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Long-term benefits of DOW FILMTEC™ RO membranes

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ABSTRACT

Reverse osmosis (RO) is a widely accepted and applied process for the purification of a variety of raw water sources, especially when there is a need for removing the bulk of the dissolved salts and other impurities present in the feed streams. Since its first applications and references, the technology has progressively been refined and improved, up to the current mature status, where, even if innovations are still to come, a solid base frame exists already. This paper will review and analyze long-term operation data from medium and large-size projects, including two different seawater desalination plants examples. It will focus on the long-term stable and reliable performances of DOW FILMTEC™ RO elements, by comparing the expected performance to the current operation data, with special emphasis on the long life of elements, and thus low replacement rates. These two installations are of particular interest given the time they have been successfully producing the required amount of drinking water. The paper will also evaluate the existing plant designs and contrast them to plant design modifications that would have been applied if those installations were designed with current membrane element technology.

Keywords: Seawater; Reverse osmosis; Long-term operation; Replacement; Maintenance strategies

1. Introduction

The long-term success of a medium/large seawater desalination project depends, among other factors, on the reliability of the Reverse Osmosis (RO) membrane elements installed.

Although a proper operation and maintenance of the system is sought, the elements are sometimes operating under challenging conditions [1], such as waters with strong fouling character, frequent cleanings and/or chemical treatments, extreme pH conditions, etc.

The following paper will evaluate the 6–7 years of operating data and membrane performance of DOW FILMTEC™ RO elements at two different seawater installations: Askhelon (Israel) and Santa Bárbara (Curaçao).

Actual normalized permeate flow and normalized salt passage values will be compared to the expected values. A description of the particularly challenging conditions the elements are exposed to will be done and the low membrane replacement rates will be discussed. Additionally, in order to assess the potential benefits of RO technology innovations, a

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comparison between the current design and an alternative one, using these innovations, is included.

2. Ashkelon, Israel

2.1. Plant description and characteristics

Ashkelon seawater RO desalination plant is located at the Mediterranean coast in the south of Israel and has a current capacity of 120 million m^3/year of drinking water. The desalination plant was started up in the second half of 2005 and it has been successfully operating for more than 6.5 years. The plant's output has been increasing gradually over years since its start up [2]. It produced 101 million m^3 in 2006, 111 million m^3 in 2008, and 120 million m^3 in 2011. With this capacity, the plant produces the equivalent of 14% of the country's domestic water demand which is equivalent to approximately 6% of the Israel's total water needs.

The consortium of IDE Technologies and Veolia Water won the Ashkelon project tender. The concession was granted on a Bbuild–operate–transfer basis. The construction of the plant was made by OTID, a consortium formed by IDE Technologies Ltd and OTV (50–50%). On the other hand, Ashkelon Desalination Operation and Maintenance Ltd (ADOM), a consortium of Veolia Water and IDE technologies Ltd were in charge of the operation of the plant.

The successful completion of the plant opened new horizons for the desalination industry. The Ashkelon project represented an outstanding milestone in the seawater desalination field in terms of size (Ashkelon was the world's largest plant during four years) and process innovation attaining one of the world's lowest ever prices for desalinated water (0.5 US cents/m^3 by 2005). Today, Ashkelon still holds the record of being the large seawater desalination plant, which has been longest in operation.

The "Pressure Center" concept and the "Cascade Concept" were the major process innovations applied in the Ashkelon project. All process innovations implemented in this project are described in detail in earlier publications [3–5]. The Cascade, IDE's multistage separation process, is one of the key innovative features of the plant. The Cascade allows a balanced and flexible removal of both TDS and boron by a combination of different membrane types working at different pH levels. In this process, part of the first-stage RO permeate is further polished in a combination of high and low pH stages removing boron and salts at a very high recovery (>95%). This combination of high and low pH stages is applied in order to efficiently accomplish the strict permeate quality requirements at a high recovery rates but diminishing the risk of scaling.

The seawater feeding the Ashkelon desalination plant contains approximately 41,000 mg/L of total dissolved solids, 22,600 mg/L of chloride, and 5.3 mg/L of boron. The feedwater temperature ranges from 13 to 32°C. The RO permeate water of the Ashkelon desalination plant needs to have the chloride concentration <20 mg/L and the boron concentration <0.4 mg/L.

The raw water source is an open intake. The pretreatment consists of dual media gravity filters containing quartz and anthracite. Before the filtration stage, feedwater pH is adjusted (Sulfuric Acid) and coagulant (Ferric Sulfate) addition takes place. The pretreatment is also equipped with flocculant injection and chlorination/de-chlorination stations; however, these are not in use in normal operation. Prior to feeding the RO membranes, the pretreated water passes through a system of safety cartridges filters of 20 microns of pore size.

The RO system was designed based on the Cascade IDE's multistage concept. The cascade process was developed and patented by IDE [6]. The cascade process [6] comprises four desalination stages. A scheme of the cascade process is shown in Fig. 1.

