LOW PRESSURE APPLICATIONS OF THIN FILM NANOCOMPOSITE (TFN) MEMBRANES

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Abstract

Over the past several years, Thin-Film Nanocomposite (TFN) membrane technology has been proven to provide improved permeability and selectivity in seawater desalination applications leading to reductions in energy consumption and increases in plant productivity. However, TFN technology was originally conceived not as a means to alter flux/selectivity, but rather as a method to change surface properties related to fouling. Further, the change in these surface properties was originally demonstrated in Brackish Water Reverse Osmosis (BWRO) membranes, not in Sea Water Reverse Osmosis (SWRO) membranes. In the original paper describing TFN RO membranes and the inclusion of zeolite Linde Type A (LTA), nanoparticles were found to increase hydrophilicity, increase the negative surface charge, decrease surface roughness and increase permeability.

Although the initial commercial introduction of TFN technology has occurred through the SWRO membrane product line, work has continued on the extension of this technology to other water types; specifically brackish water, industrial effluent and process streams, waste water, ground and well water.

This paper presents data showing how the application of TFN RO membrane technology can lead to improvements in the permeability and selectivity of low pressure RO membranes; and, how those improvements influence low pressure system performance through pilot testing. In particular, TFN membranes will be examined in low salinity waters to show how alterations of the membrane structure (charge, hydrophilicity, roughness) can be used to improve system performance.

Introduction

Over the past several years, Thin-Film Nanocomposite (TFN) membrane technology has become a proven technology for improved permeability and selectivity in seawater desalination applications leading to reductions in energy consumption and increases in plant productivity. However, TFN technology was originally conceived not as a means to alter flux/selectivity, but rather as a method to change surface properties related to fouling. Further, the change in these surface properties was originally demonstrated in brackish water reverse osmosis (BWRO) membranes, not in seawater reverse osmosis (SWRO) membranes. In the original paper describing TFN RO membranes and the inclusion of zeolite Linde Type A (LTA), nanoparticles were found to increase hydrophilicity, increase the negative surface charge, decrease surface roughness and increase permeability.

Although the initial commercial introduction of TFN technology has occurred through the SWRO membrane product line, work has continued on the extension of this technology to other water types; specifically brackish water, industrial effluent and process streams, waste water, ground and well water. This paper presents data showing how the application of TFN RO membrane technology can lead to improvements in the permeability, selectivity, and stability of low pressure RO membranes. The qualification of the TFN membrane under low pressure applications occurred in 2 phases:

- Third party BWRO test under standard conditions
- Pilot test at a commercial plant under actual BWRO conditions

Experimental Approach

1) *Third Party Independent Testing*

Avista Technologies was contracted to conduct the BWRO testing on 8-inch elements rolled with NanoH_2O TFN membranes. Five elements were sent to Avista's facility in San Marcos, CA and each of them was subject to the following testing conditions for one hour:

- 2000 ppm of NaCl
- 225 psi of feed pressure
- 15% recovery
- pH: 8
- 25° C

As a control, a competitor's BWRO Thin Film Composite (TFC) element was selected with data-sheet performance of 10,500 gpd and 99.5% salt rejection at the testing conditions described above.

2) *Pilot Testing at Lahat Station, Israel*

A pilot plant was identified at the Lahat station, located in Israel (Figure 1) where an existing commercial plant treats ground water with total dissolved solids (TDS) of 2900 ppm. The treatment process consists of a 5 micron cartridge-filter followed by a double-stage RO system.

Figure 1: Location of Lahat Station BWRO plant

Figure 2 depicts the treatment process scheme at Lahat Station. The raw water is pumped from the well and dosed with antiscalant. In the case of the feed water pH being higher than 7.4, acidification by HCl injection is applied to lower the pH to 7.2. Dosed feed water is then filtered through 5-micron cartridge filters to remove any suspended solids. The high pressure pump, controlled by a VFD, feeds the RO first stage (1S) and the 1S brine is delivered to the second stage (2S) by an inter-stage booster pump, also controlled by VFD.

A single eight-element long pressure vessel serves as the pilot unit discussed in this study. It shares the same feed as 2S as depicted in Figure 2. A full set of instrumentation around the pilot pressure vessel allows flows, pressures and conductivity measurements.

