CITY OF SCOTTSDALE WATER CAMPUS ADOPTED NANOCOMPOSITE RO MEMBRANES FOR INDIRECT POTABLE REUSE

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Abstract

Depletion of water supplies for potable and irrigation use has been a major problem in the world. Some areas in the US are facing challenges to reliably provide clean water to its population. These challenges require municipalities to pursue sustainable supply options such as Indirect Potable Reuse (IPR). IPR has become a sustainable alternative water supply. In IPR, municipal wastewater is treated and injected into a groundwater aquifer via vadose zone wells, spreading basins or other means in which water percolates through the unsaturated soil into the aquifer. The intent of IPR is to diversify water sources in order to maximize reliability of the region's water supply.

City of Scottsdale Water Campus is one of the largest and most advanced IPR facilities in the world. The Advance Water Treatment (AWT) Facility was commissioned in 1999 with initial capacity of 6 million gallons per day (MGD). It was one of the first wastewater treatment plants to use microfiltration (MF) and reverse osmosis (RO) for treating effluent from a wastewater treatment plant for injection into groundwater aquifer. It is now operating at 85% recovery with the capacity to produce 20 MGD of RO treated water for golf course irrigation and aquifer recharge.

Newly developed thin film nanocomposite (TFN) brackish water RO (BWRO) membranes which incorporate proprietary nanotechnology to improve conventional RO membrane performance. The TFN BWRO membranes aim to reduce overall cost of desalination while achieving superior product water quality. For the first time, TFN BWRO membranes are applied in a full scale IPR plant at the AWT Facility. In this study, full scale performance of TFN membranes such as individual salt rejection and fouling tendency will be presented. The study will also discuss long term TOC removal performance of TFN BWRO membranes in the full scale IPR facility.

Background

Scottsdale Water Campus Advanced Water Treatment Facility

The AWT facility at Scottsdale Water Campus treats wastewater to a level that meets or surpasses water quality criteria established by the Arizona Department of Environmental Quality

(ADEQ) for open access irrigation and groundwater recharge. The facility consists of flow equalization reservoir with ozonation, 23.6 MGD MF, 20 MGD RO, ultraviolet (UV) disinfection, and decarbonation followed by lime post treatment for stabilization as shown in **Figure 1**. Source water consists of excess effluent from the Water Reclamation Plant (WRP) treated raw wastewater suitable for golf course irrigation. The treated RO water is injected via vadose zone (the unsaturated layer above water table) wells into an aquifer 180 feet below surface. This aquifer underneath the city creates a perfect environmental buffer. In vadose zone injection, the reclaimed water percolates through the soil that filters, treats, and therefore improves the quality of the water. This process is referred to as soil aquifer treatment (SAT).

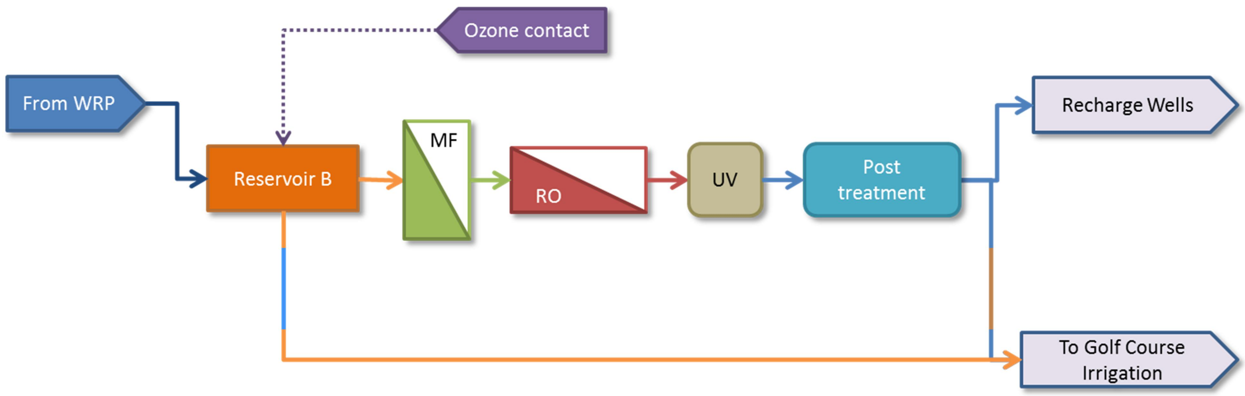

Figure 1 AWT Process Flow Diagram

The RO process, responsible for removing inorganic and organic constituents, consists of fourteen (14) 8-inch RO trains for a total of 12 MGD operating at 85% recovery in either 20:10:5 or 24:10:5-array configuration and three (3) 16-inch RO trains for a total of 8.4 MGD operating at 85% recovery in 13:7-array configuration. With six (6) elements in each 8-inch pressure vessel, the total number of 8-inch elements in the RO facility is 3,180.

