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High-permeability FILMTEC™ SEAMAXX™ reverse osmosis elements: a success story in the Canary Islands

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ABSTRACT

Reverse osmosis (RO) has developed into one of the most commonly applied technologies for the reduction of the salt content of a feed stream. While it is a widely applied purification process, the market is continuously challenging suppliers for innovation to increase the economics and sustainability. This paper will review and analyse the field performance of Dow FILMTEC™ new high-flow/low-energy seawater reverse osmosis elements—SEAMAXX™. This new seawater RO membrane, which has the highest permeability currently available, is based on innovation related to membrane chemistry. SEAMAXX can be used to increase the recovery of an existing system or to decrease the energy consumption. In either case, the final cost of water is estimated to be between 10 and 15% lower compared to previously available state of the art RO elements. This paper will focus on three different cases studies where the expected performance of SEAMAXX has been validated. Two of these cases correspond to small-size and medium-size pilot trials completed at the Water Technology Center of Dow Water and Process Solutions in Tarragona, Spain. The third experience is a commercial installation which has been in operation with SEAMAXX elements since May 2013. In this particular facility, a retrofit of the RO system was undertaken such that existing 11-year-old FILMTEC membranes were replaced with next generation SWRO membranes. This commercial installation, located in the Canary Islands (Spain) treats the seawater (Atlantic Ocean) well to produce drinking water. In this third case, the performance of the desalination plant will be compared with the performance of the previous elements as well as with the predicted or expected performance of SEAMAXX according to ROSA™ (reverse osmosis system analysis) simulation software and DOW™ FT-NORM normalization tool. Rejection of dissolved salts and in particular, rejection of Boron has been carefully monitored by regular analysis in Dow's R&D Lab and in external certified laboratories. After almost one year in operation, the performance of SEAMAXX has been validated through different seasons and

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different sets of operating conditions, confirming the expected savings in energy consumption.

Keywords: Seawater; Reverse osmosis; High permeability; Energy consumption

1. Introduction

Seawater desalination by means of reverse osmosis (RO) membranes has always been challenged by its association with high-energy consumption values.

In order to reduce the cost of water production and maximize the efficiency of desalination by RO, membrane manufacturers have been researching to reach higher permeability, especially for seawater applications, where operating pressures and the resulting energy consumption are critical factors. Dow FILMTEC has recently launched its new high-flow/low-energy RO elements, SEAMAXX™, in order to minimize both capital and operation costs by innovation related to improved membrane chemistry. The very high water permeability of SEAMAXX allows the RO system to be operated at higher recoveries (saving in initial capital costs) and comparable or even lower feed pressures (savings in operational costs) relative to standard commercially available seawater membranes. On the other hand, SEAMAXX can be operated at the same recoveries as standard products, resulting in much lower feed pressure requirements, i.e. energy savings.

SEAMAXX minimizes pressure and energy consumption, while providing reliable long-term permeate quality for either single or double pass as well as interstaged systems. The new element combines a flow of 17,000 gpd, 99.70% stabilized salt rejection and 89% nominal boron rejection.[1] Moreover, SEAMAXX combines 440 ft^2 of active membrane surface area and iLEC™ interlocking technology, maximizing the productivity of seawater RO systems at low differential pressure, low cleaning frequency and high cleaning efficiency.

In this paper, the performance of SEAMAXX in three different case studies will be described in detailed. Two of these operational experiences correspond to Dow Water and Process Solutions pilot studies completed in internal facilities. The third case is a commercial installation which has been in operation since May 2013.

2. DOW™ internal SEAMAXX performance assessment

As with any other membranes, the launch of SEAMAXX was preceded by a rigorous qualification to ensure excellent performance. Part of this qualification consisted of full-scale operation, which Dow can now accomplish not only at commercial installations but also internally, thanks to the unique Global Water Technology Center located in Tarragona, Spain. In this research centre there are various units, which operate at the same conditions as commercial installations in terms of operating flux, recovery, etc. and more importantly, they have continuous access to Mediterranean seawater.

In this paper, two of the internal demonstration trials are going to be included. The first one consists of a containerized pilot unit with two parallel RO lines, each line having six RO elements (4 inch) in series. This trial was conducted for 7 months and was focused on the long-term fouling performance of SEAMAXX compared to commercially available FILMTEC™ products. The second internal installation used as part of the SEAMAXX qualification is a medium-size installation with two lines in parallel, each line with three pressure vessels with 8-inch elements. This particular trial was used to validate the performance of SEAMAXX, not only against a commercially available product but also against FILMTEC simulation software ROSA.

