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# Santa Barbara, Curacao desalination plant expansion using Nano$H_2O$ thin film nanocomposite (TFN) SWRO membrane

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ABSTRACT

The Santa Barbara desalination plant, located in the South of the Curacao Island, was built and commissioned by Degrémont in 2005. The plant production capacity was 18,000 $m^3$/d—consisting of three double-pass trains—which supplied about 45% of the average drinking water consumption of the Island. However, to fulfill the increasing demand of potable water, the plant owner, Aqualectra, added a fourth train to produce 7,100 $m^3$/d, totaling a production capacity to 25,100 $m^3$/d. The new train is single-pass and its product blends with the product from the other three trains. Based on an innovative technical approach, Aqualectra and Degrémont awarded Nano$H_2$O the supply of the seawater RO membranes for the fourth train. The proposed membrane design by Nano$H_2$O offered the following: (i) 29% less SWRO elements per train than the existing first-pass trains; reducing the number of pressure vessels from 92 to 65; (ii) the same operating feed pressure as the existing first-pass trains while the system flux is significantly higher; (iii) better product quality than the first-pass product from the existing trains. The membrane design consists of a hybrid design where two low-flux (6,500 gpd) elements, *Q*fx SW 400SR and five higher flux (9,000 gpd) elements, *Qfx* SW 400R are internally staged within the pressure vessels. The new train was commissioned in September 2012 and accepted by Aqualectra the following month. After more than one year of continuous operation, the train performance has been stable and meets all of Aqualectra's requirements. The product has delivered a TDS concentration below 300 ppm. This represents a 40% product quality improvement when compared with the first-pass of the original three trains that carry older competitor membranes. This installation showcases the potential benefits of using low and higher flux membrane in a hybrid configuration to significantly increase the system flux, and lower capital and operational expenses when compared with traditional designs with conventional membranes.

*Keywords:* Seawater reverse osmosis; Thin film nanocomposite (TFN); Capital expenses; Operational expenses; System flux

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## 1. Background

Along with the development of new seawater RO membranes, system designers are finding ways to optimize system performance by lowering energy consumption, increasing output, or improving product water quality. One of the widely spread approaches to optimizing system performance is the use of hybrid membrane designs. The concept involves the internal staging of different RO element models, with different specification characteristics, within the pressure vessel. The typical configuration consists of placing low-flux elements in the lead positions—feed end—of the pressure vessel and higher flux ones in the rear, tail end. Fig. 1 shows the graphs of projected flux of each element in the vessel, position 1 being the lead position.

With a conventional SWRO single-stage design using one type of element, the element flux decreases as the element approaches the rear end of the pressure vessel (see curves with circle and square shaped dots). The reasons for this decline are the increase in the feed salinity and the decrease of net driving pressure when moving from the feed to the tail end. As a result, the lead element experiences the highest flux and has the highest risk of fouling.

When the system/average flux increases from 8 to 10.3 gfd by reducing the number of pressure vessels or by increasing the product capacity, the curve shifts up and the lead element flux approaches the maximum flux limit allowed by membrane manufacturer.

In comparison, the hybrid design allows the lead element flux to stay close to the one of the conventional design at 8 gfd while running at a higher system flux (see curves with triangle shaped dots). The graph demonstrates the disruption in the element flux curve—between element 2 and 3—caused by the use of different types of element—allowing the more balanced distribution of the flux [1,2].

The hybrid design can be employed to:

- Increase the production capacity.
- Reduce the number of elements and pressure vessels used in a system.
- Lower the feed pressure and energy consumption.
- Reduce the risk of fouling.

Degrémont and Aqualectra have used this approach to reduce the number of installed pressure vessels on this additional first-pass rack, while keeping both the same production capacity and operating feed pressure when compared with the existing ones. After comparing the Nano$H_2O$ membranes with others on the market, Nano$H_2O$ provided the best option to fit in the actual configuration and without jeopardizing the finished water quality.

This decision together with the advantages of this membranes resulted in a lower CAPEX due to less installed pressure vessels, less installed membranes and, on top of that, producing the same amount of permeate as the existing first-pass racks. The extra available spare spaces in train D will give the flexibility of the owner either to expand production or reduce the energy consumption further if the local regulation evolves in the future.