Starting from 2010, the original membranes installed in all 8-inch trains were being replaced by low fouling membranes. Based on the recorded operating SCADA data, even though installations were completed in 2010, the trains were not started until March 2011. Since then, these trains had been running intermittently depending on the feed flow capacity up to present. Specifications for these low fouling membranes are shown in **Table 1** below.

Table 1 Low Fouling BWRO Specifications

Permeate Flow Rate, m^3/d (gpd)	38.6 (10,200)
Minimum Salt Rejection (%)	99.0
Stabilized Salt Rejection (%)	99.7
Active Area, m^2 (ft^2)	37 (400)
Standard test condition: 2,000 mg/L NaCl, 225 psi (15.5 bar), 25 °C (77 °F), pH 7, 15% recovery	

Indirect Potable Reuse (IPR)

As IPR gains popularity, regulatory agencies are implementing more sophisticated treated water quality requirements to protect public safety. In 2010, Arizona Governor issued the Blue Ribbon

Panel (BRP) on Water Sustainability with key recommendation to create a steering committee to advance potable reuse (Arizona Department of Water Resources, 2010). In 2012, the Steering Committee for Arizona Potable Reuse (SCAPR) was formed to satisfy the recommendations from BRP. While the SCAPR specifically prohibits the use of reclaimed water for direct potable reuse (DPR), IPR projects can be implemented under a set of other water regulations.

Since no specific regulations exist yet for IPR in Arizona, the authors of this paper turned to California for regulatory guidance. California's regulatory structure has been the most developed in the country for potable reuse. According to California's State Water Resources Control Board's latest Regulations Related to Recycled Water (State Water Resources Control Board, 2015), concentration of total organic carbon (TOC) can be used as a way to monitor the product water quality. The publication states that analytical results of TOC monitoring performed shall not exceed 0.5 mg/L based on the 20-week running average of all TOC results and the average of the last four TOC results.

Installation and Operation

TFN Installation

In March 2016, the existing 630 low fouling membranes were replaced in Trains 17, 18, and 19 at the AWT Facility. These trains are in 20:10:5-array configuration and have been running for five (5) years before being replaced with TFN BWRO membranes. **Table 2** below summarizes the specifications of the RO membranes installed at the AWT Facility.

Table 2 TFN BWRO Specifications

Permeate Flow Rate, m^3/d (gpd)	39.7 (10,500)
Minimum Salt Rejection (%)	99.5
Stabilized Salt Rejection (%)	99.6
Active Area, m^2 (ft^2)	37 (400)
Standard test condition: 2,000 mg/L NaCl, 225 psi (15.5 bar), 25 °C (77 °F), pH 8, 15% recovery	

TFN Operation

Within two (2) months of installation, water samples were collected from permeate and concentrate sampling ports from Trains 18 and 19. After collected by AWT Facility staff, the samples were analyzed by a local third party analytical laboratory. Samples collected were analyzed twice (one week apart) for individual ion constituents to verify the TFN BWRO's salt rejection. Samples were also collected and analyzed for TOC once a week for 3 months, and reduced to once every two weeks for 3 months after.
During sample collection, a snapshot of Trains 18 and 19 operational data was manually recorded to accompany the water quality (WQ) analysis data. In addition to the manually recorded data, daily operational data is automatically recorded via the RO plant's SCADA system for all the trains at the AWT Facility.

Due to the variation in feed water capacity, not all the trains at the AWT Facility were operated continuously at the same time, so some trains were taken offline weeks or months at a time. **Table 3** below shows the typical operating condition for all three trains. The operating condition data shown here is averaged from 20 manual readings during sample collection events. The trains are operated by keeping constant feed and permeate flow to achieve system recovery of ~85%. Differential pressures (DPs) are monitored as indicator for membrane fouling. A Clean-In-Place (CIP) is performed on any train with DP exceeding 30 pounds per square inch (psi) at any stage or 50 psi total DP of all 3 stages.

