Energy Savings using Seawater Nanocomposite Membranes: Las Palmas III (EMALSA) Pilot Test Example

Robert L. Burk, C.J. Kurth, David Kim-Hak
rburk@nanoh2o.com; cj@nanoh2o.com ; dkim-hak@nanoh2o.com

Introduction

Reverse osmosis is the leading process for brackish and seawater desalination and is gaining rapid acceptance for freshwater purification and water reuse. Sufficient pressure applied to a saline solution forces water through a semi-permeable membrane that rejects salt and other contaminants. Membrane permeability and fouling resistance are key economic drivers for membrane-based water treatment systems. Membrane performance characteristics translate directly to the energy intensity and capital expenditures of an RO system and therefore to the economics of desalination. Accounting for 70-80% of the total expense of seawater RO desalinated water (USBR, 2003), energy consumption and capital expenditures are the primary reasons why desalination is still considered more costly than most other freshwater sources.

In 2007, the use of thin-film nanocomposite membranes for water purification was first described for brackish water reverse osmosis (BWRO) membranes (Jeong, 2007). In that work, zeolite nanoparticles were dispersed in the organic solution of an interfacial polymerization reaction. Because polymerization proceeds in the organic solution, nanoparticles present near the aqueous-organic interface became incorporated within the polyamide layer. Incorporation of such nanoparticles into a BWRO membrane formulation increased permeability and altered surface properties implicated in fouling, while maintaining salt rejection.

Since the original publication of the nanocomposite membrane concept, further efforts have developed and optimized nanocomposite membrane technology for seawater reverse osmosis (SWRO) (Kurth et.al. 2009; Kurth et.al. 2011), known commercially as QuantumFlux (Qfx) membranes. Membrane performance data, using industry-standard element testing, demonstrates that 20 cm (8-inch) Qfx membrane elements with 37.2 m^2 [400 ft^2] membrane area exhibit industry-leading flux of 51.9 m^3/day [13,700 gfd] and salt rejection at industry standards of 99.8%. Recent adjustment of the Qfx chemistry allowed production of Qfx membranes with salt rejection above industry standards. Newer higher rejection membranes are available at lower flux 24.6 and 34 m^3/day (6,500 and 9,000 gpd) and salt rejection of 99.85% to meet the demands of desalination plants with warm high salinity waters and hybrid-staged designs.

Benefits

For most membrane materials, chemical formulation can be adjusted to trade flux for selectivity; this also holds true for nanocomposite membranes. The red squares in Figure 1 show the water and salt transport coefficients for commercially available thin-film composite (TFC) membranes. The addition of nanoparticles in the highest flow nanocomposite membrane (ES) results in increased permeability with the same salt transport coefficient. By adjusting the formulation, higher selectivity products R and SR were developed and demonstrate the overall improved Qfx performance curve (blue diamonds in Figure 1).