In the cascade design, the seawater is treated in a first RO stage, where front and rear permeates are obtained. The rear permeate is treated in a second stage with high recovery and high pH for better boron removal. The front permeate is part of the total permeate and does not need further desalination. According to the previous description, the first two stages of the cascade design coincide with a two-passes conventional design. The key feature of the Cascade is that the brine of the second stage is further treated in an extra two-passes installation (namely third and fourth stages). The third RO unit consisting of two stages treats the brine of the second stage previously acidified to avoid scaling problems. In the fourth stage, also formed by two stages, the permeate of the third stage is treated to accomplish a high recovery.

The Ashkelon desalination plant uses more than 43,000 DOW FILMTEC™ RO elements.

Approximately, 29,000 seawater elements (DOW FILMTEC™ SW30HRLE-400) are in operation in the first stage. Brackish water elements are used in the subsequent stages, where approximately 10,000 DOW FILMTEC™ BW30LE-440 elements are in operation in the second stage, and around 4,000 DOW FILMTEC™ BW30-400 elements are used in third and fourth stages. Detailed information about the specifications of the membrane element types used in the different stages of Ashkelon desalination plant is shown in Table 1.

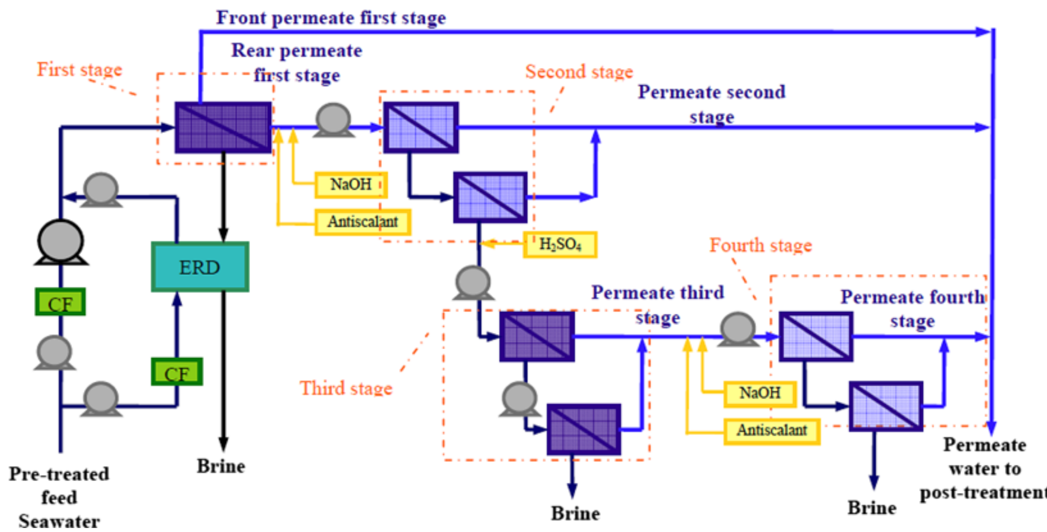

Fig. 1. Scheme of IDE's patented [6] Cascade Process.

Table 1
Specifications of DOW FILMTEC™ membrane element used at Ashkelon

Stage	Membrane element type	Permeate flow rate (gpd)	Stabilized salt rejection (%)
First[a]	DOW FILMTEC™ SW30HRLE-400	7,500	99.75
Second[b]	DOW FILMTEC™ BW30LE-440	11,500	99.00
Third and fourth[c]	DOW FILMTEC™ BW30–400	10,500	99.50

[a]The above values are normalized to the following conditions: 32,000 ppm NaCl, 5 ppm boron, 800 psi (5.5 MPa), 77˚F (25˚C), pH 8, and 8% recovery.
[b]Permeate flow and salt (NaCl) rejection based on the following standard conditions: 2,000 ppm NaCl, 150 psi (10.3 bar), 77˚F (25˚C), pH 8, and 15% recovery.
[c]Permeate flow and salt (NaCl) rejection based on the following standard conditions: 2,000 ppm NaCl, 225 psi (15.5 bar), 77˚F (25˚C), pH 8, and 15% recovery.

The project planning and execution involved accurate design and operation projections (using *Reverse Osmosis System Analysis*—ROSA software from Dow), an advanced RO element production quality control system, as well as advanced pilot testing before startup of the facility. This enabled a very smooth startup. Based on a very deep understanding of membrane performance prior to startup [7], the plant ramped up to full production very fast after its commissioning (mid-2005) and exceeded its yearly design capacity of 100 million m^3/a by 8% within the first year of operation, at an energy consumption which was 0.5 kWh/m^3 lower than expected [2]. A significant contribution of this successful start-up performance can be attributed to the RO membrane elements performance which also met and exceeded the design expected performances [4].