Table 3 Operating Conditions

Parameters	Average*	Standard Deviation
Feed pH	6.28	0.02
Feed temperature (°C)	25 – 32	Fluctuate daily
Concentrate flow (gpm)	104	2
Permeate Flow (gpm)	590	6
Feed Pressure (psi)	112	4
Concentrate Pressure (psi)	81.7	7.5
Permeate backpressure (psi)	4	0
Feed Flow (gpm)	694	5
*Average of 20 weekly/biweekly manual recording		

In August 2016, Train 19 DP began to increase while Trains 17 and 18 DPs were stable. So, on September 13, CIP was performed on Train 19. Historically, most trains at the AWT Facility underwent one or two CIPs per year. Typically, CIPs are performed at 35 °C using sodium hydroxide (NaOH) solution to reach pH 10.8 – 11. Stages 1, 2, and 3 are flushed one stage at a time at 800 gallons per minute (gpm), 400 gpm, and 200 gpm, respectively, with the same NaOH cleaning solution. During the CIPs pressure is maintained below 60 psi at between 50 – 55 psi.

Results and Discussions

Water Quality Data

The results from the water quality analyses from Trains 18 and 19 are presented in **Table 4**. Percent rejection values designated with a (>) indicate that the constituent was detected in the feed water, but the permeate concentration was below the analytical method detection limit (MDL). When permeate concentration is below MDL, rejection is calculated based on the MDL value for the worst case scenario.

Table 4 Average Water Quality Analysis Results from Trains 18 and 19

Constituents	Average* Feed Ion Concentration (mg/L)	Average* Permeate Ion Concentration (mg/L)	Average* Ion Rejection	Standard Deviation
Bromide	0.0765	0.0113	84.62%	3.48%
Barium	0.0822	ND	>99.76%	NA
Boron	0.338	0.233	31.14%	4.15%
Calcium	89.8	ND	>99.96%	NA
Magnesium	31.2	ND	>99.90%	NA
Potassium	28.2	0.620	97.85%	1.24%
Silicon	3.94	0.0425	98.92%	0.25%
Silica (Calculated)	8.44	0.0909	98.92%	0.25%
Sodium	283	7.50	97.35%	0.22%
Strontium	1.16	ND	>99.83%	NA
Total Alkalinity	123	12.3	90.09%	1.51%
Chloride	422	4.55	98.92%	0.18%
Fluoride	0.447	ND	>91.04%	NA
Nitrate as N	7.80	0.535	93.19%	1.22%
Ammonia as N	1.16	0.217	81.88%	5.29%
Nitrite as N	0.0141	ND	>42.64%	NA
Sulfate	293	ND	>99.93%	NA
TDS (calculated)	1,285	26.3	97.96%	0.23%
TOC	6.81	0.268	96.06%	0.42%

*Average of four (4) independent sample analyses
ND: Non Detected
NA: Not Available due to ND permeate reading

Table 4 shows consistent rejection performance of TFN membranes for most constituents. Multivalent ions are well rejected at over 99.9%. The three year permeate goals, as highlighted in green, are to meet TDS concentration of <70 mg/L, Sodium (Na) concentration of <17 mg/L, and Chloride (Cl) concentration of <20 mg/L. No TOC requirement needed to be met. This table shows high performance of the TFN membranes in rejecting the constituents of concern.

Operating Data

All three trains have been in operation since March 2016 up to the time this paper was submitted (approximately 8 months). **Figure 2** below shows the feed temperature entering the RO trains which elevated during the summer months. This figure also shows the feed pressure from Trains 17, 18, and 19, and projected feed pressure based on field operation condition. Feed pressure for all three trains was decreasing with the increasing feed temperature during the summer months.

This is a common phenomenon with typical polyamide (PA) membranes where they become more permeable with increasing feed temperature.

Figure 2 also shows the actual field membrane performance from the three trains matching the projected feed pressure estimated by means of a proprietary software.

