# Demonstrating Improved RO Membrane Performance When Reclaiming Secondary Municipal Waste

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## Abstract

The Orange County Water District (OCWD) of Southern California conducted side by side testing of the latest available RO membrane technology in parallel with membranes currently operating in their Ground Water Replenishment System (GRWS). The new RO elements were installed in a satellite vessel attached to the first stage of an existing three stage train. The new membrane performance was monitored for twelve months and compared to the performance of the existing membranes which had been in operation for two years. The new elements demonstrated lower differential pressure, lower feed pressures and less fouling. The construction of the new elements included thicker 34 mil feed/brine spacer which led to lower differential pressure loss and a lower tendency for fouling. Despite the thicker spacer, the new elements were constructed with the same membrane area as the existing elements and could therefore be operated at the same flux and flow. This paper will present the comparative operating data which demonstrates the improved performance of the latest RO membrane chemistry and element design. The data will be used to demonstrate the potential for reduced operating cost associated with using the improved elements in a full scale system.

## Introduction

In late 2007 and early 2008, the Orange County Water District (OCWD) of Southern California commissioned one of the world's largest wastewater reclamation facilities, the Ground Water Replenishment System (GWRS), using a combination of water treatment technologies that include submerged microfiltration as pretreatment to a reverse osmosis desalination system. OCWD obtains its secondary effluent from the Orange County Sanitation District (OCSD) located adjacent to the reclamation plant. Feedwater TOC concentrations from OCSD are about 10 mg/L, Total Nitrogen averages 25 mg-N/L, and feed TDS is approximately 1000 mg/L due to the already high salinity of the region's imported water supply – the Colorado River (Daugherty, 2005).

Pretreatment to the RO system is polypropylene (PP) submerged hollow fiber MF membrane. The PP fibers have a nominal pore size of 0.2 microns with an inner diameter of 0.39 mm and an outer diameter of 0.65 mm. Every 22 minutes, the system undergoes reverse filtration and air scouring to remove particles accumulated on the fiber surface. Every 21 days, the system undergoes a clean in place, including a three hour soak, to remove foulants not removed during reverse filtration. Feed to the MF is dosed with chlorine to maintain a 2-3 ppm chloramines residual through the MF to the RO. The residual chloramine in the feed to the RO serves to control biofouling in the RO element's feed/brine channels and on the RO membrane surface. Since organic and biological fluctuations in the wastewater can consume the chloramines, the concentration from the MF is monitored and adjusted to ensure the proper dosage to the RO is maintained.

The RO portion of the GWRS consists of 15 trains (14 in operation with one train as standby) each with a capacity of 5 MGD (18,900 m3/d) per train for a total plant capacity of 75 MGD (284,000 m3/d). The array for each train is three stages (78:48:24) with seven elements per vessel. The flux is 12 gfd (20.4 lmh) with a recovery of 85%. Final permeate TDS is less than 10 mg/L. OCWD permeate water quality objectives include the reduction of TOC to less than 0.5 mg/L and Total Nitrogen to less than 5 mg-N/L (Franks, 2007).

## Improved RO Elements

Due to potential plant expansion and the need to replace one train of existing RO membranes which began operating in a demo unit starting June of 2004 (Daugherty, 2005), the OCWD undertook a pilot study to evaluate the latest available membrane chemistry and element design. Since specifying the energy saving membranes currently operating in the plant, RO technology has evolved such that today's improved membranes have higher permeability and greater durability. In addition to the improved membrane chemistries, the design and construction of the spiral wound element has also benefited from the latest in automated manufacturing. Specifically, today's elements can be manufactured with thicker feed/brine spacers without sacrificing active membrane area and productivity.

When manufacturing the spiral wound RO element, a trade off is inevitably made between the thickness of the feed/brine spacer and the amount of active membrane surface area that can be packaged into the element. The spiral wound element currently operating at OCWD was manufactured with 400 square feet of membrane using a 26 mil spacer. Historically, if a thicker 34 mil spacer was selected, the membrane surface area would be reduced to 365 square feet. However, due to advances in materials and automated manufacturing, including the use of robotics for the precise placement of the glue lines, the latest elements are constructed with the thicker 34 mil spacer while maintaining 400 square feet of active membrane area. The use of a thicker spacer offers several advantages including lower fouling potential, improved membrane cleanings, lower differential pressure (dp) and lower feed pressure.