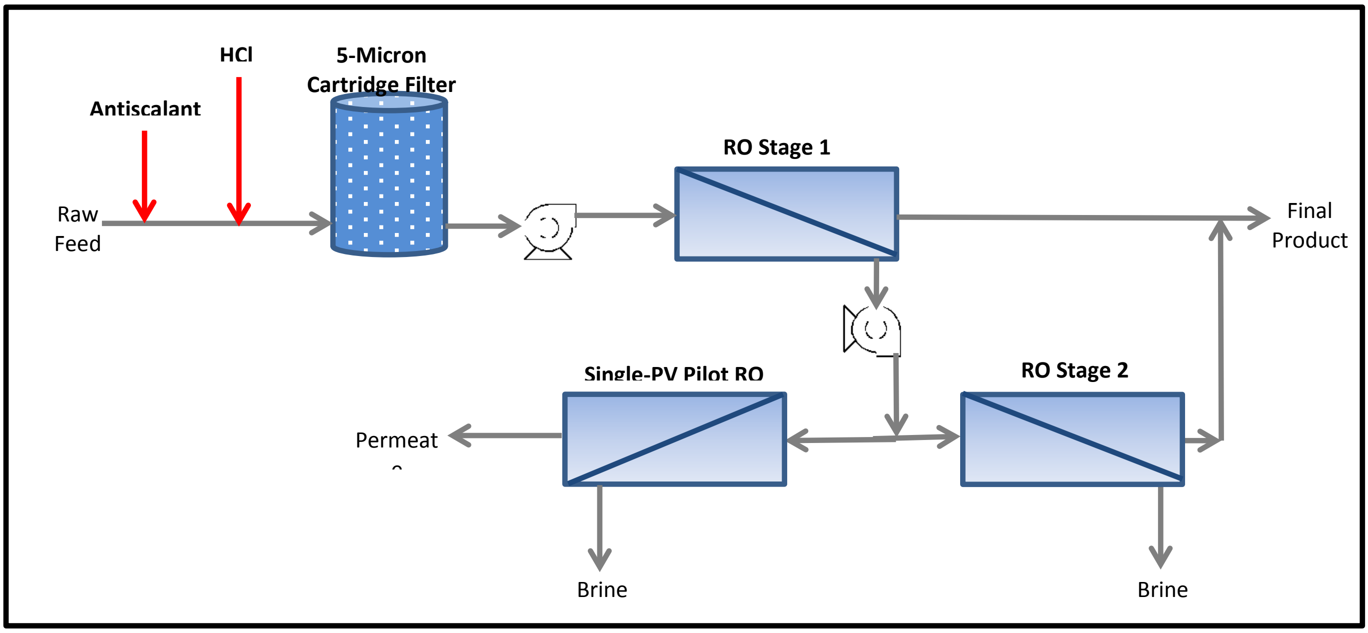

Figure 2: Lahat Station Process

Test Results and Discussions

1) *Third Party Independent Testing*

The results of the Avista tests are tabulated below.

Table 1: Avista Test Element Test Results:

NanoH$_2$O Element	Element Flow (gpd)	Rejection (%)
TFN Element #1	10068	99.82%
TFN Element #2	10129	99.74%
TFN Element #3	10864	99.75%
TFN Element #4	10887	99.60%
TFN Element #5	10270	99.81%
Average	**10416**	**99.75%**
Standard Deviation	365	0.079%
Competitor Element*	11264	99.38%

**Data sheet specifications: 10,500 gpd, 99.5%*

The measured element flows of the TFN elements are consistent with an average value of 10,416 gpd and a standard deviation of 365 gpd. The average rejection is 99.75%. The control element performed at a lower salt rejection (99.38% vs 99.5) and higher flux (11,264 gpd vs 10,500 gpd) than the data-sheet performance.

Based on the test results, the TFN elements provide one of the highest available element salt rejections with 99.75% among the BWRO TFC elements while the element flux compares well with the TFC membranes.

2) *Pilot Testing at Lahat Station, Israel*

The NanoH$_2$O TFN elements were loaded into the pilot unit on May 26th, 2013 and ran continuously for 50 days. The operators recorded one set of measurements on a daily basis. The operating conditions at the startup are presented in Table 2.

Table 2: Startup Operating Conditions

Temperature (°C)	Feed	26.4
Flow (m3/h)	Feed	10.5
	Brine	3.9
	Permeate	6.6
Syst. Recovery		63%
Syst. Flux (LMH)		22.2
Pressure (bar)	Feed	11.95
	Brine	10.66

	Permeate	0
Conductivity (µS/cm)	Feed	5,790
	Brine	12,221
	Permeate	52

Figure 3 and 4 show the normalized data collected on the pilot unit: the normalized permeate flow and salt passage of the pilot pressure vessel. Normalization was undertaken using the ASTM D4516 method.

The normalized permeate flow was stable and fluctuated between 6.2 to 6.5 m^3/hr. The normalized salt passage is consistent at about 0.925%; this represents a system rejection of 99.075%.