2.2. Long-term performance evaluation

After of a successful start-up performance it is also of key importance to keep and maintain the RO performance long term. A successful long-term performance of an RO membrane system depends on the quality of the membrane elements used and also on proper operation and maintenance of the system.

In this section, the performance of Ashkelon desalination plant during the first six and a half years of operation is reviewed in detail. The study complements the previously published five years performance evaluation from García-Molina et al. [7] and provides extended performance data from the last one and a half years. This study is specially focused on the long-term performance of the SWRO membrane elements of the first stage and BWRO membrane elements of the second stage of the cascade process.

2.2.1. SWRO unit: first stage

The first stage RO system is operated at a recovery of 46% in average (ranging from 44 to 50%) at a system flux ranging from 13 to 15 L/hm^2. The RO feed pressure ranges from 65 to 75 bar depending on the feedwater temperature and feedwater salinity.

The operating data throughout six and a half years have been normalized to determine the changes in membranes performance over time. This normalization is done by means of the FTNORM tool [8]. FTNORM 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. Data of the first days of operation once the system stabilized have been taken as reference values for normalization.

In Figs. 2 and 3, the relative normalized permeate flow and relative normalized salt passage compared to the initial stabilized flow are shown throughout the operating time of two different RO trains of the first-stage system.

The discontinuous horizontal line in light blue color shown in Figs. 2 and 3 represents the reference level in relative permeate flow terms. In February 2009, an upgrade of the system was done to increase the permeate capacity, and therefore the reference line regarding relative permeate flow is increased slightly.

The SWRO trains have been meeting or exceeding the designed long-term performance with regard to permeate production and permeate water quality.

From Figs. 2 and 3, it can be seen that the normalized permeate flow has been relatively stable among 70 and 90% of the initial permeate flow throughout the operating period. The normalized salt passage has been lower than the initially normalized salt passage most of the time, especially in train#1 south.

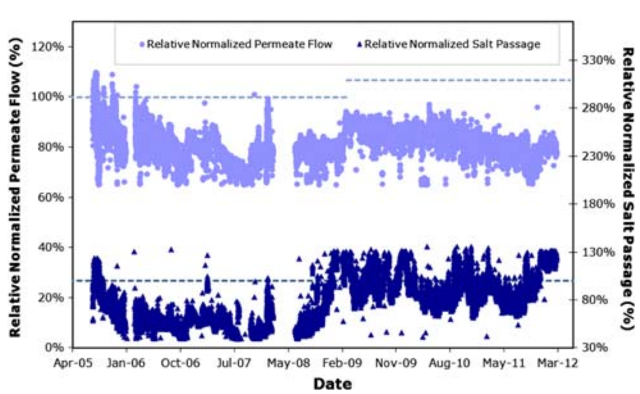

Fig. 2. Relative normalized permeate flow (light blue circles) and normalized salt passage (dark blue triangles) from train# 1 north (first stage).

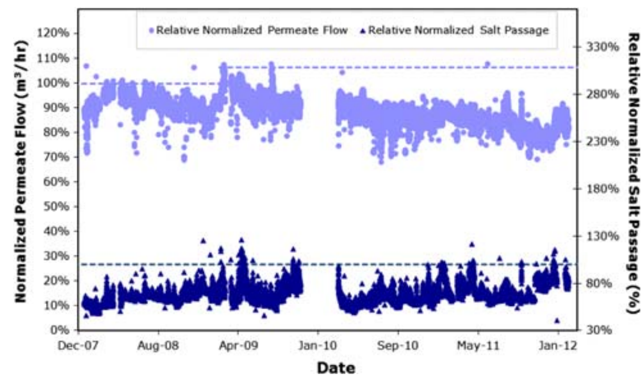

Fig. 3. Relative normalized permeate flow (light blue circles) and normalized salt passage (dark blue triangles) from train# 1 south (first stage).

It is important to indicate that the total number of RO elements replaced in Ashkelon is significantly below initial design expectations. The majority of the membrane elements currently running have been in operation throughout the lifetime of the plant, six and a half years. Despite this, the quality and quantity of the permeate water produced still meets the requirements and the initial expectations.

In addition, the SWRO membrane elements have been cleaned in a relative frequent basis throughout the operating time. The cleaning cycles are usually performed at elevated temperature (35˚C) at pH 2 and pH 12. Nevertheless, the membrane elements confirmed consistent and stable performance despite facing relatively frequent cleanings at the indicated pH and temperature conditions. This robust and consistent long-term performance of the membrane elements could be attributed to the very stable, chlorine-free membrane chemistry as well as very consistent element construction of the DOW FILMTEC™ SW30HRLE-400 elements used in the plant.

2.2.2. BWRO unit: second stage

In 2006, Gorenflo et al. [4] reported the first RO membrane performance results from Ashkelon plant. The study concluded that BWRO membranes elements from second and subsequent stages exhibited performance on a high and stable level under conditions such as high pH and high temperature. Later in 2010, García-Molina et al. [5] concluded the long performance of the second and subsequent stages was excellent taking into account that the membranes had been in operation for more than five years and that no major loss in production or rejection had been observed.