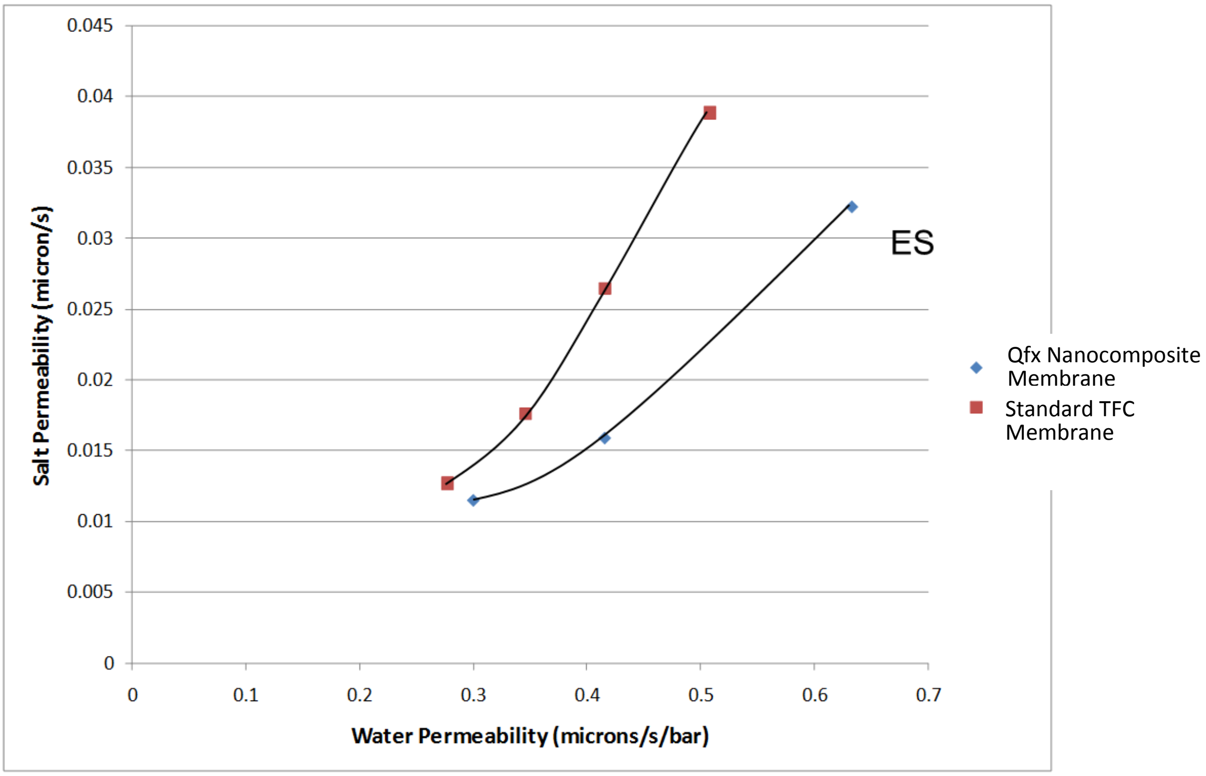

Figure 1. Performance curve comparing salt permeability and water permeability for conventional thin-film composite membranes (red squares) and Qfx nanocomposite membranes (blue diamonds).

Hypothetical Modeling Data

Increasing per-Vessel Water Production

At many locations there is an incentive to increase the amount of permeate produced from each vessel. There are two main factors which have limited such increased production rates. The first has been because of material limitations. Increased water production can be accomplished by increasing feed pressure, but this comes with the cost of increased energy consumption. Higher permeability materials can allow increased production without increased feed pressures, but only if rejection is sufficiently high to maintain water quality. The new high rejection QuantumFlux elements address this material limitation.

The second factor is because of concern about increased fouling rates that occur at high flux rates. One means to mitigate this concern is through the use of hybrid-staged designs. These designs use a blend of membrane permeabilities in a single pressure vessel to maintain a relatively flat flux through each element, thus allowing higher system capacity while keeping maximum element flux low. This is demonstrated for a hypothetical system modeled using Q+ design software. In this system three scenarios were considered using various element configurations and keeping a constant maximum element flux. Using lower flux SR and R elements followed by high flux ES elements in this example (a 1,400 m3/day plant running at 45% recovery on a 38,000 ppm feed water at 27°C) allows maximum element flux to be kept the same while system capacity is increased by 40%, by more evenly distributing the permeate production by elements throughout the vessel.

Table I. Model Data Showing the Advantage of a Hybrid-Staged Design Solution

Elements per Vessel	Element Type	System Capacity (m^3/d)	System Pressure (bar)	Permeate Salinity (ppm)	Average Element Flux (lmh)	Maximum Element Flux (lmh)
7	28.4 m^3/d	1000	55.1	248	13.4	26.7
7	Qfx SR + Qfx R	1250	56.9	165	16.7	26.7
7	Qfx SR + Qfx ES	1400	56.3	239	18.7	26.6

Performance Data: Las Palmas III Pilot Test Example

The hybrid-staged design strategy, described in general with hypothetical modeling data above, underwent pilot testing by EMALSA in the Canary Islands. Installed in late 2011, it utilizes older commercial nanocomposite Qfx 31.1 m^3/d and Qfx 20.7 m^3/d elements in the same pressure vessel (Figure 2). Both element types had an active area of 34 m^2 (365 ft^2). The plant has 10 modules with a total production of 80,300 m^3/day. Each module has 2 stages with an interstage booster pump. Each pressure vessel has 6 elements (Sadwhwani & Vesa, 2008). The pilot vessel is part of the second stage. After 200 days of operation of the pilot, water production for the QuantumFlux containing vessel has consistently been 50% higher compared to conventional elements running at the plant. Throughout this time system pressure was stable (Figure 3) and water quality was improved compared to the competitor membrane elements. Newer Qfx elements now an active area of 37 m^2 providing 24.6 m^3/day (6,500 gpd) for the Qfx SW400 SR and 34 m^3/day (9,000 gpd) for the Qfx SW400 R elements.