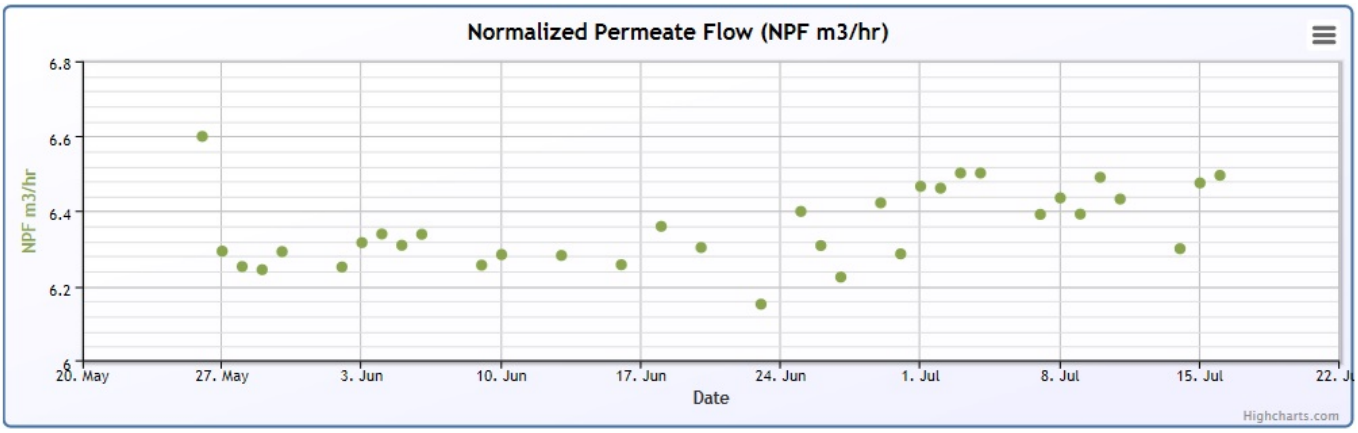

Figure 3: Normalized Permeate Flow

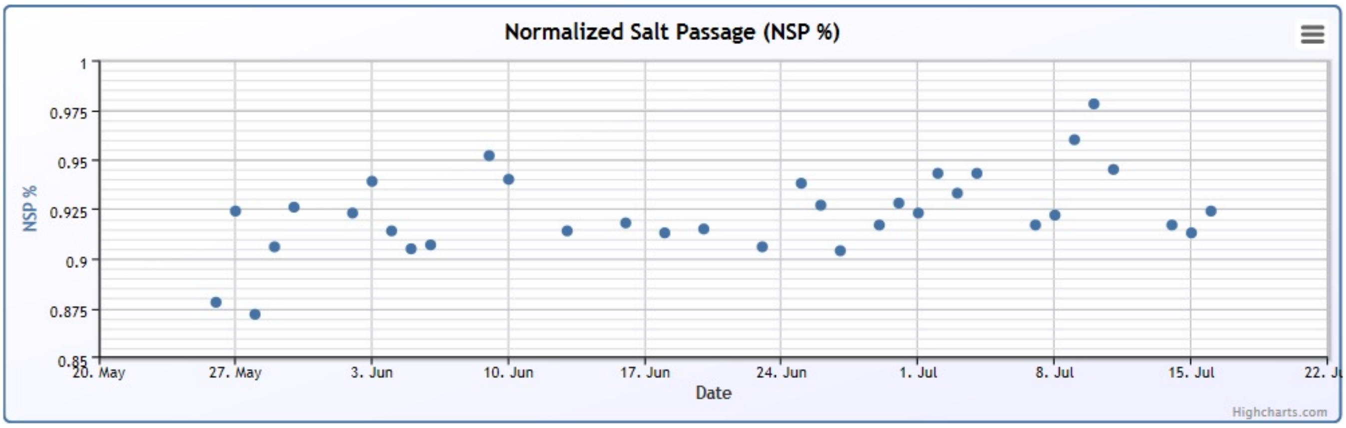

Figure 4: Normalized Salt Passage

On June 6th, samples of the feed, brine and permeate were collected for analysis (see Table 3). The feed salinity measured at 5,900 µS/cm at 26.7° C converts to a TDS of 3,600 ppm. The conversion factor between conductivity and TDS is then 0.61. The permeate TDS is approximately 25 ppm.

The calculation of the system rejection through mass balance is:

Rejection = (1-Cp/Cf) x 100%

= 99.3%

This system rejection value is greater than the one obtained from normalization of the salt passage (99.3% vs 99.075%). The rejection calculated from mass balance is more accurate as it relies on actual measured concentration of TDS while the one calculated in the normalization used an equation model to convert conductivity to TDS.

