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Breakthrough dry seawater reverse osmosis elements

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ABSTRACT

Water scarcity is one key challenge mankind is facing. Seawater reverse osmosis desalination is a promising technology to solve it. However, further innovation which needs to go beyond product specifications is needed to decrease the total cost of water while at the same time, improving sustainability footprint. This paper describes a breakthrough step-change in innovation within the desalination industry: transitioning from wet-tested seawater reverse osmosis (SWRO) elements to dry-tested SWRO elements. This new concept has been achieved by DuPont thanks to a cumulation of significant breakthrough in reverse osmosis technology: continuous advancements in membrane chemistry, automated precision manufacturing, single source manufacturing, a robust quality control, and enhancements in testing methods. Dry SWRO elements offer significant advantages over wet elements, given the requirement to monitor and eventually replace preservation solutions for wet membranes. Dry membranes enable longer storage times, lower labor costs and easier long-term warehouse planning. Dry membranes are safer to install due to a 4 kg weight reduction and are easier to handle. From the sustainability point of view, the dry-test SW concept also brings plenty of benefits: (1) Reduces fresh-water consumption as no wet testing is required; (2) Eliminates wastewater generated during wet testing; (3) Significantly reduces energy consumption by skipping wet testing; and (4) the lower membrane weight will significantly decrease the environmental footprint of dry elements, reducing by up to 20% the CO_2 generation during transportation. In a large desalination installation supplied with dry SWRO elements, the greenhouse gas emissions reduction equals those generated by a passenger vehicle driving more than 500,000 km. Additionally, dry SWRO elements offer the same water productivity and permeate quality as wet elements.

Keywords: Innovation; Reverse osmosis; Water treatment; Desalination

1. Introduction

Water resources are coming under increasing pressure as population growth, climate change, pollution and changes in land use affect water quantity and quality. Projections of water supply and demand over the 21st century show that in the absence of further adaptation efforts, serious water shortages are likely in some regions [1].

Reverse osmosis (RO) membrane technology offers an alternative solution to address the water scarcity problem, holding a remarkable market share and growing among all the desalinating technologies [2]. The increasing use of membrane desalination has been possible thanks to improvements in materials and costs reduction [3]. For years, innovation in the seawater reverse osmosis (SWRO) space has been focused on incremental improvement of product specifications. However, further innovation beyond product specifications is needed to decrease the total cost of water while improving sustainability footprint.

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This paper describes a huge step-change in innovation within the desalination industry: transitioning from wet seawater reverse osmosis (SWRO) elements to dry SWRO elements [4]. All FilmTec™ membrane elements undergo many quality tests and inspections prior to being shipped. Dry membrane elements are never wetted during the testing process, which is designed to assure the quality standards are met for these elements. This new concept has been achieved in DuPont thanks to a significant breakthrough in RO technology: continuous advancements in membrane chemistry, automated precision manufacturing, single source manufacturing, enhancements in testing methods and procedures and a robust quality control. In addition, DuPont Water Solutions boasts more than 20 y of experience with dry brackish water reverse osmosis (BWRO) elements. Dry BWRO are the standard product in the brackish water portfolio and their benefits are recognized and appreciated by the market.

This paper presents the main advantages of dry SWRO elements over wet elements. It also describes a model to estimate the CO_2 savings that can be achieved due to the use of dry SWRO elements instead of wet SWRO elements. Finally, experimental data comparing the performance of dry vs. wet elements is presented.

2. Benefits of dry SWRO elements

Dry SWRO elements present numerous advantages for both users and the environment:

2.1. Enhanced reliability and operations

Dry SWRO elements offer users significant advantages over wet elements:

- *Longer shelf life*: Dry-tested membranes do not need to be stored with the preservation solution, which helps enable longer storage times, making easier long-term warehouse planning.
- *Lower chemicals and labor cost*: dry elements do not need re-preservation while wet elements preservation solution needs to be checked after 12 months of storage and eventually replaced. This operation is very labor intensive and can lead to high costs.
- *Safety*: Because dry elements do not have a preservation solution, they are lighter (4 kg) which involves an easier and more ergonomic loading and installation.
- DuPont™ FilmTec™ elements that have been dry tested will have an extended six month initial performance warranty compared to wet elements.

2.2. Benefits for the planet – sustainability

From the sustainability point of view, dry SWRO elements also brings important benefits. The dry-testing process and lower weight for shipping will all significantly decrease the environmental footprint of these products:

- Reducing fresh-water consumption as no wet-testing is required.
- Eliminating wastewater generation generated during wet-testing.
- Significantly reducing energy consumption by skipping wet-testing.
- Savings of up to 20% in CO_2 generation during transportation due to a 4 kg reduction in weight per element.