Despite the use of low pressure membrane pretreatment such as the MF used at OCWD, marked increases in RO differential pressure can occur when treating secondary municipal waste (Knoell, 2010, Won, 2009, Franks, 2007). During the life of the RO system, upsets or changes in either the chemical or physical pretreatment lead to colloidal or biological fouling in the feed/brine spacer of the RO elements. Upsets in the pretreatment include fiber or o-ring failures in the MF membranes, insufficient chloramine concentrations to the RO, or high organic loading to the plant that in turn passes through the MF pretreatment. These potential pretreatment upsets can lead to increasing dp that are not easily recovered. An increase in dp of 10% to 20% requires cleaning. However, in typical systems, differential pressure increases by more than 50% before a cleaning is initiated. After such an increase, a portion of the feed/brine channel can become irreversibly blocked and the cleaning solution is prevented from reaching all regions of the flow channel. The use of 34 mil spacer reduces this effect.

The use of a thicker spacer will decrease overall feed pressure as well. By going from a 26 mil spacer to a 34 mil spacer, the thickness of the channel through which the feed flows is increased by 20%. A thicker channel means less pressure is lost as water travels from the feed to the brine end of the element. In the OCWD RO system, with three stages and seven elements per vessel, the water travels through twenty-one elements before exiting on the brine end of the system. The viscous flow through these elements results in a pressure loss of 60 psi. By using a thicker spacer, the hydraulic pressure loss is reduced and feed pressure is therefore reduced.

## Pilot Test Set Up

To test the latest RO elements, a separate pressure vessel was attached to the first stage of an existing RO train (Train C 01). The vessel was configured to be monitored, controlled, and cleaned independently from the parallel, full scale train. The test vessel operated at 14.8 gfd and 55% recovery to replicate the train's first stage operating conditions. Water quality, flows, and pressures were recorded manually on a daily basis. The test vessel configuration is shown in **Figure 1**. A comparison of the system elements currently in operation with the improved, element, including performance at standard test conditions, can be seen in **Table 1.**