2.1. Long-term assessment of SEAMAXX

The objective of this trial was to complete a long-term evaluation of SEAMAXX RO membranes together with a well-known and well-established product, such as FILMTEC SW30XLE–4040. The focus was set on evaluating the potential different fouling trends with time but also to quantify the energy savings related to SEAMAXX. The selected methodology was to operate the two membrane types in parallel at the same conditions of recovery (45%) and flux (14.5 lmh). The duration of the trial was more than 8 months.

Mediterranean seawater is directed to the pilot facility which is equipped with a ring filter (pore size of 250 μm) and a feed water tank, followed by 2 parallel lines containing ultrafiltration (UF) modules, cartridge filter and RO elements downstream (Fig. 1). The injection points for antiscalant and Sodium Metabisulfite (SMBS) are located after the cartridge filter. The purpose of those chemicals is to prevent the RO system from scale formation and oxidation, respectively. The UF section includes DOW Ultrafiltration

[1]Standard test seawater conditions: 32,000 mg/L, 25˚C, 800 psi and 8% recovery.

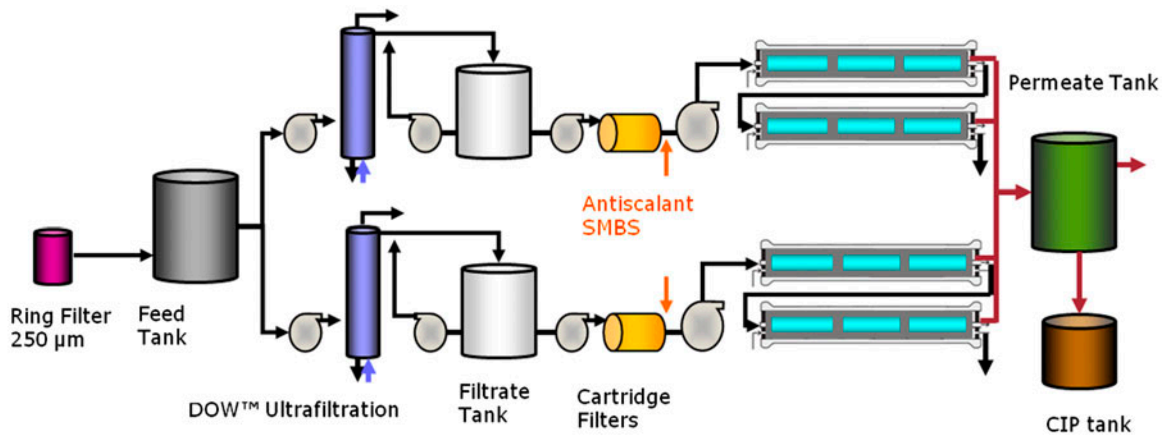

Fig. 1. Pilot unit arrangement.

2,660 modules. Each RO line has 2 pressure vessels with 3 elements (4 inch) running in series. Details for operation conditions are given in Table 1.

The feed pressure needed by the SEAMAXX™ line to maintain the desired flux and recovery was 56 bar, whereas 60 bar was needed for the FILMTEC™ SW30XLE line (Fig. 2). Since both lines are operated at the same flux, despite the pressure difference of 4 bar the permeate production of both membrane is equal to 0.65 m^3/h (Fig. 3). For a small-scale desalination unit, like in this case, the energy savings are 7% if we utilized SEAMAXX rather than FILMTEC SW30XLE.

Figs. 2 and 3 show the feed pressure and permeate flow, respectively. It should be pointed out on one hand the difference in pressure, as stated above, and on the other hand the stable performance with time, i.e. no significant fouling was identified during the months of operation.

Table 1
Operation conditions

Operating conditions	SEAMAXX™ (4-inch)	FILMTEC™ SW30XLE (4-inch)
Feed TDS (mg/L)[a]	41,250	41,250
Pressure feed (bar)	56 bar	60 bar
Flow feed (m^3/h)	1.56	1.56
Flux ($l/m^2/h$)	14.5	14.5
Recovery (%)	45%	45%
Permeate TDS (mg/L)	280 at 18˚C	200 at 18˚C
Temperature (˚C)	15–25	15–25

[a]TDS—Total dissolved solids.