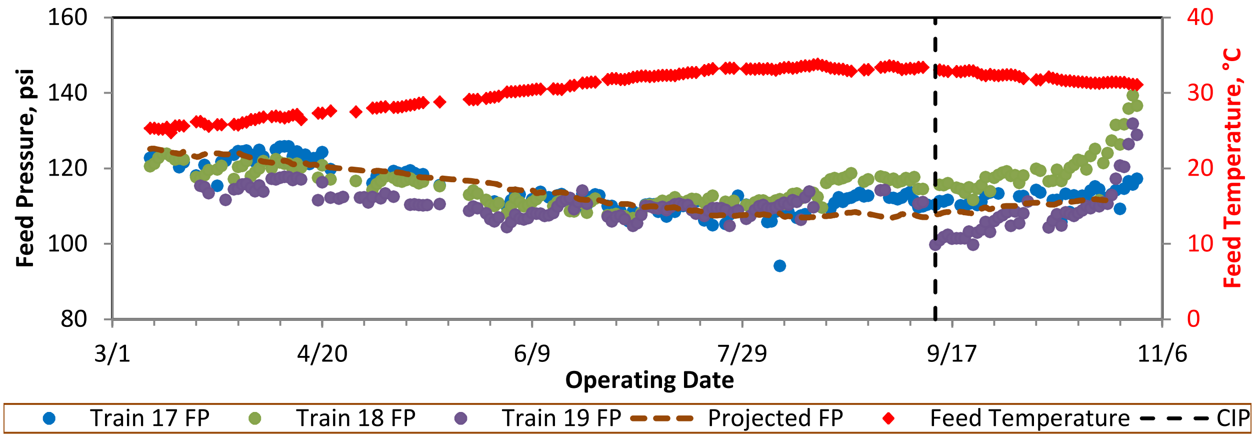

Figure 2 Feed Pressure and Temperature for Trains 17, 18, and 19

Figure 3 shows the feed TDS entering all the RO trains, and the permeate TDS from Trains 17, 18, and 19. This figure suggests that all three trains with TFN membranes are able to produce consistently high quality product water below the required permeate TDS concentration of 70 mg/L. Slight increase in permeate TDS was observed after CIP in Train 19. After a discussion with the plant operator, this is deemed normal and commonly observed in all trains.

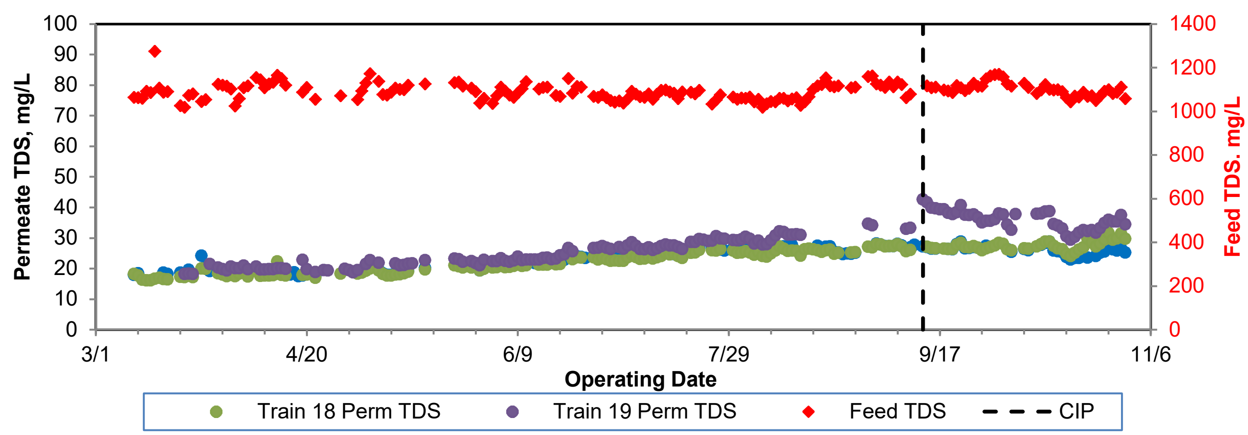

Figure 3 Feed and Permeate TDS for Trains 17, 18, and 19

Discrepancies between DP measured using SCADA data and manually recorded data was later discovered. The manually recorded data was found, by operators, to be the most reliable to monitor for membrane fouling. Due to this discrepancy, all calculation requiring DP data will be performed and shown using manually recorded data. DP was monitored for all RO trains. Trains 18 and 19 DPs are shown in **Figure 4**. CIP was initiated when DP increase was observed in Train 19 during plant operation. Shortly after CIP was performed, differential pressure returned to normal indicating successful CIP process.