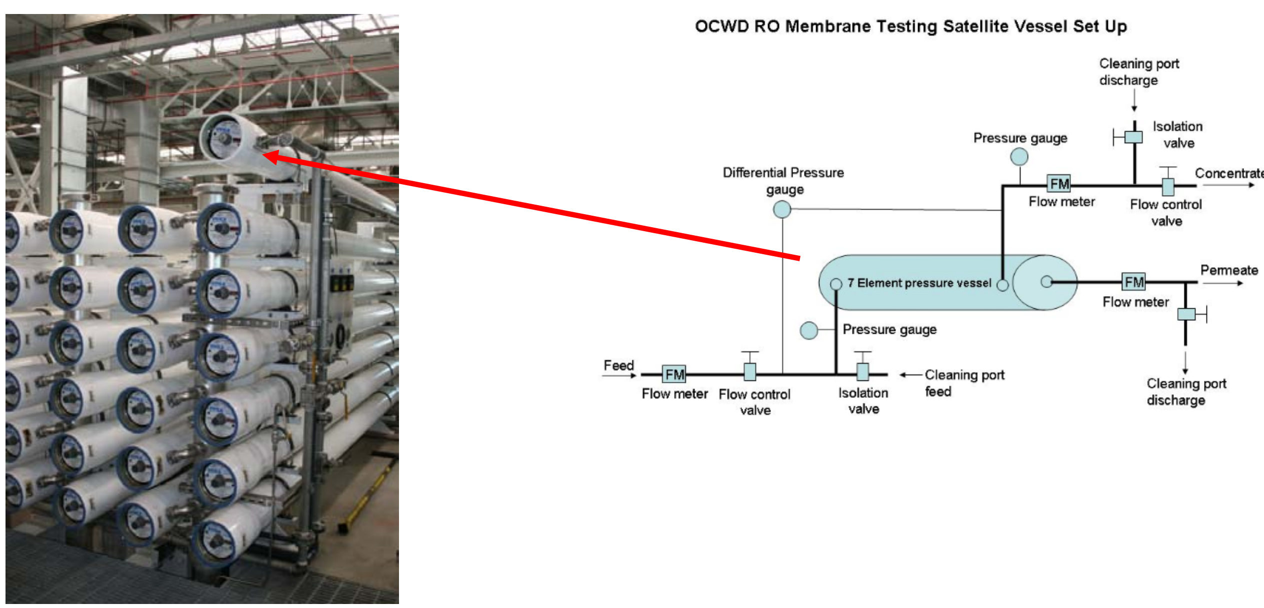


**Figure 1**. Configuration of the test pressure vessel attached to first stage of full scale Train C01.

**Table 1**. Comparison of element characteristics and performance at standard test condition (Feed pressure = 150 psi, T = 25 C, pH = 7, Feed Salinity = 1500 mg/L NaCl).

| Element | Flow (gpd) | Rej (%) | Dp (psi) | spacer (mil) | area (sq ft) | Max Cleaning pH at T = 35 C |
|---|---|---|---|---|---|---|
| ESPA2 (Currently Operating) | 9,000 | 99.6 | 4 | 26 | 400 | 11 |
| ESPA2-LD (Pilot Tested) | 10,000 | 99.6 | 3 | 34 | 400 | 12 |

## Pilot Test Results

The improved elements were loaded into the test vessel and the pilot study began on December 22, 2009. Feed pressure and differential pressure during the first eleven months of the test can be seen in **Figure 2**. As with any RO system treating a municipal waste stream, there was an initial loss in permeability of 20% caused by adsorbtion of organics onto the membrane surface. This resulted in an increase in feed pressure from 128 psi to 160 psi during the first 30 days of operation. Afterward, the feed pressure remained stable between 160 and 170 psi for the duration of the study. Due to gauge oscillations, the dp readings from the feed end to the brine end of the pressure vessel fluctuated between 10 psi and 20 psi. Despite these variations, the overall dp showed no sign of increase.

On October 24, after eight months of operation, the pilot vessel was cleaned with a high pH solution consisting of 3.0% STP+0.30% DDBS at a pH 10.80 and temperature 35 C with 30 minute recirculation followed by 60 minute soak repeated 3 times. The cleaning was initiated, not because of a loss in performance, but to demonstrate the membrane's response to a standard cleaning cycle. Because very little reversible fouling was present at the time of cleaning, the change in performance after the cleaning was minimal.