Table 2
Operation conditions

Operating conditions	SEAMAXX (8-inch)	FILMTECSW30ULE (8-inch)
Feed TDS (mg/L)	41,250	41,250
Pressure feed (bar)	50.5 bar	54 bar
Flow feed per vessel (m^3/h)	6.5	6.5
Flux ($l/m^2/h$)	18	18
Recovery	35%	35%
Permeate TDS (mg/L)	380 at 25˚C	290 at 25˚C
Temperature (˚C)	15–25	15–25

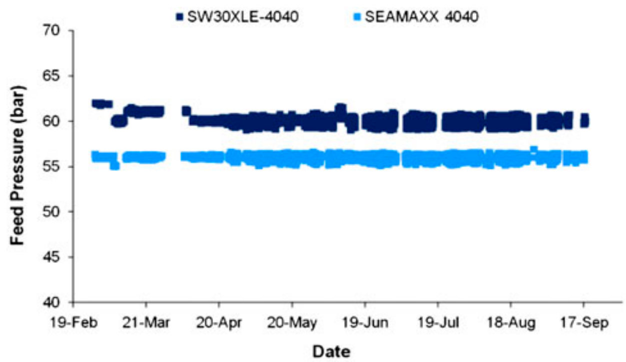

Fig. 2. Feed pressure.

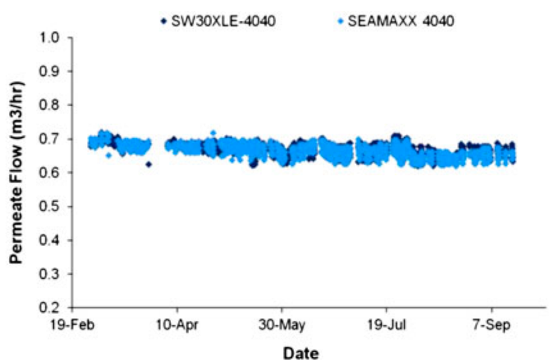

Fig. 3. Permeate flow.

2.2. SEAMAXX™ assessment in an accelerated fouling environment

The purpose of this trial was to validate the performance of SEAMAXX compared to a known product such as FILMTEC™ SW30ULE in an accelerated fouling environment. The pilot unit that was used is equipped with 6 pressure vessels divided in two lines A and B, each with 3 pressure vessels and 3 elements per vessel (Fig. 4). The vessels can be connected in series or in parallel depending on the requirements. The current setting includes two lines: Line A with 3 pressure vessels (9 SEAMAXX elements in total) running in parallel and Line B with 2 pressure vessels (6 FILMTEC SW30ULE-400) also running in parallel to serve as the control in this trial. The SEAMAXX and SW30ULE-400 elements used in this trial had an active area of 400 ft^2.

Prior to the RO system the arrangement includes a UF section, so the water filtrate from the UF is collected in UF filtrate tank. From there, low pressure pumps are carrying the water stream to the cartridge filter with a pore size of 5 μm (to protect subsequent high pressure pump and RO elements from suspended particle). Between the cartridge filter and high pressure pump, injection points of antiscalant and the SMBS are located. Feed water used for this evaluation was Mediterranean seawater.

The operational protocol followed for this trial was similar to the previous case, i.e. flux and recovery were maintained the same in both lines (SEAMAXX and