## 2. Santa Barbara plant design and operation

Curacao is an island north of Venezuela. With a population of 152,800 inhabitants and 461 $km^2$, it is the largest and most populous island of the Netherlands Antilles, West Indies. Curacao is semiarid; most

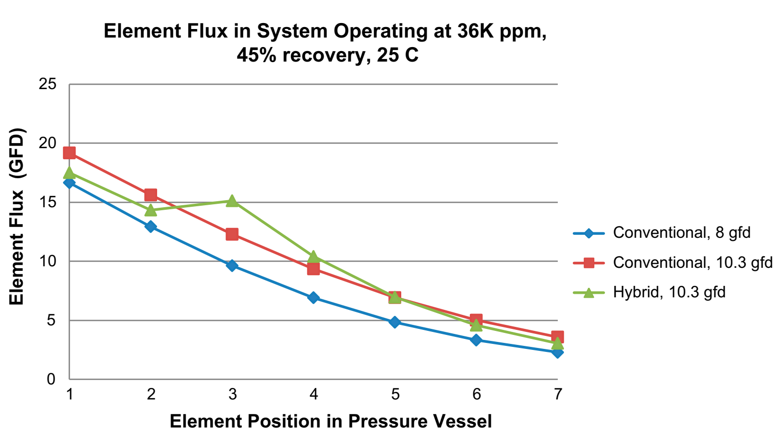


Fig. 1. Element flux vs. element position in a pressure vessel.

of the island life is of desert character. Oil refining is the principal industry, and the island has one of the world's largest refineries, receiving oil from the enormous reserves at nearby Lake Maracaibo, Venezuela. Other major industries include tourism and ship repairing. Curacao's ship-repair dry dock is one of the largest in the Americas.

With an average precipitation of approximately 500 mm, rainwater is the only natural source of freshwater. A large part of the rainwater that falls during a few days per year evaporates or flows away to the sea. Due to the growing shortage of drinking water, and the increasing demand, the Government took steps in 1928 to start desalting seawater for the production of drinking water in Curacao. The technologies were initially based on evaporation and moving forward to co-generation power-drinking water. After several experiences with the reverse osmosis technology in the 1990s, Aqualectra took the decision to move forward with this technology and in 2003 started a project for the design built of an 18,000 $m^3$/d seawater reverse osmosis desalination plant [3].

### 2.1. Santa Barbara original SWRO plant

Curacao drinking water is produced from seawater, using reverse osmosis and evaporation technologies. The Santa Barbara Desalination Plant in Curacao was commissioned at the end of 2005 and is being operated by its owner, Aqualectra formerly known as Integrated Utility Holding. It is located at the east end of the island of Curacao, providing water for approximately half of the island, and is designed to serve the growing tourism industry on this part of the island.

With a capacity of 18,000 $m^3$/d, this plant was designed on a seven-stage treatment line including infiltration-type intake (kind of beach well, with average silt density index, SDI, of lower than 1), multimedia filtration (as the plant was originally designed considering an open intake source), cartridge filters, desalination on a "full two-pass" reverse osmosis system for total dissolved solids, TDS and boron removal, UV, remineralization through calcite filters, granular activated carbon, and final chlorination before storage and distribution (Fig. 2) [3].

It was one of the first full-scale plants in operation applying stringent regulation including TDS below 150 mg/L after remineralization and boron maximal concentration not exceeding 0.3 mg/L. To do so, the first-pass RO consisted of three parallel trains, each with 92 vessels, seven elements per vessel and the second-pass had three trains too, each with 27 vessels (2:1 staged), seven elements per vessel.

### 2.2. Santa Barbara SWRO plant expansion

Due to increasing water demand on the island, an expansion of the RO plant was a necessity. The expansion took place in 2013 and increased the total water production capacity from 18,000 to 25,000 $m^3$/d. Due to the revised Water Quality Policy where the boron and TDS levels were increased from 0.3 to 1 ppm and from 150 to 200 ppm, respectively, the permeate production of the additional rack is not processed into a second-pass but it is the blended directly with the final products from other trains while maintaining the product within specification. Degrémont has been awarded to install a single-first rack with a capacity of 7,100 $m^3$/d.

As the existing plant was already designed and even some parts of the plant like the intake, outfall, and control system were already in place, the extension is based on a "copy—paste" principle of the existing first rack with the exception of the membranes. The infiltration-type intake as well as the pretreatment units was not modified, meaning that the filtration velocity was increased due to the extension without any negative impact on the pretreated water quality.