In this study, the performance of the second stage is evaluated. This stage of the cascade treats the rear permeate water of the first stage. The second stage system is operated at a recovery ranging from 75 to 87%. NaOH is injected to the second-stage feedwater in order to increase the pH, and thus shift the boron present in the water towards the better rejected species, $B(OH)_4^-$. The pH of the second-stage feedwater has been ranging from 9.5 to 10.3, being 9.9 the average pH value.

Detailed performance data from the first array of the second stage of Ashkelon desalination plant have been evaluated. In Fig. 4, the relative normalized permeate flow and relative normalized salt passage referenced to the initial design values are plotted throughout the last 3.75 years (from May 2008 to February 2012).

The normalized permeate flow is stable at around 80% of the initial design value. The normalized salt passage has been relatively stable and better than the design value throughout the operation period.

Despite the fact that the membrane elements are more than six-years-old and that they have been operated at high pH levels throughout the operating life, the membrane elements of the second stage have been consistently meeting the permeate production and exceeding the salt rejection requirements.

2.3. Membrane technological update: latest developed SW30XLE technology in operation at Ashkelon

During these six and a half years that the Ashkelon desalination plant has been in operation, DOW FILMTEC™ SWRO membrane technology has evolved attaining higher salt rejections and higher permeate water productivity, i.e. lower the energy needs, compared to the SWRO membrane element available six and a half years ago.

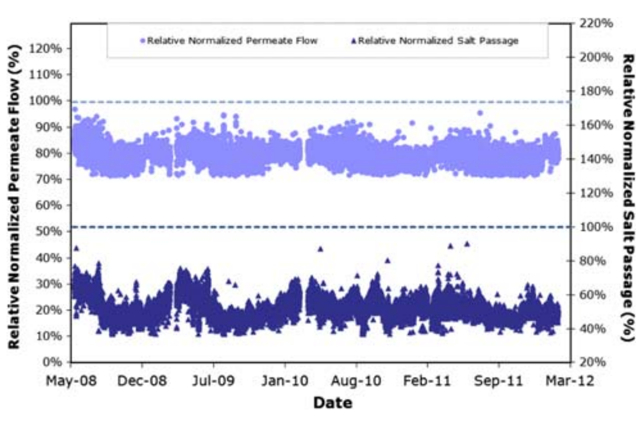

Fig. 4. Relative normalized permeate flow (light blue circles) and relative normalized salt passage (dark blue triangles) from train# 1 north (Second stage).

Latest DOW FILMTEC™ innovative membranes have been tested in Ashkelon for potential replacement of the original SW30HRLE-400 membrane elements. After having done a thorough and successful pilot trial of six months, Dow's latest Extra Low Energy (XLE) DOW FILMTEC™ seawater RO element has been selected for the 2012 scheduled partial replacement of the original DOW FILMTEC™ SW30HRLE-400 elements operating in Ashkelon. This demonstrates the continuous focus of ADOM in optimizing energy consumption and installation productivity.

Dow's latest innovation in seawater membranes has enabled the substantial improvement in the rejection properties of the XLE DOW FILMTEC™ seawater RO element without impairing its minimum energy consumption. The new generation of DOW FILMTEC™ SW30XLE-440i RO membranes, with a 99.8% salt rejection, 91.5% boron rejection, and 440 ft^2 of guaranteed active area, represents the optimum and most reliable compromise between permeate production and rejection for single and multiple pass seawater installations.

The table below shows the product specifications of the current DOW FILMTEC™ SW30XLE-440i membrane element and the DOW FILMTEC™ SW30HRLE-400 originally installed in Ashkelon by 2005 an the current specs of DOW FILMTEC™ SW30HRLE-400 (see Table 2).

The new DOW FILMTEC™ SW30XLE elements will not replace full trains of DOW FILMTEC™ SW30HRLE-400, but they will replace some old elements from the trains and they will be installed evenly in determined positions of the pressure vessels.

By running two ROSA simulations considering the configuration of one train of the Ashkelon's first stage: one simulation considering a full train with the original membrane elements and the other with the newest DOW FILMTEC™ SW30XLE-440i at the same Flow Factor (FF) and at the same average system flux, one could clearly observe the very significant advantages of the newest developed membrane element.

The simulation results showed that the train using DOW FILMTEC™ SW30XLE-440i membrane elements could deliver 10% more permeate water at around 2–2.5 bar less feed pressure while providing even better permeate water quality compared to the original DOW FILMTEC™ SW30HRLE-400 (specs from 2005).

This exemplifies the significant improvements achieved of the DOW FILMTEC™ SWRO technology in only a bit more than half a decade.