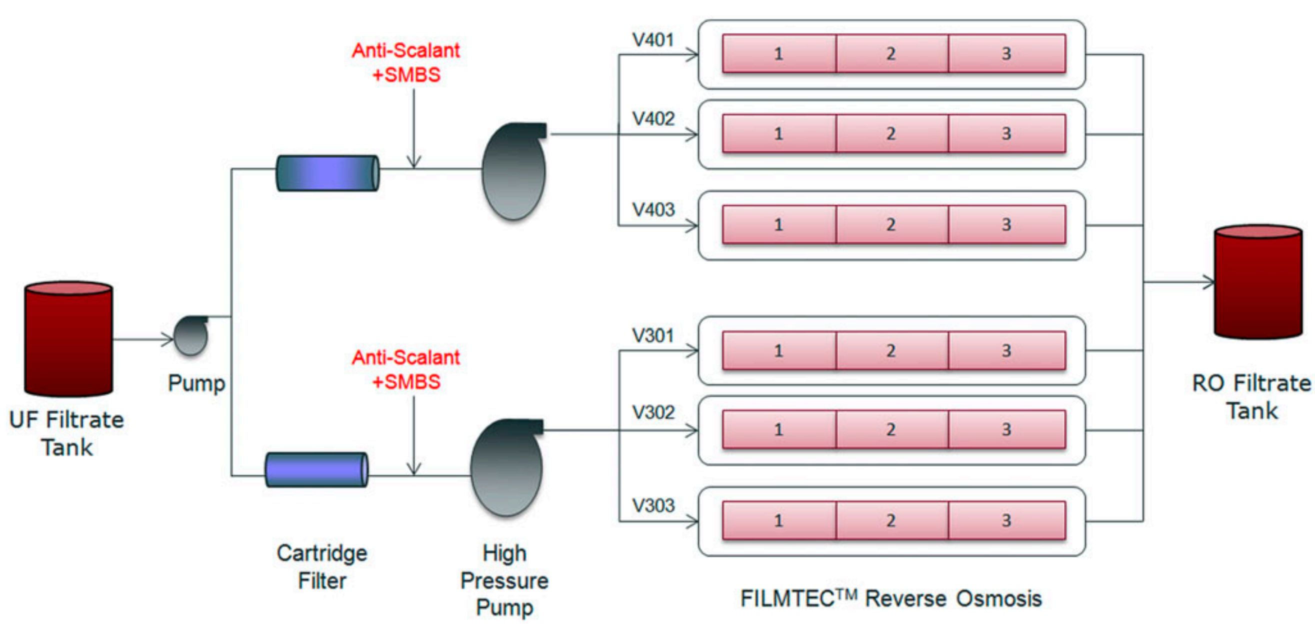

Fig. 4. Pilot unit arrangement.

SW30ULE) and feed pressure was adjusted in each one of the lines to meet such parameters. In particular, flux was set at 18 L/m^2 h and the recovery at 35%. Feed pressure needed by the SEAMAXX™ line to reach this flux and recovery was found to be 50.5 bar whereas for the SW30ULE line, 54 bar were needed. It should be noted that given the relatively short duration of the trial, the flux and recovery selected were challenging to a certain extent. These conditions were selected in order to have more chances to see any differences between the two different membranes.

The feed pressure difference is 3.5 bar between FILMTEC™ SW30ULE-400 and SEAMAXX throughout the trial (Fig. 5). In other words, SEAMAXX requires less energy (electrical consumption) to meet the same permeate production capacity than SW30ULE-400 membranes. Another remarkable fact from this trial was the different permeate flow loss between the two lines. It should be emphasized that as mentioned earlier, this was an accelerated fouling performance test, and thus, aggressive conditions of flux and recovery were selected, i.e. 18 L/m^2 h and 35% recovery. Flux is higher than the average flux recommended for such feed water and recovery is high considering that there are only 3 elements per pressure vessel. From Fig. 6, it is observed that as expected, a certain level of fouling occurred during the trial. It is also remarkable that a larger permeate flow loss was observed in the SW30ULE system. These results are actually very promising considering that the higher permeability of SEAMAXX results in a more uneven permeate flow distribution inside the vessel. In other words, the first element of the pressure vessel in the SEAMAXX system was operated at a higher flux compared to the flux of the first element in the SW30ULE system. This performance actually confirms that the new membrane chemistry used for SEAMAXX results not only in a

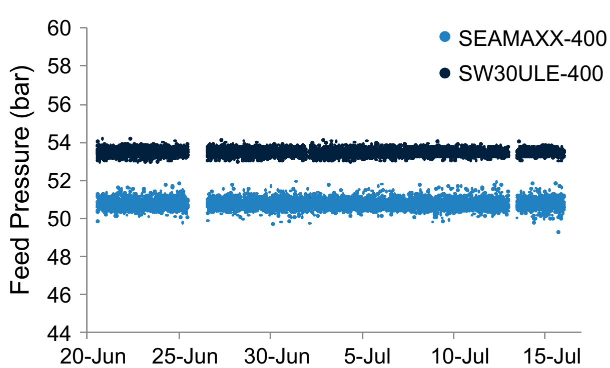

Fig. 5. Feed pressure.
Note: The gaps observed in the plot for the feed pressure as well as for the permeate flow between 25th of June and 14th of July are due to shutdown of the unit.

