DESIGN AND OPERATION OF A HYBRID RO SYSTEM USING ENERGY SAVING MEMBRANES AND ENERGY RECOVERY TO TREAT SOUTHERN CALIFORNIA GROUND WATER

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Introduction

Reverse Osmosis System designs have become increasingly innovative in an effort to reduce energy and meet water quality requirements while minimizing the risk of fouling and scaling. RO system designers strive to use the latest energy efficient components and design concepts to achieve lowest life cycle costs while achieving permeate quality targets. Such an approach also allows eligibility for incentives provided by federal and state governments for projects that demonstrate environmentally friendly, “green” designs that reduce energy consumption and carbon footprint.

The City of Oxnard, located in Southern California just sixty miles northwest of Los Angeles, commissioned its first large scale, brackish reverse osmosis water treatment facility in November 2008. The facility is part of the city’s comprehensive regional water resources development program. Designed to meet the city's water supply needs through the year 2030, the facility has an initial capacity of 7.5 million gallons with room for future expansion to 15 million gallons per day to meet the region’s growing demands. The Oxnard Desalter is the first phase of Oxnard’s *G.R.E.A.T* (Groundwater Recovery, Enhancement, and Treatment) *Program* that includes plans for groundwater desalination, wastewater reclamation and groundwater desalination, injection, storage and recovery.

The Oxnard Reverse Osmosis Plant treats local brackish groundwater to produce high quality potable water that is later blended with local groundwater before its distribution throughout the community. Oxnard’s plant utilizes a hybrid membrane design and incorporates an energy recovery device (ERD). Two different types of Hydranautics’ Energy Saving Polyamide membranes are used in a two stage system. The energy recovery device recovers energy from concentrate and uses it to boost 2nd stage feed pressure to optimally balance flux throughout the system, there by lowering overall system energy consumption. The system’s hybrid design and use of ERD improves performance and reduces energy costs.

Design Consideration for the RO System

The Oxnard RO system is designed with three parallel identical trains to achieve a 7.5 MGD total permeate flow. Each train is designed for 1737 gpm (2.5 MGD) of permeate flow. At 80% recovery, the required feed flow for each train is 2170 gpm. The first stage consists of 46 x 7M vessels and the second stage consists of 23 x 7M vessels. An energy recovery device (Turbocharger, PEI) is included between the two stages of each train. Designing the reverse osmosis system at Oxnard required consideration of several factors including feed source and permeate quality requirements, pretreatment, energy recovery, pressure vessel and membrane selection.

Feed Source and Permeate Quality Requirements
Oxnard's RO system treats well water with an approximate salinity of 1500 ppm and a temperature ranging between 18 ^oC and 25 ^oC. The typical well water composition prior to pretreatment is shown in Table 1 below. RO feed turbidity ranges between 0.26 NTU and 0.36 NTU after the cartridge filters. The permeate water quality goals include total dissolved solids (TDS) concentration below 54 ppm and total hardness below 14 ppm as CaCO3.

Table 1: Feedwater Analysis for Oxnard Well Water

Parameter	**units**	
EC	umhos	1970
pH		7.2
Temperature	Degrees C	18-25
Na	ppm	134
Ca	ppm	231
Mg	ppm	79.5
SiO2	ppm	34.7
Cl	ppm	70.7
F	ppm	0.553
NO3	ppm	62.2
SO4	ppm	737
K	ppm	6.21
TDS	ppm	1,594
Alkalinity	ppm CaCO3	258

Pretreatment
In order to achieve stable performance and high recoveries, both chemical and physical pretreatments were utilized. Oxnard has a unique plant layout. In some cases, the treatment process in a brackish application uses well pumps

that feed water directly to a reservoir or storage tanks. The feed water is then re-pumped through cartridge filters at lower pressure before it is boosted by high pressure pumps prior to feeding into the RO membranes.