Table 2
Specifications of latest SWRO membrane elements vs. original SWRO element used at Ashkelon

Element type	Active area ft^2 (m^2)	Permeate flow rate gpd (m^3/d)	Stabilized boron rejection (%)	Stabilized salt rejection (%)
DOW FILMTEC™ SW30HRLE-400 (specs by 2005)	400 (37.2)	7,500 (28.4)	89.0	99.75
DOW FILMTEC™ SW30HRLE-400 (current specs)	400 (37.2)	7,500 (28.4)	92.0	99.80
DOW FILMTEC™ SW30XLE-440i (current specs)	440 (40.9)	9,900 (37.5)	91.5	99.80

Note: The above values are normalized to the following conditions: 32,000 ppm NaCl, 5 ppm boron, 800 psi (5.5 MPa), 77°F (25°C), pH 8, and 8% recovery.

3. Santa Barbara, Curaçao

3.1. Plant description and characteristics

Santa Bárbara is a 18,200 m^3/d seawater desalination plant, located in the Island of Curaçao, in the southern Caribbean Sea, off the Venezuelan coast.

The raw seawater is pumped from an open intake collecting pit to a dual-media filtration step, enhanced by previous coagulation. After cartridge filtration, high pressure pumps with energy recovery turbines feed a double pass RO system. The RO permeate is then posttreated by means of UV, limestone filters with associated CO_2 injection, activated carbon and chlorine dosing.

The RO system is based on a full double pass design. The first pass includes three equal trains in parallel, each of them based on 92 pressure vessels, seven DOW FILMTEC™ SW30HRLE-380 elements each. The second pass includes also three trains in parallel, each of them based on a two-stage design: 20 pressure vessels in the first stage and seven pressure vessels in the second. The second-stage pressure vessels contain seven DOW FILMTEC™ BW30LE-440 elements. The second pass feedwater pH is adjusted with sodium hydroxide in order to enhance the second pass boron rejection.

The product water quality aimed TDS < 150 mg/L after posttreatment and boron < 0.3 mg/L, to comply with the transitory regulations. The boron limit was later widened to < 0.5 mg/L.

The plant was constructed by Degremont during 2003–2005. After the commissioning of the RO section, completed in late 2005, the operation was turned over to Aqualectra. Full details about the plant startup and first-year performance was widely discussed by Bonnelye et al. [9]

Since its commissioning, the operational strategy of the plant has aimed to control biofouling. Dorival et al. [10] discussed in detail the enhanced operating cycles achieved through offline biocide dosing treatment, in conjunction with an optimized RO cleaning formulation.

3.2. Normalized data: flow and salt rejection

The original RO elements have now been in operation for more than seven years without any element replacement and continue to provide excellent performance. This is even more significant given the severe biofouling and subsequent frequent cleanings which was experienced during the first year of operation until the cleaning and sanitization protocol was optimized.

The operating data have been normalized to determine the changes in membranes performance over time. This normalization is, again, done by means of the FTNORM tool [8].

In terms of normalized permeate flow (see Fig. 5), the average equivalent ROSA FF (representing the membrane aging) of first pass trains A, B, and C is currently equal to 0.79. The reduction in FF is primarily due to irreversible fouling on the membranes and is the current equivalent FF that corresponds to a membrane in operation (not necessary to be chemically cleaned).

This figure stands out when compared with the expected value of FF that is equal to 0.80 for clean membrane, which is expected to be reached by the end of the second year of operation. If this expected value is reached, the average membrane age on the system is then maintained constant by partial element replacements.

Concerning the normalized salt passage (see Fig. 6), the average increase in Salt Passage (as % value) for trains A, B, and C (First Pass) is equal to 2,01%, when compared to the maximum expected values.

The operation under this condition is possible, since the design of the plant was made to comply with the local drinking water regulation at the time of the plant construction, limiting the boron value to 0.3 mg/L.

A later versions of the regulation, including reviewed and higher boron limits (first 0.5 mg/L and later on 1 mg/L), made it possible to continue the