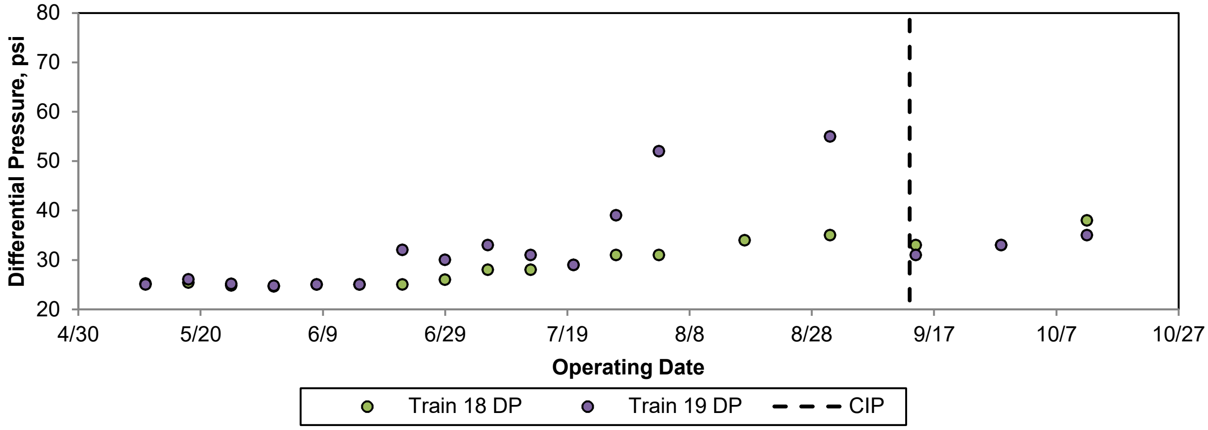

Figure 4 Differential Pressure for Trains 18 and 19

Normalized Data

Specific flux for Trains 18 and 19 are shown in **Figure 5**. Even though DP increase was observed, specific flux appeared to be stable throughout operating time for both Trains 18 and 19. For both trains, the specific flux maintains relatively high values of above 0.12 gallons per square foot per day per pound per square inch (gfd/psi) throughout the operation period.

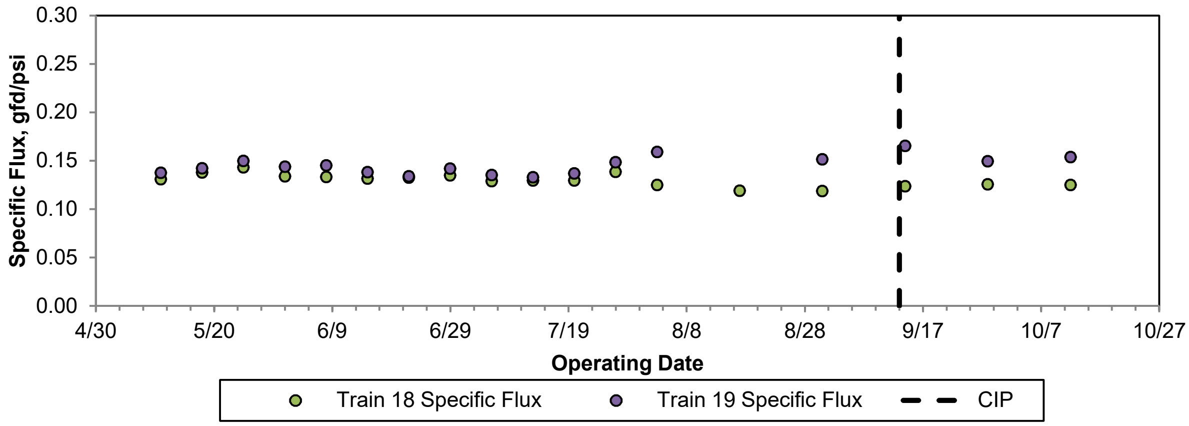

Figure 5 Specific Flux for Trains 18 and 19

Figure 6 below shows the normalized salt passage for Trains 18 and 19. Slight increase in salt passage can be observed after CIP. According to discussion with the operators, this increase in salt passage is expected and commonly observed with all the RO trains.

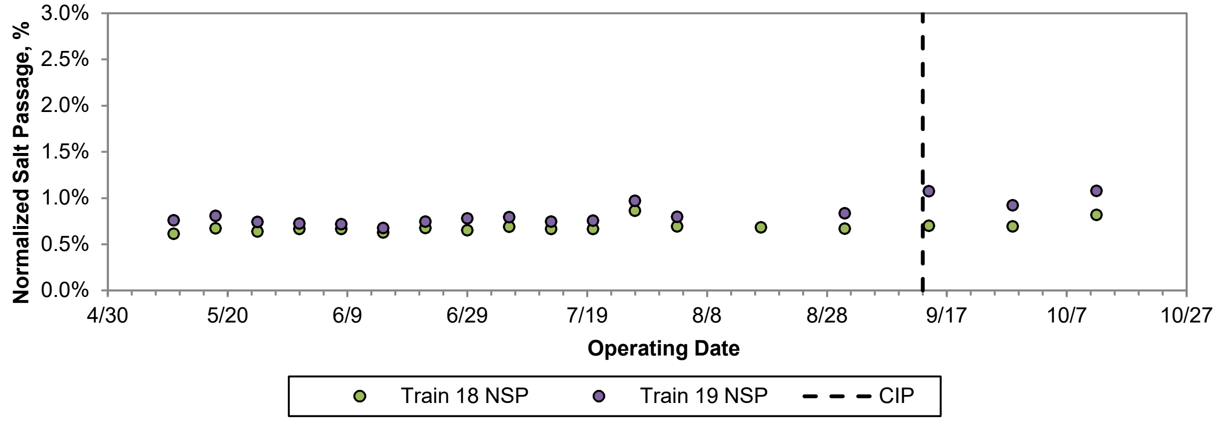

Figure 6 Normalized Salt Passage for Trains 18 and 19

Comparison Data

The previous low fouling membranes installing at the AWT Facility were installed at the end of 2010, and operation was started in March 2011. One train is selected from these trains and will be called non-TFN train. Start-up data from this non-TFN train is analyzed and compared with a TFN train. No changes in pretreatment had been recorded since the initial non-TFN start-up in 2011 except a change in antiscalant manufacturer and model.