Table 3: Water Analysis on June 6th, 2013

Parameter	Units	RO Feed water	Permeate	Brine
Alkalinity	mg/l	678.0	-	-
Bicarbonate	mg/l	830.0	-	-
Barium	mg/l	0.2	-	-
Calcium	mg/l	149.0	-	-
Chloride	mg/l	1460.0	11.0	3774.0
Fluoride	mg/l	3.5	-	-
Potassium	mg/l	10.4	-	-
Magnesium	mg/l	150.0	-	-
Nitrate	mg/l	97.0	-	-
Sodium	mg/l	921.0	-	-
Silica	mg/l	64.0	-	-
Sulfate	mg/l	210.0	-	-
Strontium	mg/l	4.0	-	-
TDS	mg/l	3600.0	~ 25	-
EC	µS/cm	5900.0	56.0	13860.0
Temp	°C	26.7	26.4	26.5
pH	-	7.6	5.5	7.7

Daily operating data was used to normalize the data into an average element performance at 2000 ppm and 225 psi by calculating the element A and B values.

Figure 5 shows the trend of the average element performance throughout the pilot test run. The element performance was stable at about 10,700 gpd and 99.75% salt rejection. Those values agree with the results obtained in the third-party independent test undertaken by Avista during their BWRO test.

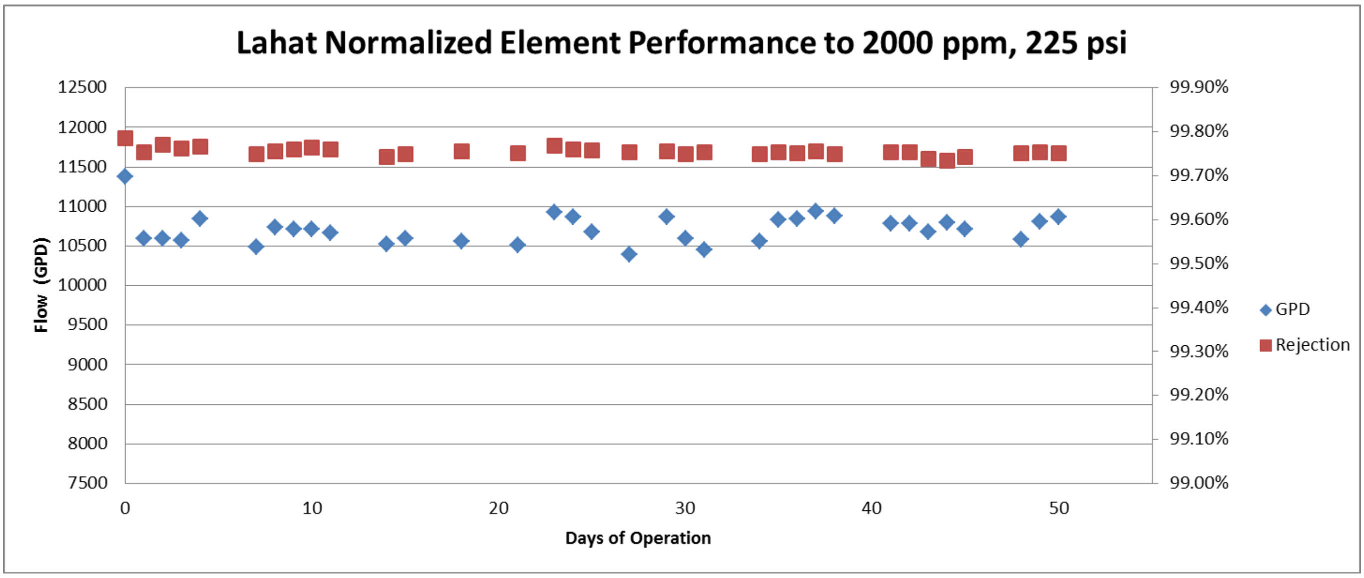

Figure 5: Normalized Element Performance

Conclusion

The third party independent test undertaken at Avista at standard BWRO test conditions demonstrates the TFN elements performs consistently at about **10,500 gpd and 99.75%** rejections. The pilot test under field BWRO conditions at Lahat Station, Israel validates the performance data obtained by Avista as the TFN elements performed to similar flux and rejection capabilities. The normalization of the data collected also shows the stability the system performance over the pilot test period.

With specifications of 10,500 gpd and 99.75% under the standard BWRO test conditions (2000 ppm NaCl, 225 psi, 15% recovery, 25C, pH: 8), the TFN element has one of the highest salt rejections among BWRO elements available in the market while maintaining a high flux.

References

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3. ASTM D4516, “Standard Practice for Standardizing Reverse Osmosis Performance Data”, *ASTM* ,Vol. 11.02