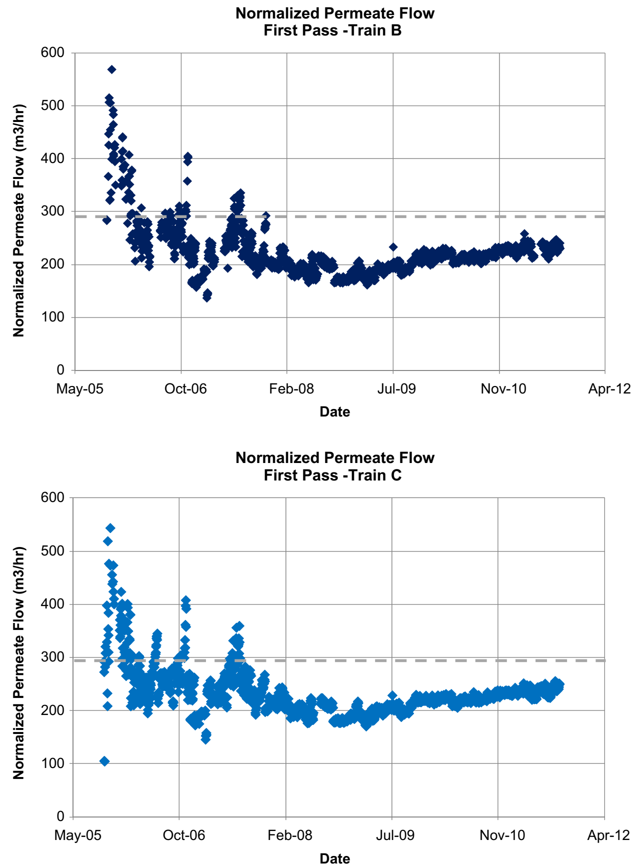

Fig. 5. First pass. Trains B and C. Normalized permeate flow.

operation, since the TDS levels of the permeate were largely complying with the requested limits.

3.3. *Maintenance: online and offline biocide treatments, high pH CIPs*

The control of biofouling in the plant's first passes has been critical to the operational strategy. Since the first months of operation of the plant, an important fouling, mainly made up by aliphatic hydrocarbons, bacterial slime, and sulfate-reducing bacteria, according to Dorival et al. [10], was identified. This fouling was causing an prominent and fast increase in dP (differential pressure between feed and brine). Since the operation exceeding the limits of the differential pressure (per multi-element vessel or per single element) might lead to mechanical damages, a complete preventive and corrective strategy was implemented, with the purpose of controlling it. It included:

- The optimization of pretreatment operation and chlorine dosings, associated to the reduction of bisulfite addition on the first pass feed.

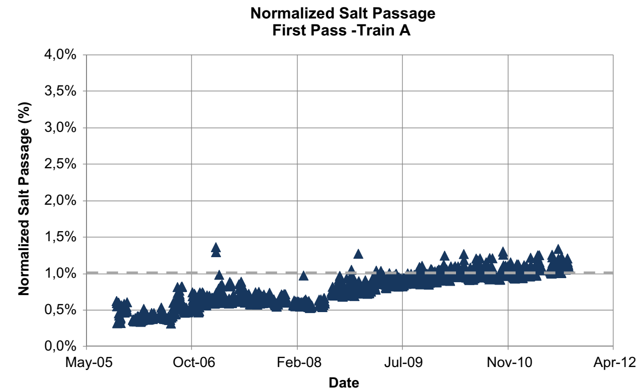

Fig. 6. First pass. Train A. Normalized salt passage.

- Online biocide treatments (DBNPA based), complemented by offline soakings and recirculation.
- Optimized formulated CIPs, now performed not only with commodities, but with formulated cleaning products.

Since then, regular weekly treatments, as well as more aggressive biocide soakings every two months, are performed in all of the first pass trains.

High pH CIPs (pH = 12), are also regularly performed, using a formulated alkaline cleaner.

3.4. *Second pass performance on high pH conditions*

As already discussed, the plant was originally design to comply with the local regulation limit of boron <0.3 mg/L. Thus, alkali was dosed on the second pass feed stream so to attain higher boron rejection.

Bonnelye et al. [9] discussed the trials performed during the plant startup, mentioning values of pH up to 10.1 on the second pass feed, to obtain levels of boron around 0.3 mg/L on the second pass permeate.

Since the local drinking water regulation was modified later on, after the plant startup, and during its history of operation, accepting higher values of boron (0.5 mg/L first, and 1 mg/L later), the pH adjustment was adjusted in consequence. Still, the average pH of the second pass feed stream, for operation at high temperature, is around 9.6.

Despite its operation at high pH, the performance of the second pass elements, in terms of both normalized permeate flow and salt rejection show a stable performance during their operation in almost seven years with no replacement (see Fig. 7).

3.5. *Plant performance and replacement rates*

As already mentioned, because of the special conditions of the plant design and following evolution

