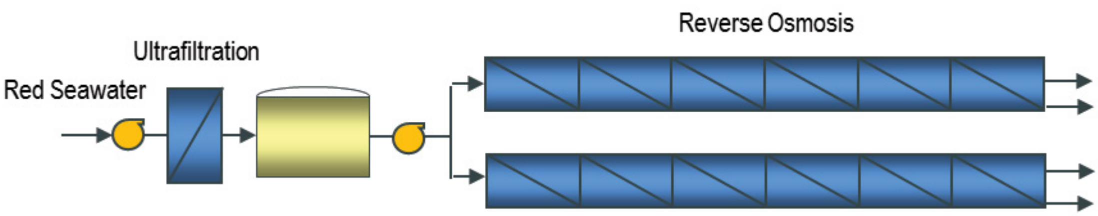

Fig. 5. The DuPont's MEIC Water Solutions pilot plant scheme, fed by Red Seawater.

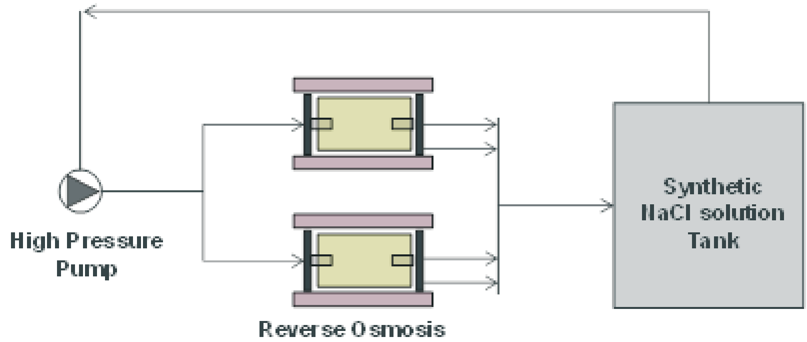

Fig. 7. Durability study pilot plant.

3. Results and discussion

3.1. Single element pilot plant

The new seawater fouling-resistant membrane element was able to offer up to 34% lower pressure drop than its previous generation, as it can be seen in Fig. 8.

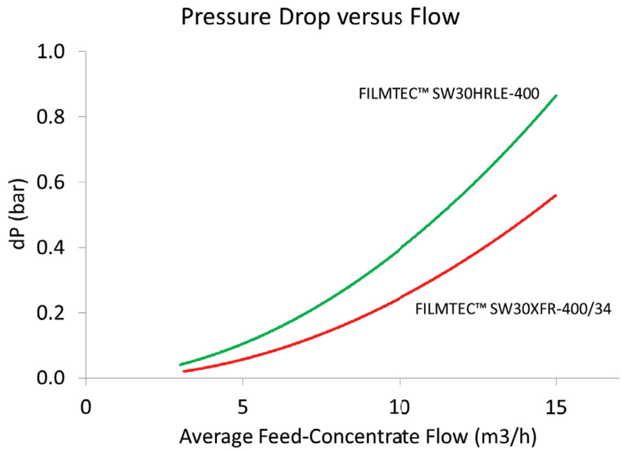

Fig. 8. Pressure drop comparison of new FilmTec™ SW30XFR-400/34 membrane vs. the previous generation SW30HRLE-400.

3.2. Synthetic seawater recirculation experiment

Stabilized permeate flow is compared in Fig. 9, where it can be seen that the new seawater fouling-resistant membrane, the FilmTec™ SW30XFR-400/34, was able to get the same permeate flow than the conventional FilmTec™ SW30HRLE-400. Additionally, both membrane elements presented the same permeate flow evolution over time.

Stabilized permeate conductivity is compared in Fig. 10, where it can be seen that the new seawater fouling-resistant membrane element, the FilmTec™ SW30XFR-400/34, was able to get the same permeate conductivity than the FilmTec™ SW30HRLE-400. Additionally, both membrane elements present the same permeate conductivity evolution over time.