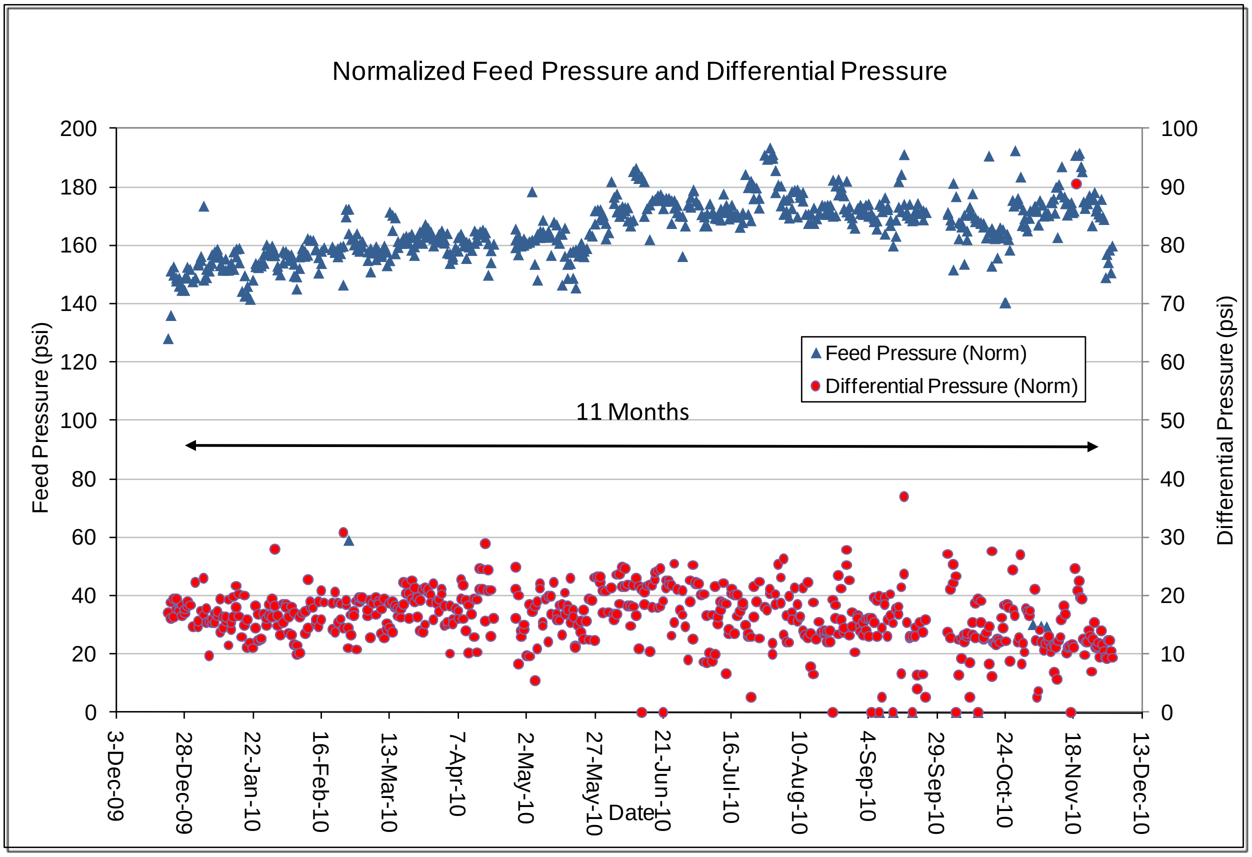


**Figure 2.** Eleven months of normalized feed pressure and differential pressure using the improved energy saving elements in a single pilot vessel attached to the first stage of Train C01.

As with permeability, salt passage dropped during the first 30 days from 0.8% to 0.4% where it stabilized for the remainder of the test. The pilot salt passage demonstrated the elements ability to meet the system permeate requirements of less than 0.5 mg/L TOC and less than 5.0 mg/L of Total Nitrogen as N. A feed and permeate analysis from the pilot can be seen in **Table 2** below.

**Table 2**. Feed and permeate water analysis from ESPA2-LD pilot vessel.

| | F (ppm) | Na (ppm) | K (ppm) | Ca (ppm) | Mg (ppm) | SiO2 (ppm) | Cl (ppm) | NO3-N (ppm) | SO4 (ppm) | Alk (ppm as CaCO3) | TOC (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Feed | 1.05 | 220 | 16.5 | 75.24 | 22.9 | 26.7 | 225 | 9.5 | 247 | 135 | 7.1 |
| Perm | 0.018 | 2.45 | 0.180 | 0.003 | 0.002 | 0.075 | 1.01 | 0.11 | 0.092 | 4.2 | <0.5 |

The eleven month test of the new elements met its primary objective of demonstrating successful and stable performance of the improved membrane and element design when treating the same municipal feed as the existing membranes in the full scale plant. In addition to meeting the primary objective, the pilot also served to demonstrate the operational benefit of the improved elements. The comparison of pilot performance with system performance below shows the improved elements had lower differential pressure, lower feed pressure, and a lower rate of fouling.

## Pilot Performance vs System Performance

Since commissioning in early 2008, the full scale RO trains at OCWD have run successfully, though not without challenges (Patel, 2010). The primary concern has been silica scaling of the third stage, which has resulted in an increasing feed pressure and frequent cleaning of the third stage. However, as shown in **Figure 3**, first stage differential pressures have increased as well.