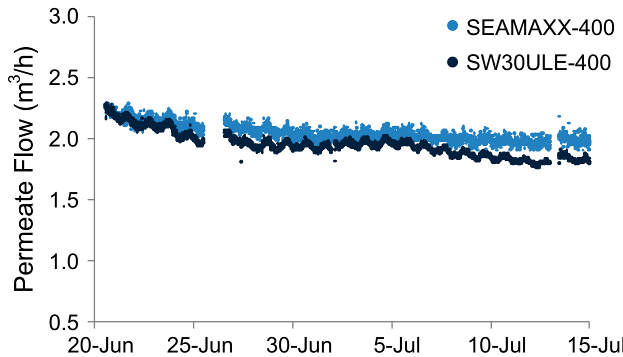

Fig. 6. Permeate flow.
Note: The gaps observed in the plot for the feed pressure as well as for the permeate flow between 25th of June and 14th of July are due to shutdown of the unit.

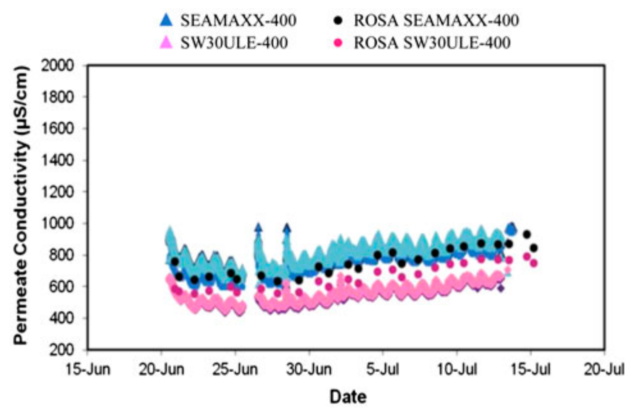

Fig. 7. Assessment of permeate conductivity vs. simulation with Dow FILMTEC ROSA.

much higher permeability but also in increased fouling resistance.

Concerning the evaluation of the performance of both SEAMAXX and SW30ULE elements and its comparison vs. simulations (projections performed using reverse osmosis system analysis—ROSA software from Dow™), the total dissolved solids (TDS) values projected for the permeate water quality of the system are, as shown in Fig. 7, very close to the actual associated conductivity levels of the system. This confirms the suitability of Dow Chemical ROSA software to simulate the expected performances of a RO system including SEAMAXX elements.

3. Seawater reverse osmosis desalination plant, Canary Islands

3.1. Plant description and revamping characteristics

The Canary Islands seawater reverse osmosis desalination plant was designed and built by Veolia Water

Systems Ibérica, back in 2003. The plant includes a beach well, followed by a pretreatment consisting of pressurized dual media sand filter and a cartridge filter 5 µm. It was originally equipped with a high pressure pump with variable frequency drive and Pelton turbine as energy recovery device.

With a configuration of 4 pressure vessels, each of them with 7 elements per vessel, the plant was originally equipped with Dow FILMTEC™ SW30HR-380 elements. The original production capacity was 400 m^3/d of permeate water and, since a different energy recovery device was installed, the average specific energy consumption recorded was 4.9 kWh/m^3 of permeate water (whole installation including pretreatment).

The permeate water produced is used for drinking water purposes. To comply with the local regulations, the permeate water Boron levels were below 1 ppm. Concerning the TDS, the values registered were below 400 ppm.

After 11 years in operation, the plant was requiring a revamp. Once again, Veolia Water Systems Ibérica was responsible to upgrade the installation. This upgrade included the substitution of the existing high pressure pump and existing energy recovery device, the installation of a different energy recovery system, together with the loading of a new set of seawater RO elements.

The revamping of the installation was seeking three objectives: increasing the capacity of the unit, reducing the specific energy consumption requirement, and maintaining the quality of the permeate water produced. Through its delegation in the Canary Islands, the Technical Direction of Veolia Water Systems Ibérica, together with Dow Water and Process Solutions Technical Service, evaluated alternatives with regards to the change of seawater RO elements.

The configuration selected for the RO membranes included a hybrid combining two types of elements: Dow FILMTEC SW30XHR-440i were installed in the first three front positions of the pressure vessel, while Dow FILMTEC SEAMAXX™ elements were installed in the four rear positions.