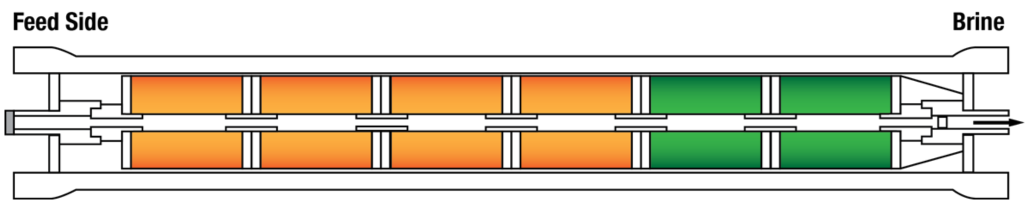

Figure 2. Staged design used for the Las Palmas III pilot includes 4 Qfx SW365 SR and 2 Qfx SW365 R elements.

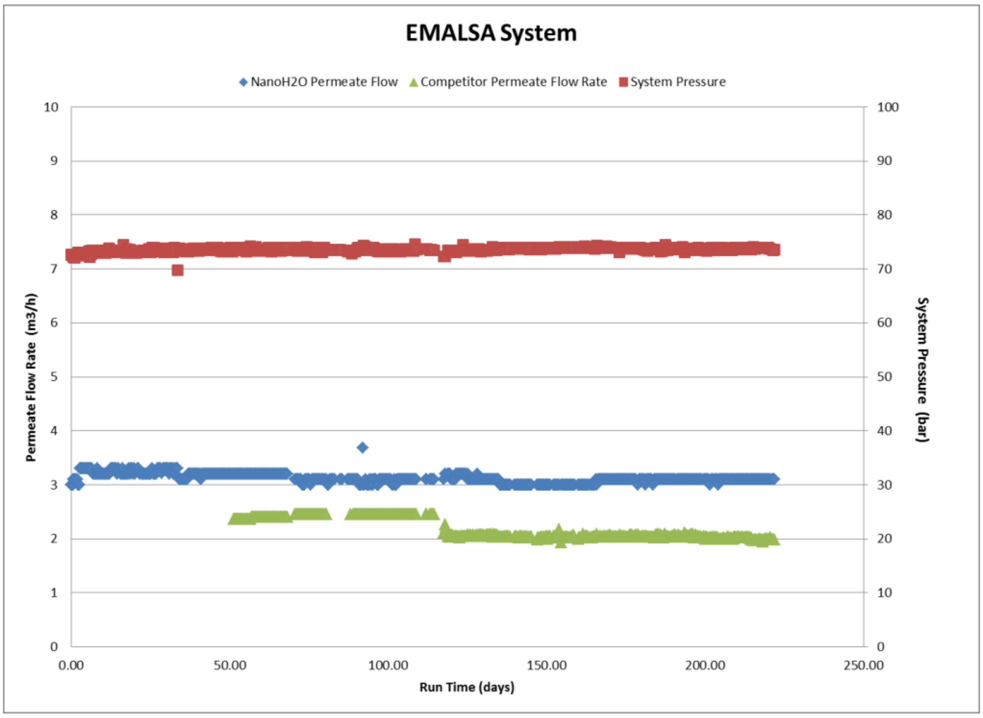

Figure 3. Stable permeate flow rate and system pressure during a 200-day period at the Las Palmas III pilot.