3. CO_2 savings model

The dry-testing process and lower weight for shipping significantly decrease the energy usage and greenhouse gas emissions. In the following sections, a model to estimate the CO_2 emissions savings due to the use of dry SWRO elements instead of wet SWRO elements is presented.

The total carbon dioxide emissions avoided (S_{Total}) is considered as the sum of two terms: (1) the carbon dioxide emissions reduction due to transportation (lower elements weight), ($S_{\text{Transport}}$) and (2) the carbon dioxide emissions reduction due to the energy saved in wet testing ($S_{\text{Wet-test}}$):

$$S_{\text{Total}} = S_{\text{Transport}} + S_{\text{Wet-test}} \tag{1}$$

3.1. Total CO_2 emissions avoided due to energy saved in wet testing

The estimated CO_2 emissions avoided due to the energy saved in the wet testing can be calculated as:

$$S_{\text{Wet-test}} = n \cdot E_{\text{wt}} \sum_{i=1}^{m} x_i \cdot \sigma_i \tag{2}$$

where $S_{\text{Wet-test}}$: CO_2 emissions reduction due to the energy saved in wet testing (CO_2 tons); n: number of dry SWRO elements; E_{wt}: the amount of energy required to perform the wet testing (kW h); x_i: fraction of the total energy used during the wet testing obtained from fuel source i (%); σ_i: carbon dioxide emissions by fuel i (CO_2 tons/kW h).

3.2. Total CO_2 emissions avoided due to transportation

The estimated CO_2 emissions saved during transportation due to the lower element weight for shipping can be calculated as:

$$S_{\text{Transport}} = n \cdot \Delta W_{\text{wt}} \sum_{j=1}^{m} d_j \cdot \alpha_j \tag{3}$$

where $S_{\text{transport}}$: CO_2 emissions reduction due to the energy saved in wet testing (CO_2 tons); n: number of dry SWRO elements; ΔW_{wt}: weight reduction in dry SWRO elements (kg); d_j: average transport distance by mode of transportation j (km); α_j: CO_2 emission factor of freight transport method j (CO_2 tons/kg-km).

3.3. Example: 250,000 m^3/d SWRO plant in Middle East

In order to assess the impact on CO_2 and greenhouse gas emissions savings due to the replacement of wet SWRO elements by the new dry SWRO elements, an example of a potential SWRO plant is presented in this section. Estimation has been done considering the model previously described.

For this example, a permeate production of 250,000 m^3/d has been considered. The number of SWRO elements required would be 18,200 and the plant would be located in Middle East.

Dry SWRO elements weight 4 kg less than wet SWRO elements. Elements would be shipped from DuPont's manufacturing site in Edina (Minnesota) to Customer Site in Middle East. CO_2 emission factors for the different transportation methods have been taken from the information reported by The Network for Transport and the Environment [5].

The amount of energy required to perform the wet testing has been assessed to be 4 kWh. The different energy fuel sources in the Upper Midwest U.S. region have been reported by Xcel Energy [6]. For each type of fuel, the carbon dioxide emissions have also been reported [7].

Therefore, if the 250,000 m^3/d permeate flow SWRO plant located in Middle East was supplied with dry SWRO elements, it would save approximately 127 metric tons of carbon dioxide—the equivalent to burning 63 tons of coal or driving more than 500,000 km in an average passenger vehicle [8].

This model has been implemented in a calculator that is available in DuPont Water Solution website [9].

4. Performance of dry vs. wet elements

4.1. Experimental plant

Experiments were carried out at DuPont's Global Water Technology Center (GWTC) in Tarragona. The testing asset consisted of two parallel pressure vessels (PV) of 8″ where three elements were installed. The plant configuration allowed to run side-by-side experiments, comparing the newly developed dry SWRO elements against the equivalents wet SWRO elements.

Experiments were run in once-through mode with Mediterranean seawater (Feed TDS: 40,796 mg/L) for around 2 weeks to assess stabilization time and overall performance. Water was pretreated by DuPont's Ultrafiltration modules. Feed flow to each RO vessel was 6.6 m^3/h, and the recovery was set to 22% which results in an average permeate flux of 13 LMH.

Feed flow and permeate flow were recorded using accurate flow indicator transmitters. Also, temperature, feed conductivity and permeate conductivity were recorded. Finally, feed, concentrate and permeate pressure and feed-concentrate differential pressure were also automatically monitored and recorded. Fig. 1 shows a schematic diagram of the plant and a picture of the 8″ RO vessels is shown in Fig. 2.