Pressure drop evolution is compared in Fig. 11, where it can be seen that the new seawater fouling-resistant membrane element, the FilmTec™ SW30XFR-400/34, was able to offer a 34% lower pressure drop than the FilmTec™ SW30HRLE-400. Additionally, both membrane elements present the same pressure drop evolution over time.

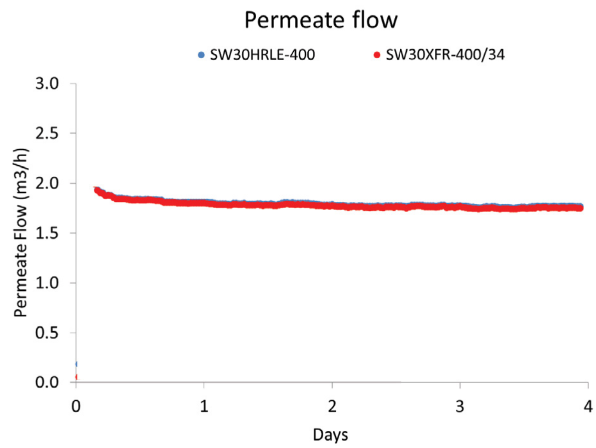

Fig. 9. Permeate flow evolution over time of FilmTec™ SW30HRLE-400 vs. SW30XFR-400/34.

3.3. Red Seawater experiment

Stabilized permeate flow and salt rejection have been kept similar for both Membrane A and FilmTec™ SW30XFR-400/34. Nevertheless, it can be shown that despite both elements starting from a similar pressure drop, then new SW30XFR-400/34 showed superior biofouling resistance, as it can be seen from Fig. 12. This data shows that when both elements are cleaned at the same pressure drop (dP) cleaning trigger, in this case selected at 1.5 bar, the Membrane A need to be chemically clean at day 22, while the new fouling-resistant membrane element was cleaned at day 30. These additional 8 days of extended operation before reaching its cleaning trigger, represented an extended operation time of 32%, which meant that in a year, the new fouling-resistant element would need to be cleaned 32% less often.

3.4. Durability study

The new fouling-resistant membrane element has been compared against another manufacturer's fouling-resistant product. Despite both membrane elements initially showed

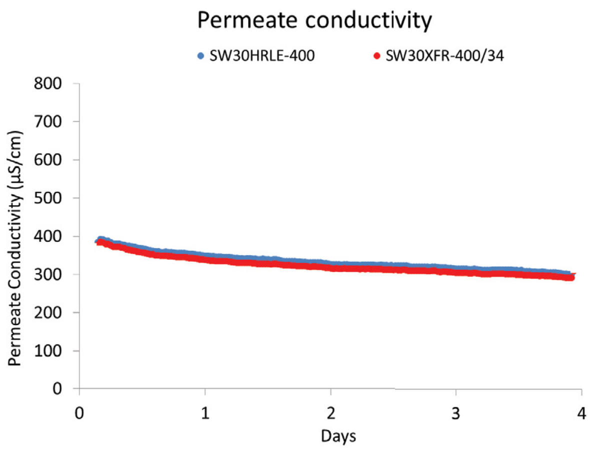

Fig. 10. Permeate conductivity evolution of FilmTec™ SW30HRLE-400 vs. SW30XFR-400/34.