Feed salinity in the second stage averaged approximately 59,000 ppm (TDS) and temperature ranged from 22-25°C. Permeate flow ranged from 3.3 to 3.2 m^3/hr. and system salt transport was stable with a b-value of approximately 1.5 x 10^{-8} m/sec (Figure 4). Initial boron values in the feed were 6.9 mg/l and 0.8 mg/l in the permeate. Average feed pressure was 72.5 bar, consistent within one bar of the Q+ projection software used to model this plant, and stable over the test period. System recovery was 25%.

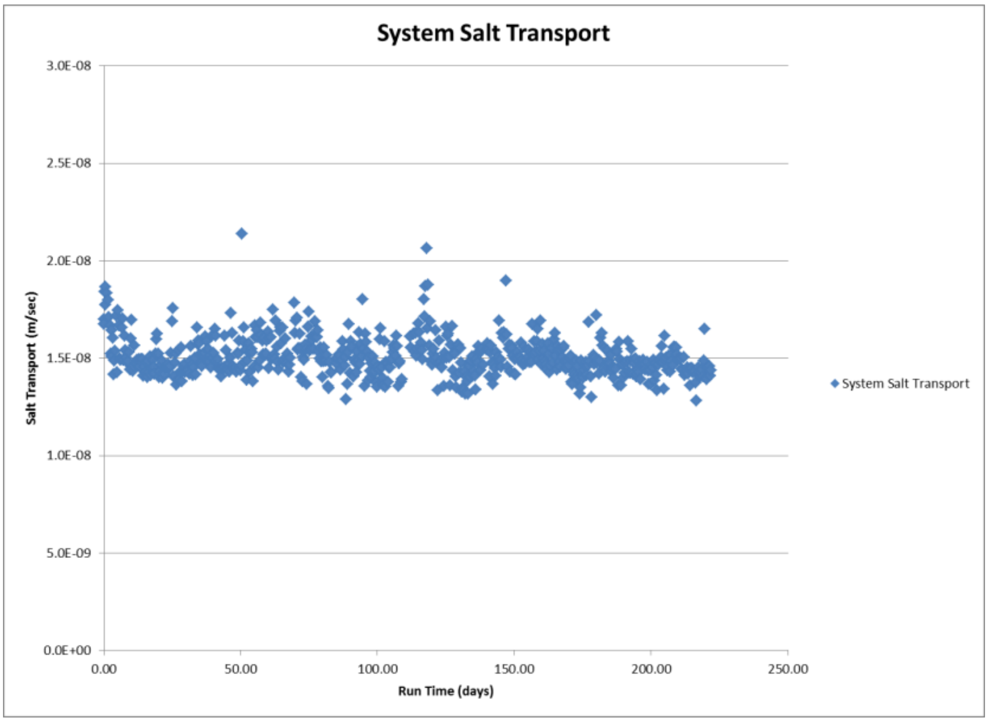

Figure 4. Las Palmas III pilot system salt transport expressed as b-value.

Conclusions:

Use of nanomaterials in the thin film of polyamide membranes enhances flux as has been previously demonstrated (Kurth et.al. 2011; 2009). Further adjustment of nanomaterial chemistry has resulted in lower permeability membranes with higher salt rejection values. As advances continue to be made in using nanomaterials to increase salt rejection, these membranes have the ability to improve the economics of desalination by increasing water quality and, in some cases, avoiding the need for a second pass. The data from field locations further demonstrates the ability of nanocomposite membranes to advance the performance limits imposed by standard polyamide chemistry.

References:

Jeong B.H., E.M.V. Hoek, Y. Yan, A. Subramani, X. Huang, G. Hurwitz, A.K. Ghosh, and A. Jawor, 2007, Interfacial polymerization of thin film nanocomposites: a new concept for reverse osmosis membranes. Journal of Membrane Science 294, 1-7.

Kurth C.J., R. Burk, and J. Green, 2011, Utilizing Nanotechnology to Enhance RO Membrane Performance for Seawater Desalination: IDA World Congress Perth, Australia

Kurth C.J., R. Burk, and J. Green, 2009, Leveraging nanotechnology for seawater reverse osmosis. IDA World Congress.

Sadwhwani, J.J. and J. M. Veza, 2008, Desalination and Energy Consumption in Canary Islands. Desalination 221, 143-150.

U.S. Bureau of Reclamation and Sandia Laboratories, 2003, Desalination and water purification technology roadmap. Springfield, Virginia.