4.2. Results and discussion

Normalized values of salt rejection and permeate flow are shown, for different SWRO elements, in Figs. 3–5. As it can be seen, both types of products, dry and wet, require a short time to fully stabilize and show similar performance in terms of water productivity, permeability or permeate quality.

4.3. Dry SWRO references

Starting in 2020, DuPont Water Solutions has produced and supplied dry seawater reverse osmosis FilmTec™ elements to several seawater treatment plants (Table 1). These plants are operating according to expectations and have shown a high adoption rate.

More than 1,300 thousand m^3/d are being treated by dry seawater reverse osmosis elements, and this quantity is continuously increasing.

5. Conclusions

Dry SWRO elements offer significant advantages over wet elements.

Fig. 2. 8″ RO section of the testing asset.

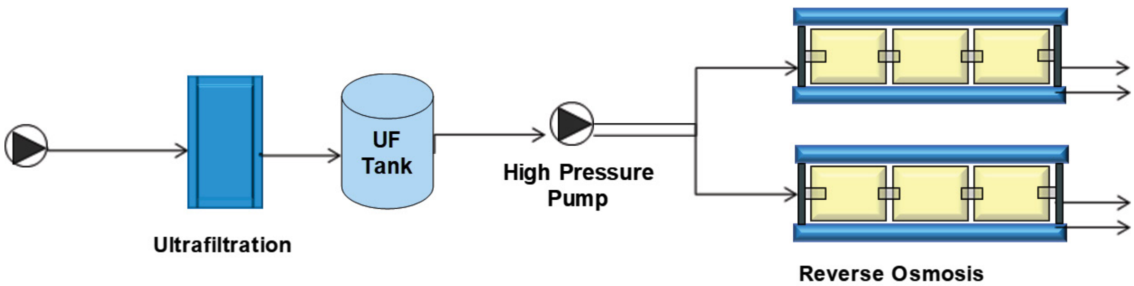

Fig. 1. Experimental plant set-up.

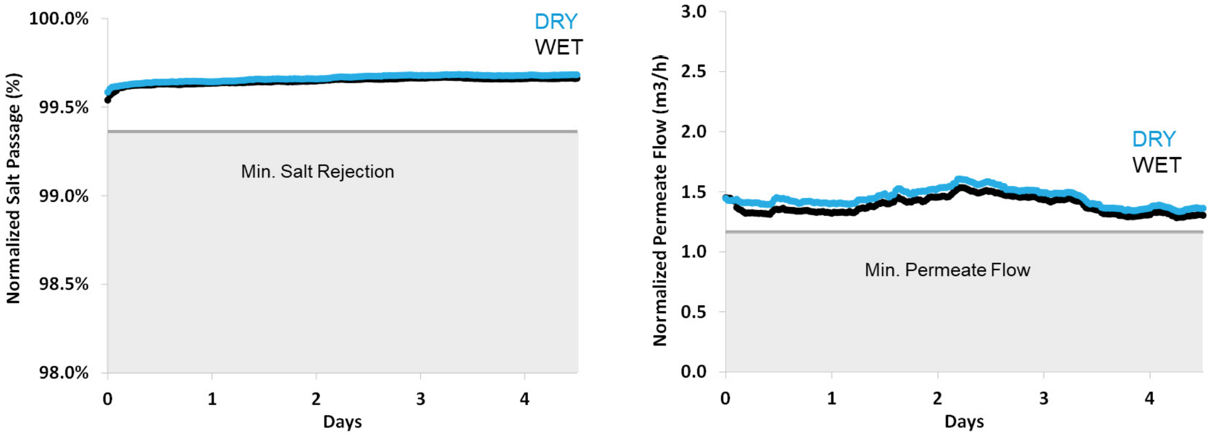

Fig. 3. Normalized salt rejection and normalized permeate flow over time vs. specification for SW30HR-380.