The aim of the new configuration, during the project planning and execution, was to offer a design able to comply with the local regulations in terms of permeate water quality, while ensuring increased capacity and reducing the specific energy consumption. The design calculations were performed with Dow FILMTEC's reverse osmosis system analysis—ROSA software. Comparison between the expected and actual performance will be explained later. Besides the change of RO elements, the high pressure pump with frequency converter and Pelton turbine was replaced by a new

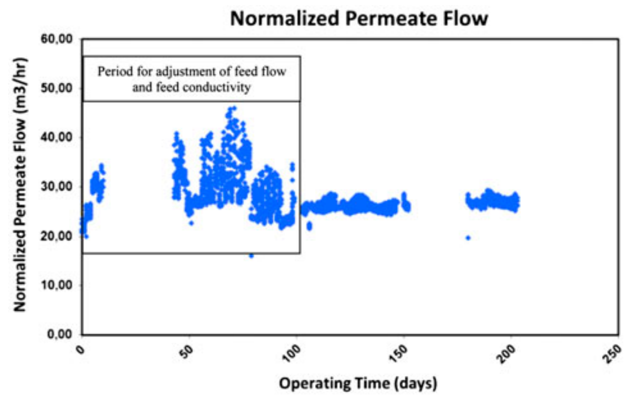

Fig. 8. Normalized permeate flow.
Notes: The gaps observed in the plot for the normalized permeate flow as well as for the normalized salt passage between days 8 and 48, and 155 and 175 correspond to issues with the data recording system.

generation exchange pressure system I-SAVE 40 with a high pressure pump APP-24, both from DANFOSS.

For the follow-up of operational parameters of the unit, besides the control by PLC, corresponding HMI and associated instruments (conductivity, pressure, flow rate and differential pressure), Veolia Water Systems Iberica installed as well a DATA-LOGGER from JUMO, with Software PAC-3000. This DATA-LOGGER registers and stores the most representative data for the follow-up and control of the plant: feed and permeate flowrates, permeate conductivity, feed and concentrate pressure, and total specific energy consumption (including pretreatment).

Also, the following information is recorded manually, with appropriate frequency: raw water temperature and conductivity both in the raw water stream to the plant and the feed to RO elements (so the percentage of mixing in the energy recovery device is monitored), and the individual energy consumption associated to low pressure pump, high pressure pump and energy recovery device.

3.2. Operational performance evaluation of RO elements

The revamping work was performed and finished in the beginning of 2013. The new set of RO elements, including SEAMAXX was installed and put in operation in May 2013. Long-term normalized operational data is shown in Figs. 8 and 9.

The performance of the desalination plant will be compared with the performance of the previous elements, and also to Dow FILMTEC's reverse osmosis

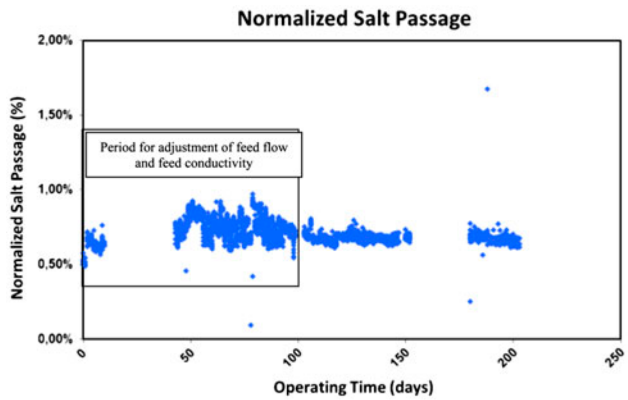

Fig. 9. Normalized salt passage.
Notes: The gaps observed in the plot for the normalized permeate flow as well as for the normalized salt passage between days 8 and 48, and 155 and 175 correspond to issues with the data recording system.

Table 3
Operation conditions

Operating conditions	SW30HR-380	SW30XHR-440i + SEAMAXX-440i
RO feed TDS (mg/L)	34,500	34,500
RO feed boron (mg/L)	4.5	4.5
Pressure RO feed (bar)	61	50.5
Permeate flowrate (m^3/d)	400	550
Recovery	41%	41%
Permeate TDS (mg/L)	<400	<400
Permeate boron (mg/L)	<1	<1
Specific energy consumption-pretreatment + RO section—kWh/m^3	4.9	2.1
Temperature (°C)	19–23	19–23

Fig. 10. Pictures of Canary Islands SWRO desalination unit.

system analysis—ROSA simulation software and DOW™ FT-NORM [1] normalization tool[2].

Table 3 summarizes the operational parameters registered before and after the revamp of the unit. Rejection of salts and in particular, rejection of boron has been carefully monitored by regular analysis in third-party certified laboratories.