This allowed for an increase in the overall water conversion 40–41%, and for a slight reduction of the specific energy consumption of the plant. A hybrid configuration with Nano$H_2O$ reverse osmosis membranes was selected leading to less pressure vessels and obtaining the same plant output (Fig. 3).

Having the Santa Barbara extension in operation, integrated with the existing SWRO plant at Mundo Nobo Water and Power plant, the total production of potable water by Aqualectra using RO technology is 70% nowadays, where the remaining production capacity of 30% is produced using evaporator units (MSF and MED plants). Aqualectra is contemplating to decommissioned evaporator units in the upcoming years. This will yield in a drinking water production capacity of 52,000 m/d with an average water demand of 36,000 m/d.

With Santa Barbara in operation and integrated with the existing SWRO plant at Mundo Nobo Water and Power plant, the total production of potable water by Aqualectra using RO technology will be 100%.

### 2.3. Train performance

By late 2012, the additional fourth train, D, and the existing three trains were online and producing water. The average performance of each train at one year average-membrane-age (first year of operation) is outlined in Table 1. Historical data of Train A, B, and C

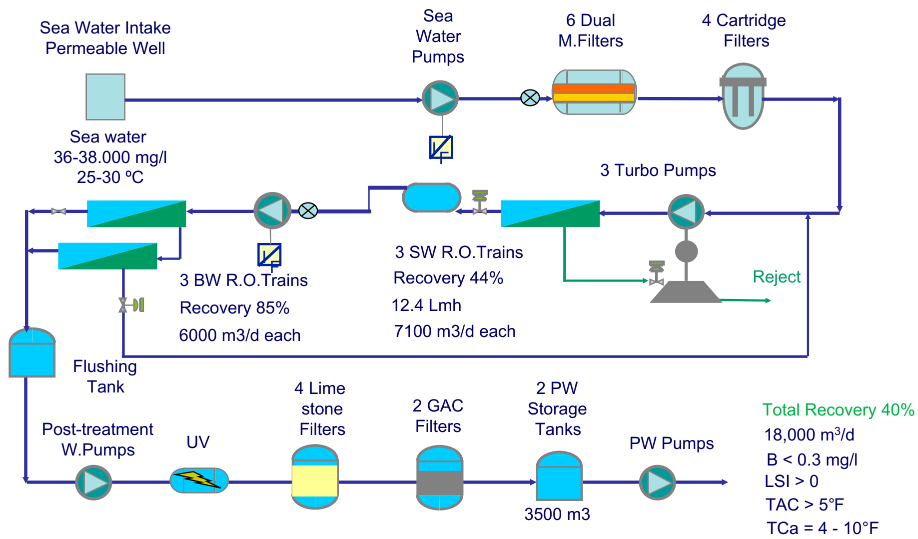


Fig. 2. Santa Barbara original plant design.

during their first year of operation are compared with the current performance of Train D.

All four trains are fed by the same feed water at a salinity of about 35,000 ppm. Each train runs at 44% recovery producing 300 $m^3$/h.

However, the Train D operates with 27 less pressure vessels than the three original trains. This represents a 29% reduction in elements used and results in an increase of the average flux by 40% (10.5 gfd) of Train D.

Despite the higher average flux, the combination of two low-flux (6,500 gpd) nanocomposite elements, *Qfx* SW 400SR and five higher flux (9,000 gpd) elements, *Qfx* SW 400R, of the hybrid design allows the train to operate a similar transmembrane pressure (52 bar) as the original trains during the first year of operation.

The product of Train D is below the required 300 ppm; it is sent directly to the final product tank where is blended with the second-pass product of Train A, B, and C.

Table 1
Comparison of operating data

| | Unit | Train A–C | Train D |
|---|---|---|---|
| *Operating conditions* | | | |
| RO Feed TDS | ppm | ~35,400 | ~35,400 |
| Temperature | ℃ | 27.0 | 27.0 |
| Production capacity | $m^3$/h | 300 | 300 |
| Recovery | | 44.00% | 44.00% |
| Average flux | gfd | 7.4 | 10.5 |
| *SWRO design* | | | |
| # PV | | 92 | 65 |
| # Element per PV | | 7 | 7 |
| Element configuration | | Element A | Hybrid design<br>(2) Qfx SW 400 SR<br>(5) Qfx SW 400 R |
| *Performance* | | | |
| TDS | ppm | <350 | <295 |
| Transmembrane pressure | bar | ~52 | ~52 |