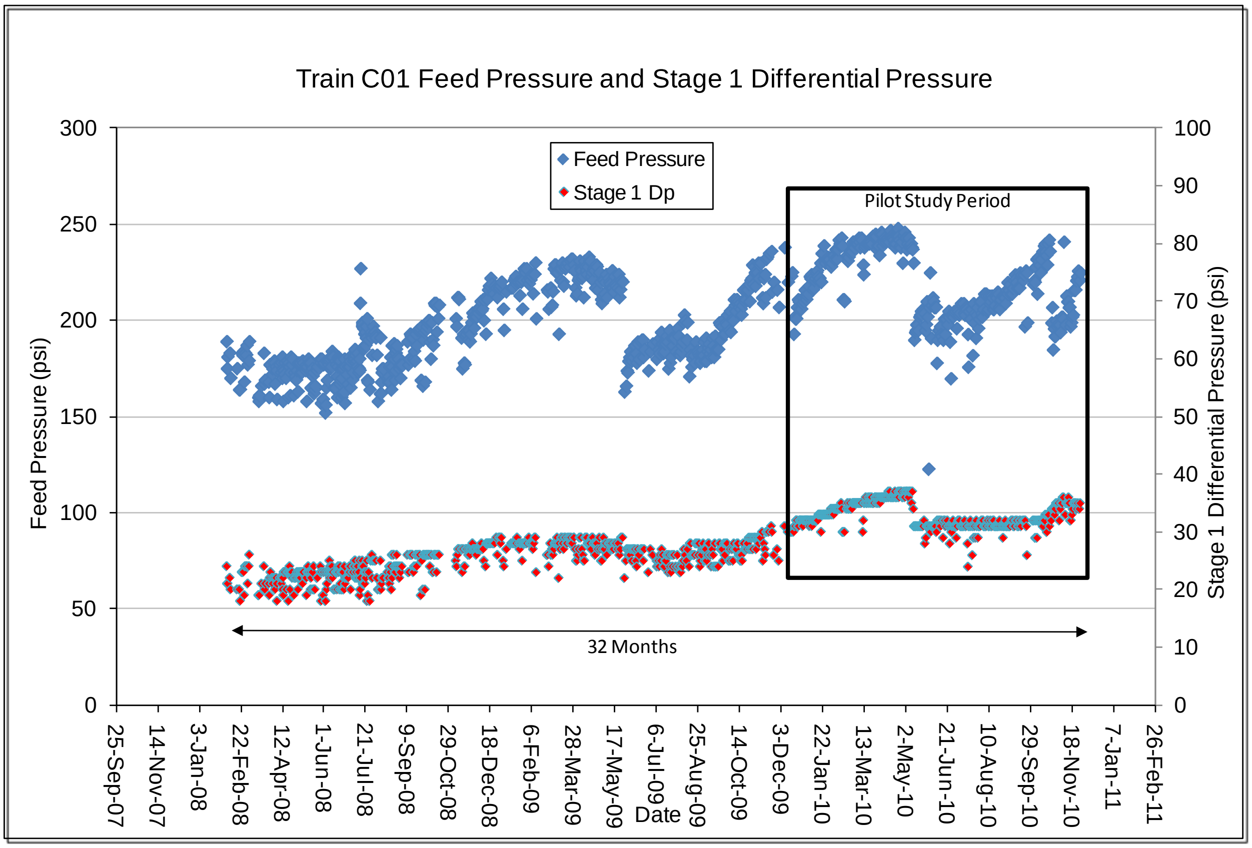


**Figure 3.** Three years of RO feed pressures and first stage differential pressures (Train C 01).

During the first eighteen months of operation, the dp of elements currently installed in the first stage showed only a gradual increase. Three cleanings performed during this time did little to recover dp to startup values. In late 2009, a few months before the parallel pilot test was initiated, the first stage dp began a more rapid increase over the next six months from 22 psi at startup to 35 psi – a 60% increase. Visual inspection of the lead elements during this time revealed a brown slimy film on the element face. The fouling of the elements was associated with feed water upsets coming to the plant as the Orange County Sanitation District transitioned its activated sludge process to a nitrification - denitrification mode. During this transition, there were spikes in the suspend solids concentration as seen in **Figure 4**. These suspended solids upsets continued to occur after the start of the pilot study. While the train elements continued to experience an increase in dp, the dp of the pilot elements remained stable.