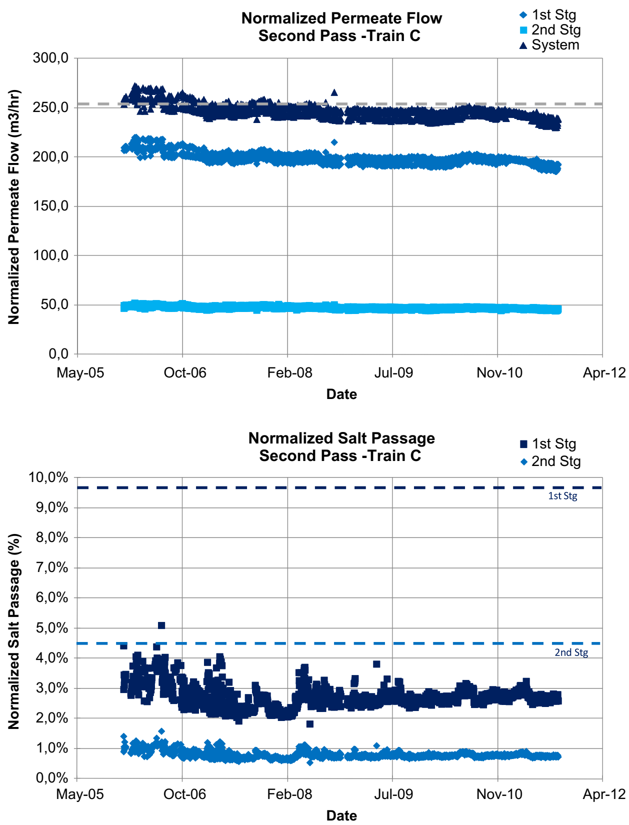

Fig. 7. Second pass. Train C. Normalized permeate flow and normalized salt passage.

of local drinking water regulation, adopting higher requested limits of boron on the final permeate; the plant has been operated during almost seven years without a single element being replaced.

The outstanding long-term performance of both first pass (despite the frequent biocide treatments on and offline, as well as high pH cleanings) and second pass DOW FILMTEC™ RO elements (despite the high pH operation) is still able to provide permeate water largely complying with the requested limits.

3.6. Technological update

If the original design, made in the early 2000s, was performed today, with the current technological know-how (including currently available membrane chemistries and design concepts), savings in both CAPEX and OPEX might be possible.

An updated technical design, observing, from the existing plant, both the operating fluxes of first and second passes, as well as the overall system recovery, might consist in the following:

- First pass including three trains in parallel, each of them using 83 pressure vessels, each of them seven elements DOW FILMTEC™ SW30XLE-440i, with upgraded salt rejection (see Table 3, commercialization started in 2011). A front permeate split might be proposed: 10–17% of the First Pass permeate could be sent to the permeate production tank, while rear permeate would be treated by the second pass.
  Alternatively, an Internally Staged Design (ISD), based on DOW FILMTEC™ SW30XLE-440i and DOW FILMTEC™ SW30ULE-440i might also be proposed.
- Second pass including also three trains in parallel, each of them based on 18 pressure vessels on first stage and six pressure vessels on the second stage, all of them including seven elements DOW FILMTEC™ HRLE-440i type (see Table 3), per pressure vessel. pH adjustment might be performed in between passes, with similar pH values as the original design, so to meet the originally requested value of boron <0.3 mg/L.

In terms of operating pressure, the updated design, based on DOW FILMTEC™ SW30XLE-440i and DOW FILMTEC™ HRLE-440i, would be associated to lower feed pressure for both passes: an average of 1.5 bar less for first pass and an average of 0.9 bar less for second pass, meaning from 2.0 to 4.7% lower specific energy consumption to produce the same quantity and quality of permeate water.

Table 3
Specifications of latest DOW FILMTEC™ RO elements considered for technological update discussion

Element type	Active area ft^2 (m^2)	Permeate flow rate gpd (m^3/d)	Stabilized boron rejection (%)	Stabilized salt rejection (%)
DOW FILMTEC™ SW30XLE-440i[a]	440 (40.9)	9,900 (28.4)	91.5	99.8
DOW FILMTEC™ SW30ULE-440i[a]	440 (40.9)	12,000 (28.4)	89.0	99.7
DOW FILMTEC™ HRLE-440i[b]	440 (40.9)	12,650 (48)	–	99.5

[a]The above values are normalized to the following conditions: 32,000 ppm NaCl, 5 ppm boron, 800 psi (5.5 MPa), 77˚F (25˚C), pH 8 and 8% recovery.

[b]Permeate flow and salt (NaCl) rejection based on the following standard conditions: 2,000 ppm NaCl, 150 psi (10.3 bar), 77˚F (25˚C), pH 8 and 15% recovery.

4. Conclusions

This paper has reviewed the long-term performance of DOW FILMTEC™ elements installed in two seawater desalination installations: Santa Bárbara (Curaçao) and Askhelon (Israel).

By evaluating the operating data of the last 6–7 years of operation, the paper quantifies the evolution of both normalized permeate flow and normalized salt rejection of the various RO passes, and compares the real performances to the expected and/or start-up values.

The paper describes as well some particularly challenging conditions, the RO membrane elements are exposed to: highly fouling potential water feeding first passes and associated frequent biocide and high pH cleanings (Santa Bárbara), relatively frequent high and low pH cleanings of the first pass SWRO membrane elements (Ashkelon), as well as high pH operation for the second pass systems of both plants. Even under these circumstances, the long-term performance of the membrane elements is shown to be outstanding, with associated replacement rates lower than initially expected or even inexistent.

The specific conclusions for each of the studied desalination plants are shown below.