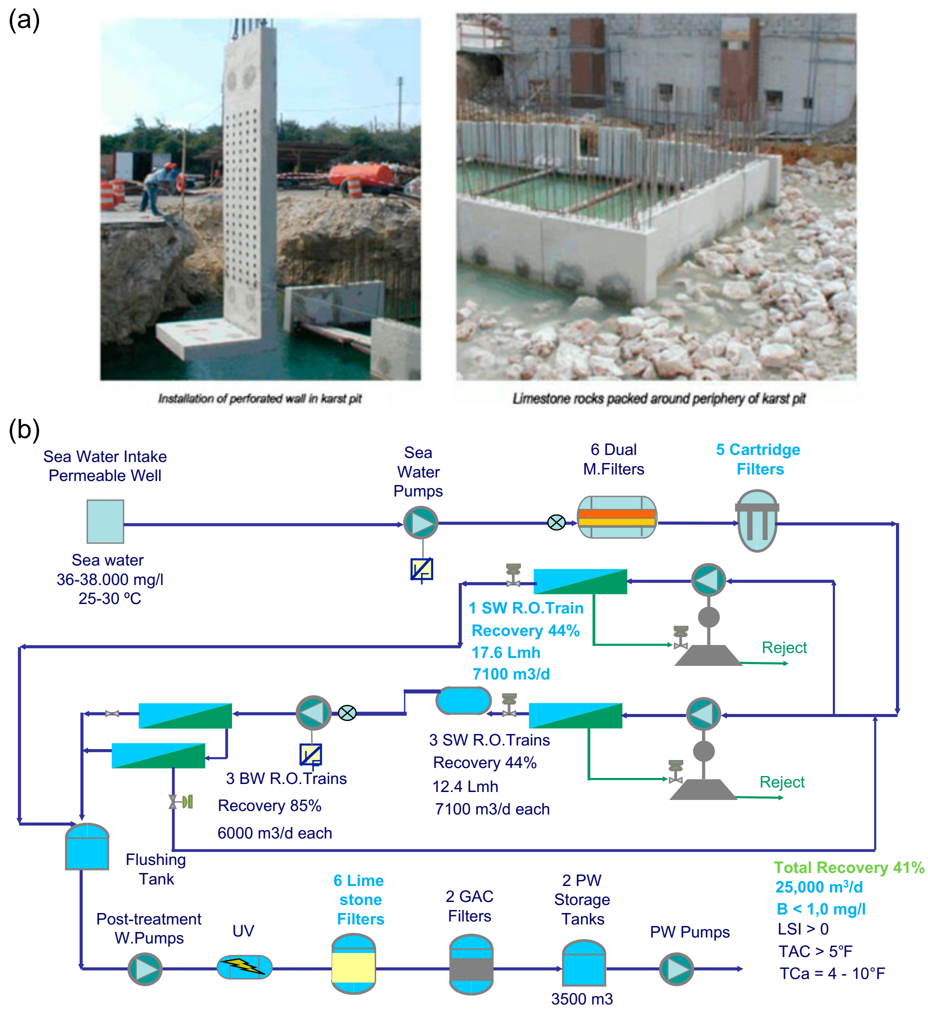


Fig. 3. (a) Beach well construction and (b) upgraded design of the plant after extension of its production capacity.

## 3. Results and discussion

A common risk of running a SWRO system at such high average flux with a conventional system is fouling the elements—primarily the lead elements. Fouled elements affect the system performance by increasing of the differential pressure, feed pressure, and salt passage.

However, the hybrid design used by Nano$H_2O$ on Train D can minimize the fouling and the data below demonstrates the system performance over one year of operation and without clean-in-place, CIP [4].

### 3.1. Differential pressure

Fig. 4 shows the graph of the differential pressure on Train D over a one-year period. The differential pressure is defined by the feed pressure minus the brine pressure. The slow increase (10%) from 1.35 to 1.5 bar is less than the 25% limit that membrane manufacturers typically use to recommend a cleaning.

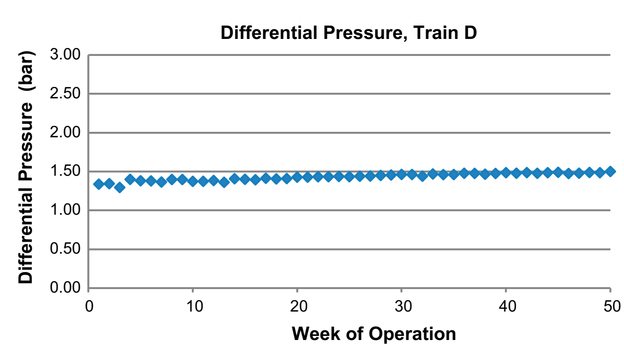


Fig. 4. Evolution of the differential pressure.