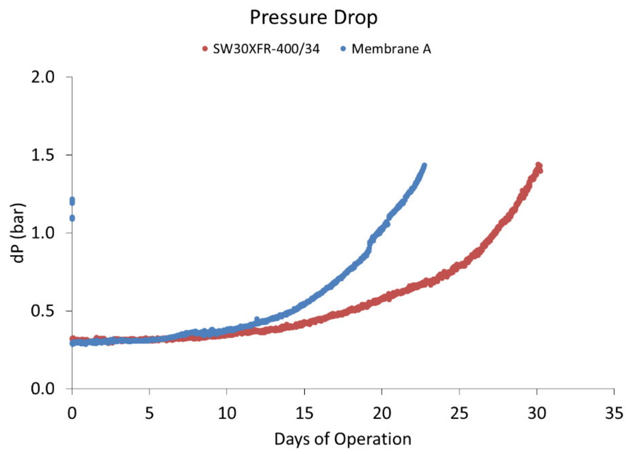

Fig. 12. Normalized pressure drop evolution for FilmTec™ SW30XFR-400/34.

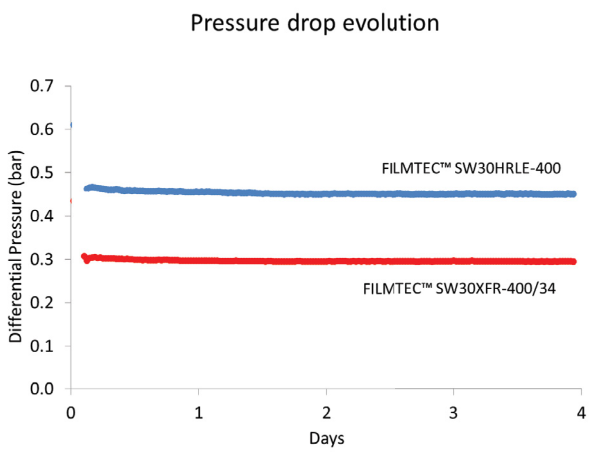

Fig. 11. Pressure drop evolution of FilmTec™ SW30HRLE-400 vs. SW30XFR-400/34.

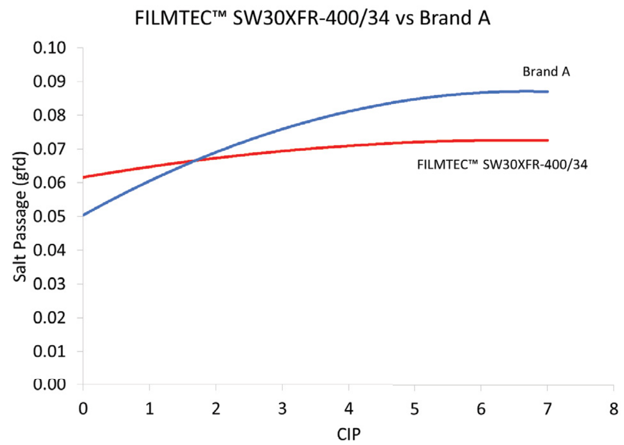

Fig. 13. Durability study comparing FilmTec™ SW30XFR-400/34 vs. another manufacturer named Brand A.

a similar salt passage, after 7 chemical cleanings (CIPs), the new fouling-resistant membrane element showed a stable performance with a slight salt passage increase of 15%, while the element from another membrane manufacturing was suffering an 85% increase in salt passage. This is particularly relevant; taking into consideration a typical CIP frequency of 2–3 months in seawater desalination plants, this would mean that after a 1 year, the membrane named Brand A from another manufacturer will start to show a poor performance in terms of permeate conductivity. This study can be seen in Fig. 13.

4. Conclusions

The new FilmTec™ fouling-resistant membrane, FilmTec™ SW30XFR-400/34, is presented as an innovation compared to the standard and well-known FilmTec™ SW30HRLE-400. This membrane was able to offer 34% lower pressure drop than previous generations with a stable performance in terms of normalized permeate flow and salt rejection. Additionally, it was able to offer promising chemical resistance when chemical cleanings (CIPs) are performed, where an element from another membrane manufacturing was experiencing an 85% increase in salt passage. This is especially important, since this would mean that in the case of frequent chemical cleanings, after one year of operation, the membrane named Brand A from another manufacturer will start to show poor performance in terms of permeate conductivity.

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