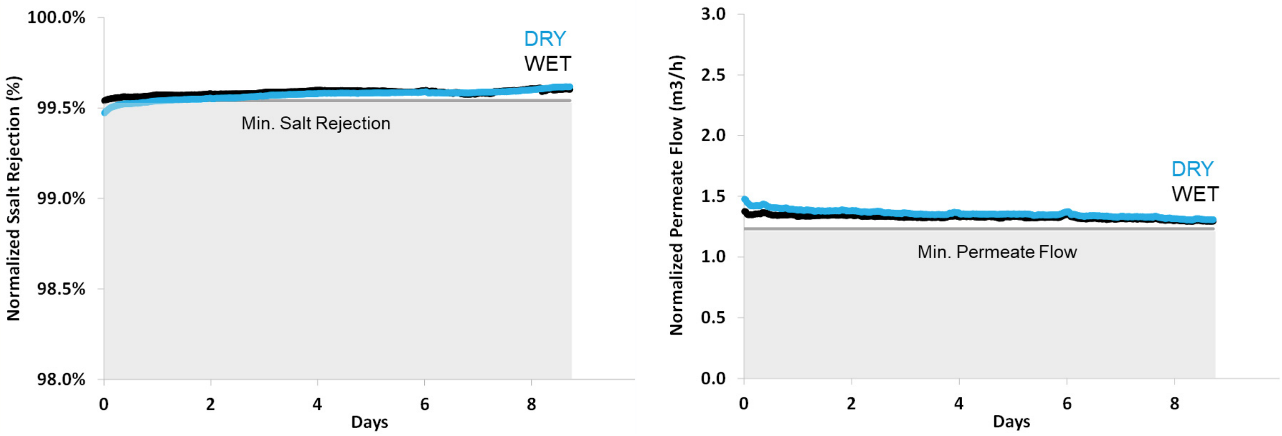

Fig. 4. Normalized salt rejection and normalized permeate flow over time vs. specification for SW30HRLE-400.

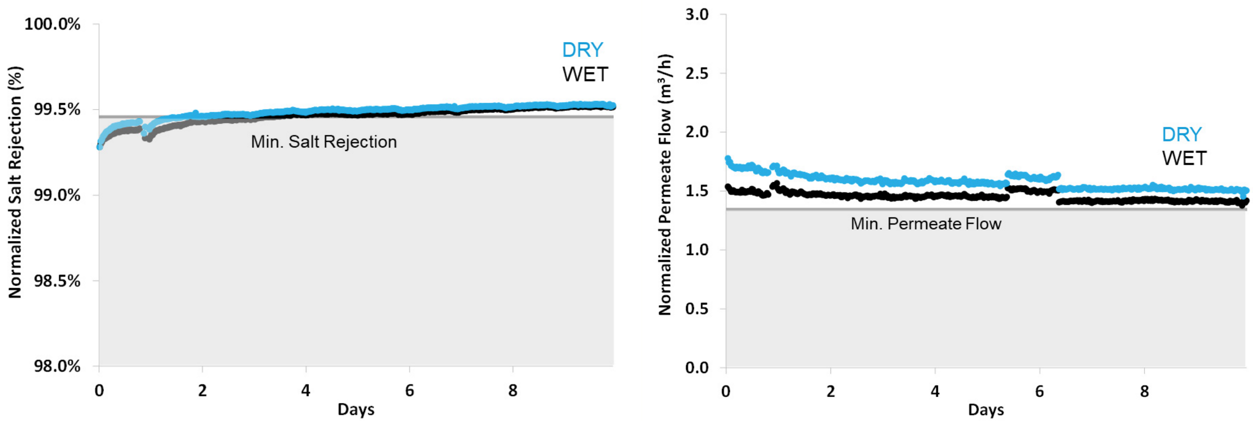

Fig. 5. Normalized salt rejection and normalized permeate flow over time vs. specification for SW30XLE-400.

- Inventory and warehouse management benefits: Given the requirement to monitor and eventually replace preservation solutions for wet membranes, dry membranes enable longer storage times, lower labor costs and easier long-term warehouse planning.
- Safer installation and ease of handling due to lightweight (4 kg weight reduction).
- Sustainability benefits: (1) Reduces fresh-water consumption as no wet testing is required; (2) Eliminates wastewater generated during wet testing; (3) Significantly

Table 1
DuPont™ dry seawater reverse osmosis elements reference list [10]

Country	Capacity (m^3/d)	Delivery date
Israel	550,000	2021
Singapore	318,000	2020
China	150,000	2020
Taiwan	105,000	2020
India	100,000	2020
Egypt	80,000	2020
UAE	22,000	2020
UAE	13,000	2020
Indonesia	12,000	2020
China	7,000	2020
KSA	4,000	2020
KSA	3,000	2020
Iraq	2,000	2020

reduces energy consumption by skipping wet testing; and (4) the lower membrane weight will significantly decrease the environmental footprint of dry elements, reducing by up to 20% the CO_2 generation during transportation.

- Based on the presented CO_2 saving model, in a large desalination installation supplied with dry SWRO elements, the greenhouse gas emissions reduction equals those generated by a passenger vehicle driving more than 500,000 km.

Additionally, dry SWRO elements offer the same water productivity and permeate quality as wet elements.

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