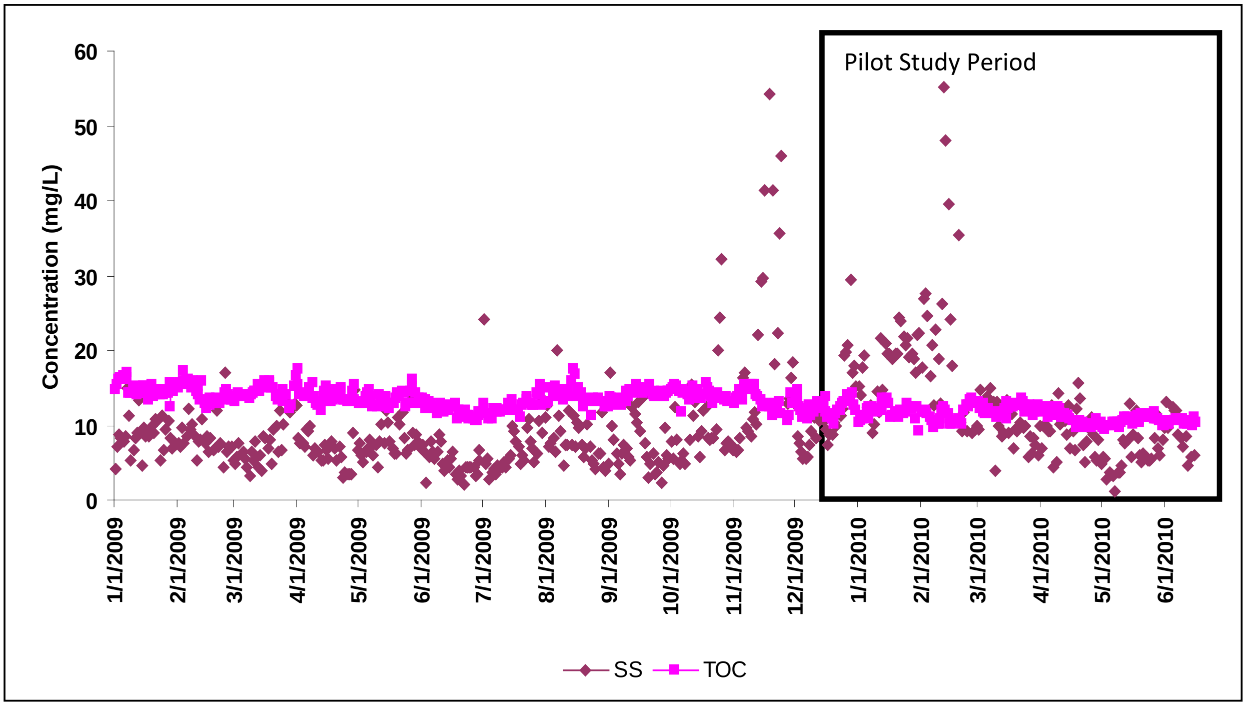


**Figure 4**. Suspended solids and TOC in feed to the MF membrane pretreatment.

A cleaning of the train's first stage on December 8th of 2009, two weeks before the parallel pilot study began, did little to recover differential pressure. This cleaning consisted of a generic formulation (3% STPP, 0.35% SDDBS) at pH 11.5 and 35 C using a 30 minute recirculation followed by a 1 hour soak. In May 2010, there was some reduction in the train's first stage differential pressure and system operating pressure using a reverse flush, higher cleaning temperature of 40 C, and a longer, five hour soak.