### 3.2. Salt passage and product quality

The system salt passage is the ratio of the product TDS over the RO feed TDS. The value is normalized with respect to the initial stabilized performance at startup. The graph of the normalized salt passage over the one year of operation (Fig. 5) indicates a slow increase from week 10 to week 50; the percent increase is about 5%.

Overall, the salt passage is very low and translates to a system salt rejection of about 99.1%.

Fig. 6 shows the product TDS fluctuates around 260 ppm. The consistency of the product quality delivered by train D is explained by the stability of the nanocomposite element performance (salt passage) and the constancy of the operating conditions (feed salinity and temperature) throughout the year.

### 3.3. Pressure and production capacity

The transmembrane pressure is the difference between the feed pressure and the permeate pressure. The transmembrane pressure is reported instead of the feed pressure in order to account for any variation of the permeate pressure. Indeed, because the high-pressure pump is set to deliver a constant feed flow at 55 bar, any changes in the feed pressure demand is adjusted on the permeate backpressure.

The normalized permeate flow varies between 300 and 315 $m^3/h$ while the transmembrane pressure remains constant at around 52 bar. The results demonstrate that the permeability of the nanocomposite elements is stable over the one year of operation (Fig. 7).

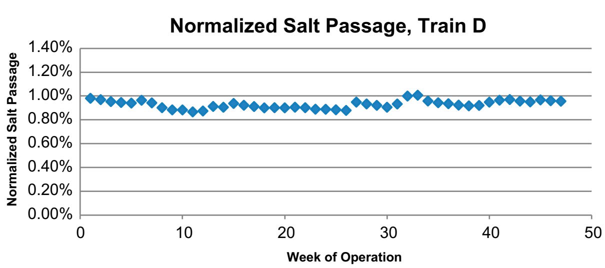


Fig. 5. Evolution of the normalized salt passage.

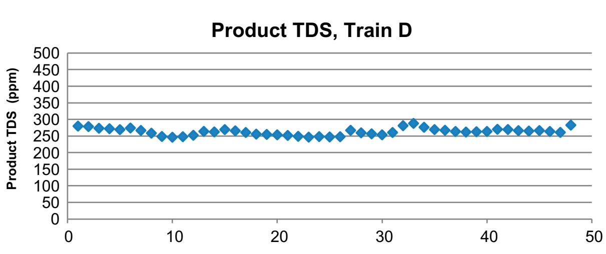


Fig. 6. Evolution of the product TDS.

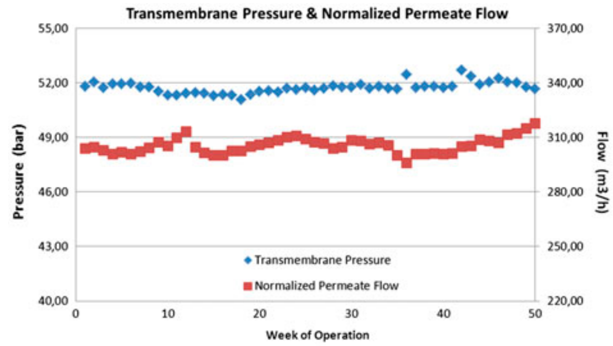


Fig. 7. Evolution of the transmembrane pressure and normalized permeate flow Train D.

## 4. Conclusion

Based on an innovative technical approach, Aqualectra and Degrémont awarded Nano$H_2O$ the supply of the seawater RO membranes for the Train D. The membrane design and operation proposed by Nano$H_2O$ offered the following:

- 29% less SWRO elements per train than the existing first-pass trains; reducing the number of pressure vessels from 92 to 65.
- The same operating feed pressure as the existing first-pass trains while the system flux is significantly higher.
- Better product quality than the first-pass product from the existing trains.
- Relative stability of the salt passage and permeability of the elements despite the system running at a higher average flux.

This installation at Santa Barbara Curacao showcases the benefits of using low and higher flux nanocomposite membrane in a hybrid configuration to significantly increase the system flux, and lower capital without compromising the product quality and the performance stability over time.

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