Figure 7 and **Figure 8** below show the feed conductivity and temperature for TFN train at start up in 2016 and non-TFN train at start up in 2011. Even though the trains were operated at 5 years apart, the feed conductivity and temperature for both trains are very similar.

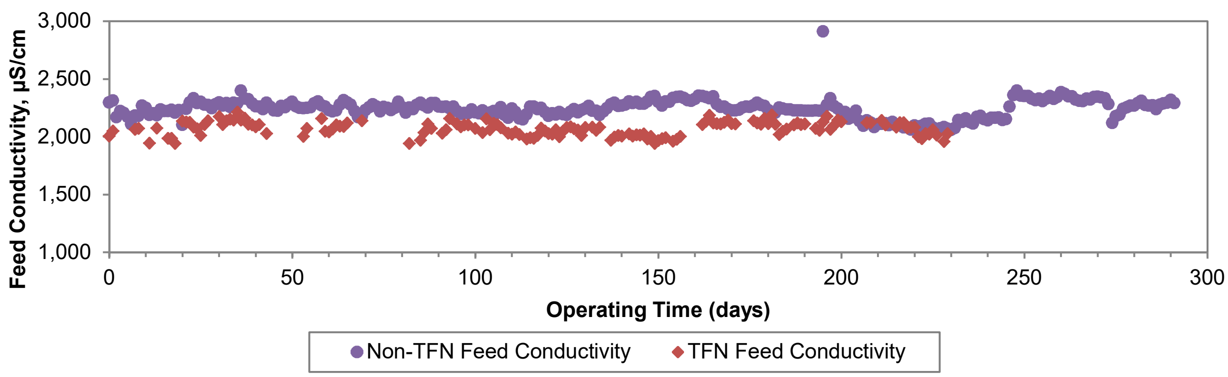

Figure 7 Feed Conductivity for Non-TFN Train vs. TFN Train

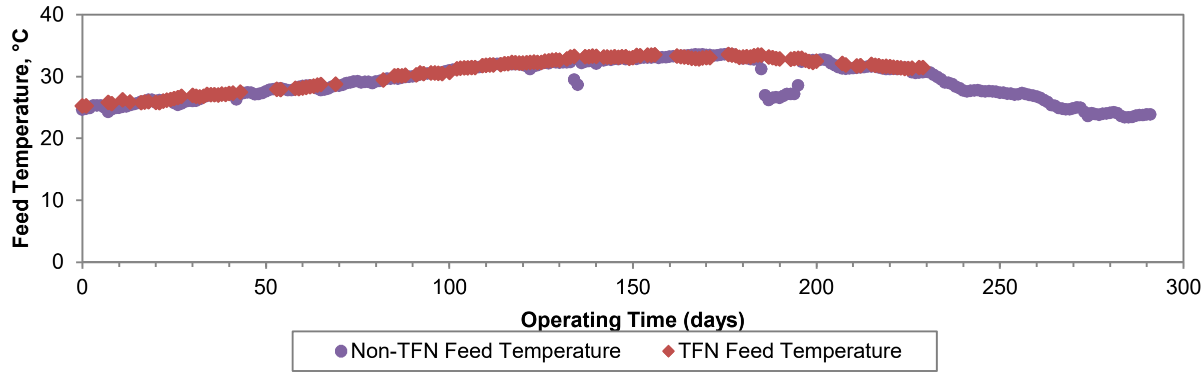

Figure 8 Feed Temperature for Non-TFN Train vs. TFN Train

Figure 9 and **Figure 10** show the feed pressure and permeate conductivity for non-TFN and TFN trains during the first year after start up. The feed pressure data from the non-TFN train shows a pattern that commonly indicates membrane fouling and multiple CIP events. Two CIPs were in fact performed on the non-TFN train in 2011. When compared to feed pressure data from the TFN train, the TFN shows stable performance. It is possible that the change in antiscalant might have impact on the performance. Both TFN and non-TFN trains feed water came from the same pretreatment process.