The performance of the RO membrane system is recorded continuously, and frequently normalized by means of FTNORM. Data of the first days of operation once the system was stabilized have been taken as reference values for normalization.

Fig. 8 shows steady values for the normalized permeate flow, after a first period of instability, mainly associated to problems with the high pressure pumping group (including the new energy recovery device). Fig. 10 shows stable normalized salt passage values, with some noise during the first operation period, for the same reason stated above. The new configuration including SEAMAXX™ elements, despite the increase in production capacity to 550 m^3/d of permeate water, provides average specific energy consumption values of 2.1 kWh/m^3 of permeate water (including pretreatment and RO section) (Fig. 11). The quality of the permeate water produced is still compliant with the local drinking water regulations.

[2]FTNORM [1] is a Microsoft® Excel® spreadsheet-based program which allows normalizing operating data and graphing the selected parameters, such as normalized permeate flow and normalized salt passage.

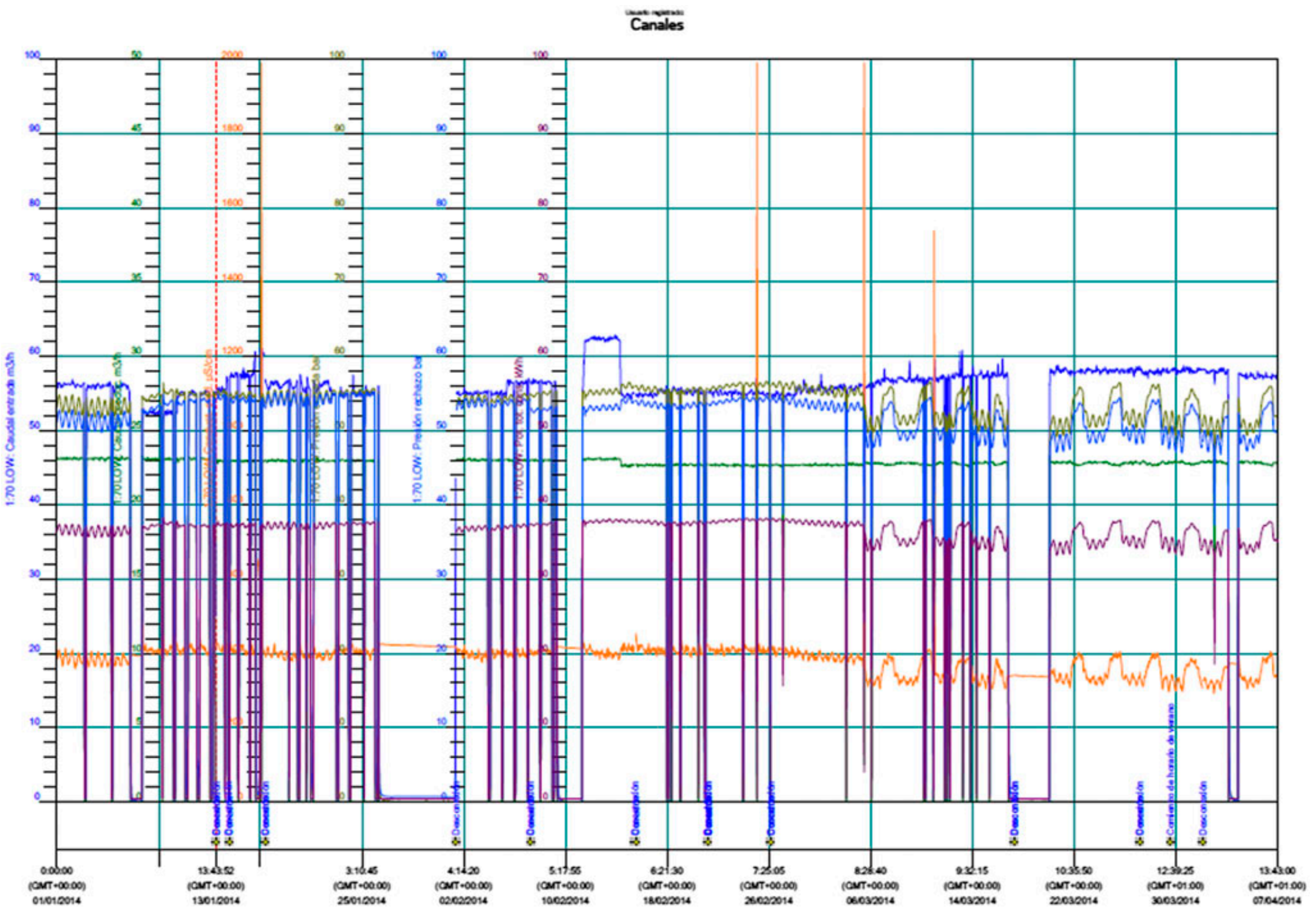

Fig. 11. Canary Islands SWRO desalination unit. Typical view of DATA-LOGGER register of operational data and graphic representation.