Oxnard’s RO system eliminates the use of a cascading series of pumps that require additional equipment and energy loss. Groundwater is pumped directly through the cartridge filters (figure 1a) to the RO membranes by the well pumps (figure 1b). High pressure cartridge filters are used to capture particulates larger than 5 microns. The design eliminates the break tank, low pressure pumps and high pressure booster pumps by selecting larger wellhead pumps and high pressure cartridge filters. This design increases the efficiency of pumping and keeps the pumps outside of the building which reduces the footprint. The facility’s noise level is also much lower than traditional designs.

a b

Figure 1: Oxnard’s High-Pressure Cartridge Filtration System and Well Pumps

Antiscalant is injected at 3 ppm to reduce the likelihood of saturated salts precipitating onto the surface of the tail elements.   The pH of the feed water is lowered from 7.5 to 6.7 in order to maintain an acceptable Langlier Saturation Index (LSI) of less than 2 in the concentrate. Though target range for recovery is 80%, Oxnard is considering running at recoveries as high as 85% in the future. However, silica levels within the feed water limit the level to which the brine may be concentrated without the occurrence of silica scaling.

Turbo Boost Energy Recovery Device

An Energy Recovery Device (turbo booster) is used to increase the feed pressure in the second stage and balance flux between the two stages. The turbo booster recovers the energy in the high pressure concentrate stream of the second stage and transfers it to the feed stream of the second stage feed stream.

The use of energy recovery device provides several advantages:

1. The ERD harnesses available energy from the second stage concentrate that would otherwise be wasted (by a throttling valve), thus reducing energy consumption
2. The ERD increases the average flux through stage 2
3. The increased flux in the second stage improves overall flux distribution between the lead and tail elements of the system
4. The pressure boost provided to the second stage reduces the head requirements for first stage feed
5. The improved flux distribution also reduces fouling in the lead element.
6. The increased flux through the second stage improves permeate quality from the second stage.

Pressure Vessel Selection

The RO system at this facility uses seven elements per vessel instead of the conventional six elements per vessels. The primary design parameter that limits the number of elements per pressure vessel is the minimum concentrate flow per pressure vessel that is needed to maintain sufficient cross-flow velocity (12-16 gpm). However, in the case of the Oxnard RO, there is sufficient cross flow in each vessel to keep the tail elements flushed, even with use of seven elements per pressure vessel. The added membrane area within the longer vessel required the use of fewer vessels, which saved on capital costs. The use of 7M vessels enables the RO to run at a recovery of 80% in only two stages and in future at 85% recovery.

Figure 5: Oxnard Desalter’s Two Stage 46x23 RO with ERD Turbo Booster

Membrane Selection

The membrane system design was intended to reduce operating costs by reducing energy consumption. The hybrid design uses a mix of two different energy saving membranes to improve flux distribution, improve permeate quality, and reduce pressures. The first stage of the system uses the Hydranautics' ESPA1 membranes (99.3% rejection, 12,000 GPD productivity at standard wet test conditions). The second stage contains Hydranautics' ESPA2 (99.6% rejection, 9,000 GPD productivity at standard wet test conditions). The ESPA 1 is the more permeable of the two membranes while the ESPA2 produces better permeate quality. To better understand the rationale behind the selection and placement of each membrane type in their respective stages, four other designs are considered below and compared to the actual design that was selected for Oxnard:

1. **High Rejection Design-No ERD** : Using higher rejection ESPA2 in both stages without increasing second stage feed pressure with an ERD
2. **High Flux Design-No ERD**: Using higher flow ESPA1 in both stages without increasing second stage feed pressure with an ERD
3. **Poor Flux Distribution Design-No ERD**: Using the higher flow ESPA1 in stage 1 followed by the higher rejecting ESPA2 in the second stage without increasing second stage feed pressure with an ERD.
4. **Alternative Hybrid Design-No ERD**: Using higher rejection ESPA2 in stage 1 followed by the higher flow ESPA1 in the second stage without increasing the second stage feed pressure with an ERD t.
5. **Selected Design**: Using higher flow ESPA1 in the first stage followed by the higher rejection ESPA2 in the second stage while using the ERD to balance the fluxes by boosting second stage pressure.

Figure 6 compares the permeate quality and power requirement of these five designs. Using ESPA2 elements in both stages would require the most energy and produce a permeate TDS far lower than the permeate TDS requirement (54 ppm TDS). Using all higher flow ESPA1 membranes in both stages would use much less energy, however the permeate TDS would be too high.