The Ashkelon seawater desalination plant has been a reference installation for the desalination world since the day the project was conceived. The Ashkelon project represented an outstanding milestone in the seawater desalination field in terms of size (the world's first mega-capacity SWRO plant) and process innovation attaining one of the world's lowest ever prices for desalinated water. Ashkelon was started up in mid-2005, and it holds the record of being the large seawater desalination plant which has been longest in operation and it continues supplying drinking water of the highest quality. This paper evaluated in detail the performance of the first and second stage of the cascade process of the plant. The SWRO trains have been meeting or exceeding the designed long-term performance with regard to permeate production and permeate water quality, specially, taking into account that the replacement rates of the SWRO membrane elements have been below the initial design expectations and the majority of the currently operated SWRO membrane elements are six and a half years old. The second-stage performance evaluation confirmed the good and stable performance with regard to permeate production and salt rejection. The six and a half years old membrane elements of the second stage still perform exceeding the stage requirements in terms of salt rejection despite the continuous operation at a feed pH of 10.

Additionally, after an extensive pilot trial, Dow's latest XLE DOW FILMTEC™ seawater RO element (DOW FILMTEC™ SW30XLE-440i) will be installed in the SWRO stage of the Ashkelon plant during the scheduled partial replacement of old DOW FILMTEC™ SW30HRLE-400 elements, during 2012. This demonstrates the continuous focus of ADOM in optimizing energy consumption and installation productivity.

Santa Bárbara (Curaçao), was designed starting 2003, and commissioned in 2005, to serve the drinking water needs of the Island, in the southern Caribbean Sea, off the Venezuelan coast. Since its startup, and thanks to the evolution of boron limits by the local regulation, it has been kept in operation without a single element replaced in more than seven years. This paper illustrates the plant normalized operating data, for both first and second passes, with special emphasis on the stable long-term performances, with regard to permeate production and salt rejection, obtained. These performances have been obtained despite the regular high pH cleanings performed on the first pass, as well as the continuous operation at high feed pH for Second Pass (9,6–10,1 for high temperature operation).

Following the evaluation of the existing elements performance and after an extensive technical study, Dow's latest XLE DOW FILMTEC™ seawater RO element (DOW FILMTEC™ SW30XLE-440i) has been, once again, proposed for the future partial replacement of old DOW FILMTEC™ SW30HRLE-380 elements, as well as for the expansion of first pass capabilities, during 2012.

The successful and smooth long-term performance of over 43,000 DOW FILMTEC™ elements at Ashkelon desalination plant and almost 2,500 DOW FILMTEC™ elements at Santa Bárbara (Curaçao) can be attributed to a number of key elements: proper and efficient plant design, reliable and robust membrane chemistry and element construction, continuous monitoring, excellent operating discipline based on extensive operating experience, and effective preventative maintenance.

5. Industry data and product information

The industry data provided in this article were collected from 2005 until the first quarter of 2012 and are included to illustrate the long-term field experiences with DOW FILMTEC™ TM RO systems 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.

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References

[1] FILMTEC™ Elements Still Delivering Outstanding Performance After 15 Years In Service. Dow Case History. Available from: http://www.dow.com/scripts/litorder.asp?filepath=liquidseps/pdfs/noreg/609-02138.pdf.
[2] M. Taub, First year performance of the Ashkelon plant, in: Israel Desalination Society Conference IX, December 2006.
[3] B. Liberman, Pressure center and boron removal at Ashkelon desalination plant, in: IDA 2003 World Congress on Desalination and Water Reuse, September 28–October 3, 2003.
[4] A. Gorenflo, M. Brusilovsky, M. Faigon, B. Liberman, High pH operation in seawater reverse osmosis permeate: First results from the world's largest SWRO plant in Ashkelon, in: Euromed Conference. Montpellier, France, May 2006.
[5] V. García Molina, M. Taub, L. Yohay, M. Busch, Long term membrane process and performance in Ashkelon Seawater Reverse Osmosis Desalination plant, in: Euromed Conference Tel Aviv, Israel, October 2010.
[6] Israel Patent IL141642; European Patent EP1363856; US Patent US20040094480A1.
[7] J. Redondo, M. Busch, J.P. De Witte, Boron removal from seawater using FILMTEC™ high rejection SWRO membranes, Desalination 156 (2003) 229–238.
[8] The Dow Chemical Company, FT-Norm, Midland, 2012 Available from: http://www.dowwaterandprocess.com.
[9] V. Bonnelye, H. Gouverneur, M.A. Sanz, L. Francisci, J. Laraudogoitae, G. Cremer, Curacao desalination plant: One-year operation 2d-pass boron removal at high pH, in: IDA World Congress, Maspalomas, Gran Canaria, Spain, October 2007.
[10] M. Dorival, J. Maduro, M. Pereira, A. Hallsby, D. Lopez, Long-term operation of the Santa Barbara—Curaçao seawater desalination plant, in: IDA World Congress, Dubai, November 2009.