3.3. Comparison of plant performance vs. ROSA

Besides the follow-up of the operational parameters by the means of FT-NORM [1], the plant follow-up has as well been done by comparing its actual performance with operation projections (using reverse osmosis system analysis—ROSA software from Dow).

The evaluation of operational pressure and observed permeate quality is performed through the calculation of average equivalent ROSA flow factor (FF), and the comparison of permeate water quality as per expected through ROSA and TDS/Boron content in permeate samples taken and evaluated both Tarragona's Dow Water & Process Solutions R&D Lab and in external certified laboratories.

The evaluation of the observed operating pressure when compared to ROSA FF calculation leads to equivalent values of 1.12–0.96 since start-up. The ROSA FF is understood to reflect multiple phenomena such as slight changes in membrane permeability during service life as well as the impact of fouling.

Note no chemical cleaning (CIP) has been performed since the start-up of the unit in May 2013.

The comparison of ROSA simulations for the permeate water quality and the values measured from the samples taken in different moments of the operation of the unit since start-up shows very similar values both in terms of TDS and Boron. The quantification of the deviation (measured value vs. value obtained from the simulation) is a leading steady calculated deviation, in the ranges of 3–2%.

4. Conclusions

This paper has reviewed the field performance of Dow FILMTEC™ new high-flow seawater RO elements—SEAMAXX™, focusing in three different cases studies. Two studies performed in Dow Water and Process Solutions internal facilities and a third reference, corresponding to the retrofit of a commercial installation where existing 11-year-old FILMTEC™

SW30HR-380 membranes were replaced by next generation SEAMAXX™ elements.

Pilot and field testing has shown that SEAMAXX is meeting the target specifications in terms of permeate production and salt rejection, under very different arrangements: 4-inch and 8-inch modules, proving that SEAMAXX can offer a stable low-energy alternative operation. The long-term (8 month) internal trial was part of the SEAMAXX qualification prior to the launch of the product in October 2013. This particular test was undertaken to demonstrate robust and reliable long-term performance of the element and was conducted together with a known commercial element (FILMTEC SW30XLE). The key conclusion from this successful trial was that SEAMAXX met the expectations, not only in terms of energy consumption (feed pressure) and quality of permeate, but also in terms of long-term stability. The second internal trial, which was equally part of the product qualification, consisted of an assessment of SEAMAXX under accelerated fouling conditions (high flux and high recovery). This second trial was conducted with SEAMAXX membranes operated in parallel with FILMTEC SW30ULE-400 elements. Key conclusions from this trial were on one hand good correlation between ROSA software and also actual operation in terms of feed pressure requirements and permeate quality. In addition, exceptional good performance of SEAMAXX was observed in terms of fouling resistance.

The case study from Canary Islands confirms that SEAMAXX can provide great long-term benefits. This showcase discusses long-term operation with SEAMAXX, in a context of RO system revamp and RO element replacement. All the activities performed for the revamp of the plant, including, but not limited to the replacement of 11-year-old Dow FILMTEC elements by an Internally Staged Design including SEAMAXX have led to a decrease in specific energy consumption from 4.9 to 2.1 kWh/m^3 with an increase in the production flow rate of 150 m^3/d.

The above study confirms the positioning of SEAMAXX as a proven opportunity for desalination plants aiming to minimize the operating cost through reduction of energy consumption.

5. Industry data and product information

The industry data provided in this article was collected in 2013 and 2014 and is included to illustrate the field experiences of Dow FILMTEC RO elements in the seawater desalination arena. Industry data and product information are provided in good faith for informational purposes only. The authors assume no obligation or liability for such data presented herein. No warranties are given; all implied warranties of merchantability or fitness for a particular purpose are expressly excluded.

Reference

[1] The Dow Chemical Company, *FT-NORM*, Midland, 2012. Available from: http://www.dowwaterandprocess.com.