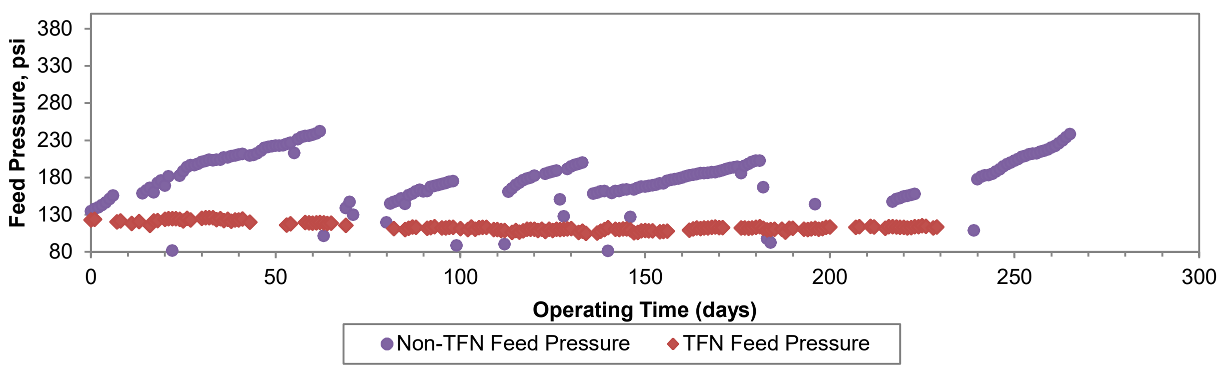

Figure 9 Feed Pressure for Non-TFN Train vs. TFN Train

Figure 10 shows permeate conductivity data from both non-TFN and TFN trains. The data shows slight increase in permeate conductivity which coincides with the increase in feed temperature. The warmer temperature caused the membranes to be more permeable allowing slight increase in salt passage.

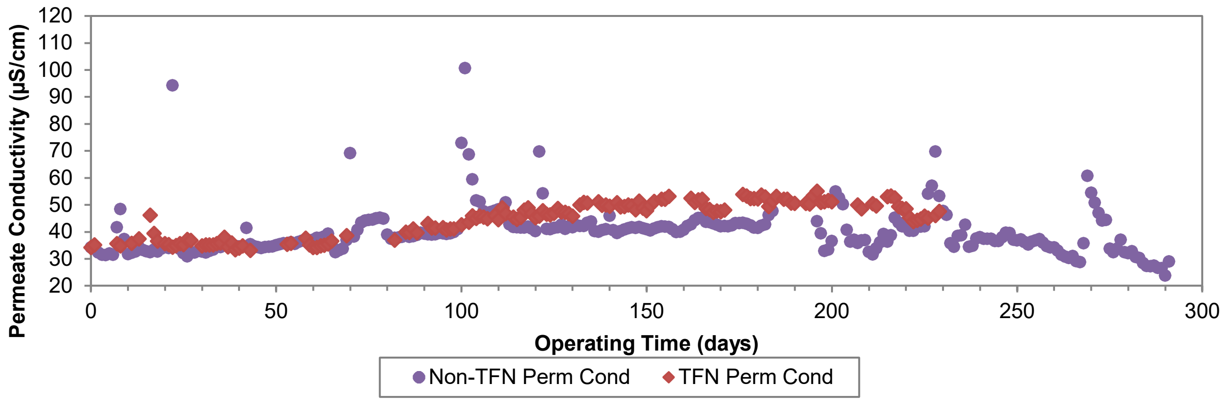

Figure 10 Permeate Conductivity for Non-TFN Train vs. TFN Train

Figure 11 shows the specific flux for non-TFN and TFN trains relative to the initial specific flux. After adopting TFN membrane, the membrane performance gets more stable with only slight decrease in specific flux.