Because the full scale system monitors differential pressure loss by stage, a comparison of the pilot vessel dp (**Figure 2**), which was located on the first stage of Train C01, is easily made with the train's first stage dp shown in **Figure 3**. As expected, the thicker, 34 mil brine spacer in the pilot resulted in a lower differential pressure across the seven element vessel. Initial differential pressure loss across the test vessel was 18 psi. The first stage of the existing train, when commissioned in early 2008, had an initial differential pressure of 22 psi; 22% higher than the pilot element vessel. During the period of increasing train dp in early 2010, the pilot dp remained constant and no cleanings were required.

Based on data obtained from the single vessel pilot study, a projection was made of the full RO train performance assuming the whole train was loaded with improved elements. This projected train performance was then compared to the actual train performance. Based on this comparison, the projected difference in energy and cleaning cost between the two systems was calculated. **Table 3** compares the actual RO train performance to the projected performance using the improved elements. Since the unfouled dp of the train loaded with 26 mil spacer was 60 psi, the estimated dp of the same train, if it were loaded with the thicker, 34 mil elements, would be approximately 50 psi.

The estimated increase in feed pressure of the train with the currently installed elements is based on an unfouled 172 psi feed pressure plus a 15 psi increase associated with the train's first stage increase in dp – all of which occurred when treating the most challenging feed water during the pilot study period. The increase in feed pressure assumes no third stage scaling. Likewise, the estimated number of annual cleanings is based on first stage fouling only. The effect of element design on scaling tendency was beyond the scope of the pilot study and was not considered in this comparison. The lower dp of the improved element system, along with the improved membrane's higher permeability, results in an average 31 psi lower system feed pressures which leads to 17% lower power consumption and a potential annual savings for the plant of $1.2 million. An additional $90,000 could be saved in reduced cleaning cost.

**Table 3.** RO performance with currently installed elements compared to projected RO system performance with new elements based on data from the one year pilot study from Dec 2009 to Dec 2010.

| | Actual RO Performance with Current Element | Projected RO Performance with Improved Element | Annual savings |
|---|---|---|---|
| RO Element | ESPA2 | ESPA2-LD | |
| Total Elements/train | 1050 | 1050 | |
| Feed Pressure (psi) | 187 | 156 | |
| Differential Pressure (psi) | 60 to 75 | 50 | |
| Energy (kwhr/kgal) | 2.07 | 1.72 | |
| Annual Energy Cost ($0.13 / kwhr) | $ 7.3 million | $ 6.1 million | $ 1.2 million |
| Cleanings per year | 2 | 1 | |
| Annual Cleaning Cost ($6,000 per cleaning per train) | $ 180,000 | $ 90,000 | $ 90,000 |

## Conclusions

The pilot study at OCWD successfully demonstrated the latest improvements in RO membrane chemistry and element design while treating the same municipal feed as the elements currently operating in the full scale plant. During the eleven month study, feed pressures in the pilot remained constant at 160 psi and the differential pressure showed no sign of increase. Salt passage was also stable and demonstrated the membrane's ability to consistently meet the plant's permeate quality requirements of less than 0.5 mg/L TOC and less than 5.0 mg/L of Total Nitrogen as N. Relative to elements currently operating at the plant, the improved elements showed up to 25 psi lower differential pressure, 31 psi lower feed pressure, and a 50% reduction in the rate of fouling. The improved performance could save over $ 1.2 million in annual operating cost.

Though the study proved successful, there were limitations. Future studies should include a true side by side comparison of the improved elements with the currently installed element configuration. During this study, the existing plant elements had been in operation for two years before startup of the pilot elements. The existing elements had already experienced some fouling and the upset in feed water quality that caused increasing differential pressures had begun before initiation of the pilot study. Likewise, the pilot studied only stage 1 performance. But the increase in feed pressure of the train was influenced by scaling issues in the third stage as well. Future studies should include monitoring performance from improved elements loaded in all three stages of the train. Nonetheless, based on the new element performance obtained from this pilot study, it can be concluded that the improved membrane chemistry and element design, including the use of a thicker 34 mil spacer, is a preferable, cost saving, option for treating secondary effluent with RO membranes.


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