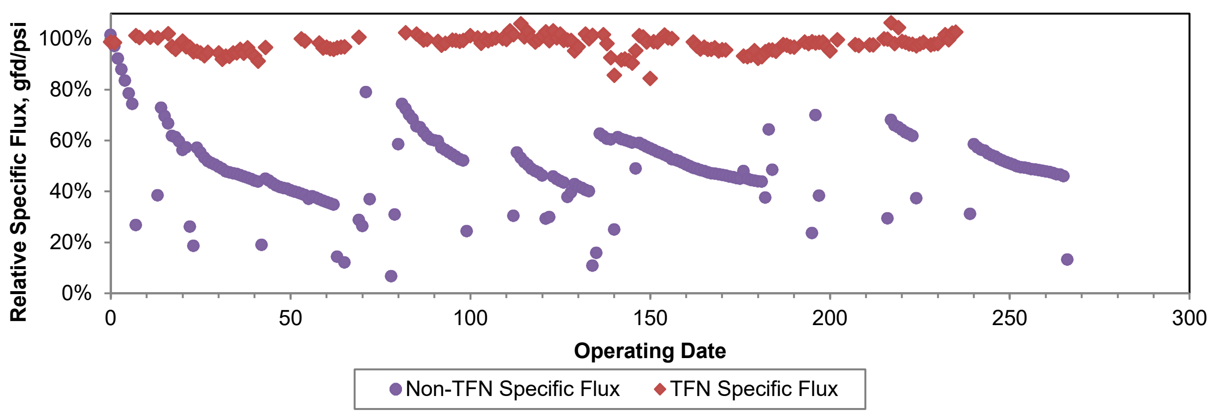

Figure 11 Specific Flux for Non-TFN Train vs. TFN Train Relative to Initial Performance

TOC Analysis Results

In Arizona, permeate TOC is not regulated for IPR application. However, in California, the state with the most developed regulatory structure for potable reuse, TOC is considered one of the critical ways to monitor product water quality. According to California's State Water Resources Control Board's latest Regulations Related to Recycled Water, the analytical results of the permeate TOC from SAT process similar to the AWT shall not exceed 0.5 mg/L based on the 20-week running average of all TOC results and the average of the last four TOC results.

TOC sample collections were done on the feed and permeate streams from two of the TFN trains. The results from the analyses are presented in **Figure 12** below. The data shows that the feed TOC concentration is consistent throughout the change in feed temperature, and the permeate TOC concentration is consistently below the target of 0.5 mg/L. Even after a CIP performed on Train 19, the permeate TOC concentration was not affected.

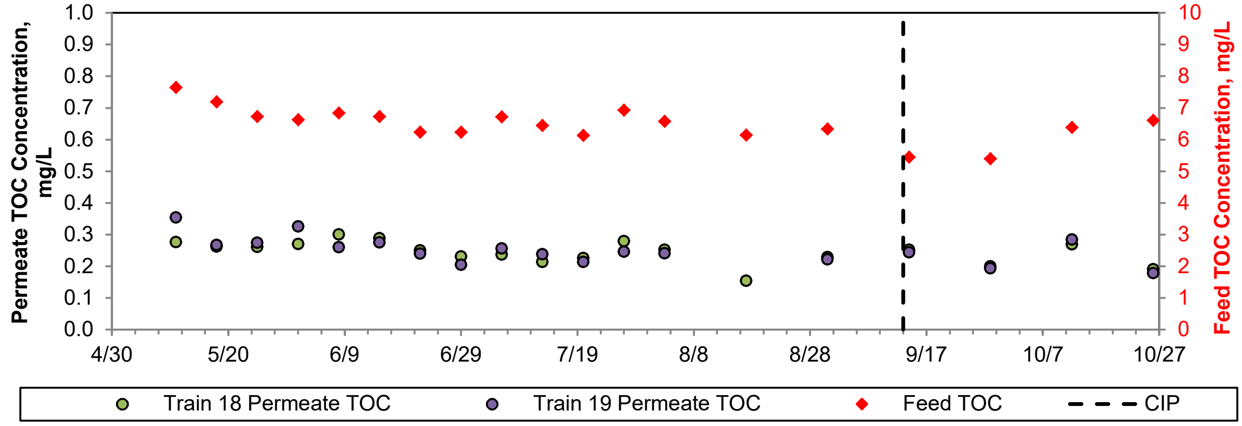

Figure 12 Feed and Permeate TOC Concentration for Trains 18 and 19

Conclusion

The TFN membranes were installed 7 months before this paper was submitted, and all three trains have been operating with stable performance. Water quality analysis performed on the TFN trains indicates high rejection on most constituents. Permeate WQ is well within the three-years target set by Water Campus. DP increase was observed on one of the trains which led to a CIP. After a successful CIP process, DP returned to normal. System performance data was compared between trains with TFN membranes versus the trains with non-TFN membranes. It is not possible to make side-by-side performance comparison for the TFN membrane and the non-TFN membrane since the two membranes were installed at different periods. However, based on normalized operation data, the TFN membrane generally performs better than the non-TFN membrane. In addition, permeate TOC concentration has been continuously stable and well within California's 0.5 mg/L target for SAT IPR application.

References

Arizona Department of Water Resources. (2010, November 30). *Blue Ribbon Panel*. Retrieved October 20, 2016, from ADWR: http://www.azwater.gov/AzDWR/waterManagement/BlueRibbonPanel.htm

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