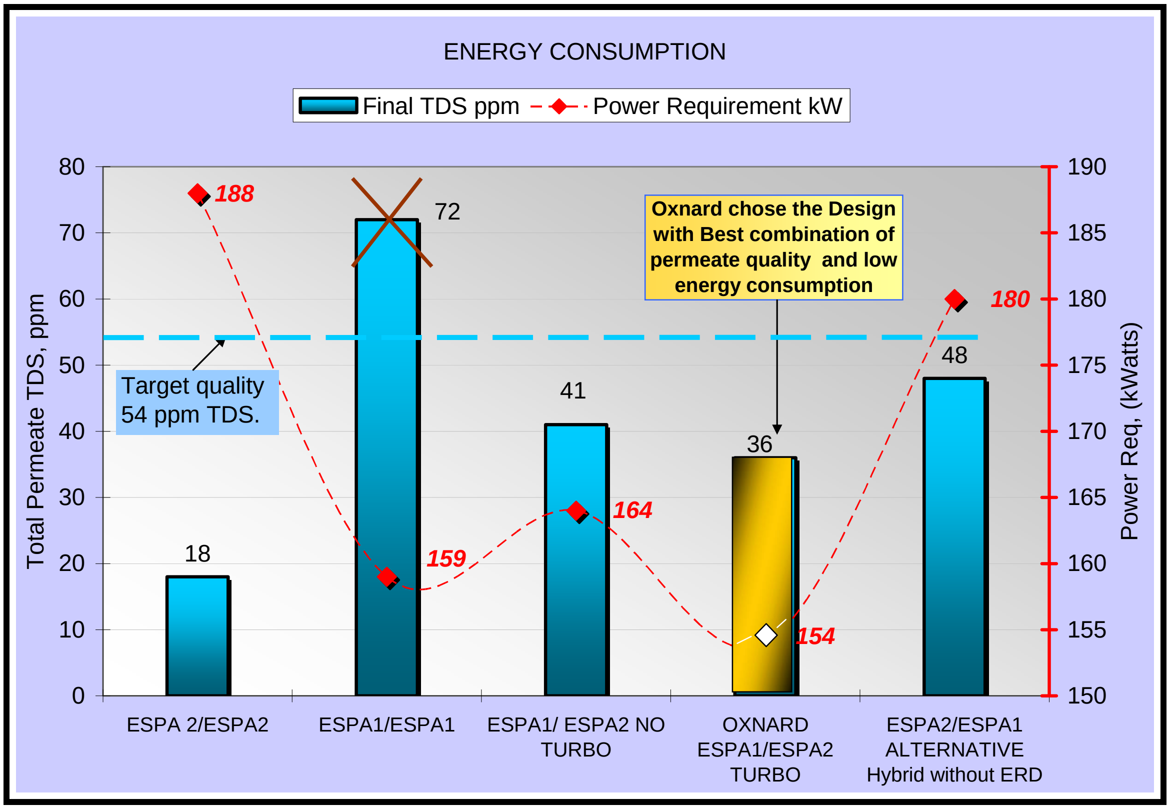

Figure 6: Energy Consumption and Permeate Quality of Different RO Designs using Combinations of Membranes and ERD

The hybrid design with ESPA1 in the first stage and ESPA2 in the second stage offers an acceptable combination of low power requirement (164 kW) and good permeate quality (41 ppm TDS). However, the drawback of this design, as will be discussed below, is the extreme flux imbalance.

At 154 kW, the lowest energy consumption of the four design options is the design that was finally selected with higher flow ESPA1 in the first stage, higher rejection ESPA2 in the second stage, and an interstage turbocharger to balance flux. This placement of elements is the inverse of what is typically staged in a two stage system that does not include a turbocharger between the two stages. In a typical two stage hybrid system, the lower fluxing elements are placed in the first stage and the higher fluxing elements are placed in the second stage in order to distribute the work throughout the entire 2 stage system and to avoid placing too much flux on the front end that might lead to fouling, mechanical damage, and too little cross flow in the latter elements.

An alternative hybrid design without turbo using ESPA2 in stage1 followed by higher fluxing ESPA1 in stage 2 is also included in Figure 6. The placement of the membranes in this design is typical of a hybrid system that does not have a turbo to balance flux. The final permeate quality meets target levels at 48ppm and flux is distributed well throughout the system. However, neither energy nor quality is superior to that of the Hybrid-ERD design Oxnard ultimately chose.

Figure 7 below shows flux distribution as it pertains to element position within vessels in series. The ESPA1, a very high fluxing membrane shows a dramatic flux drop across 14 membranes in two stages: a system problem created due to its higher productivity. Using ESPA1 in the first stage and ESPA2 in the second stage leads to a greater flux imbalance. The placement of the elements in this design is identical to the Oxnard design only without the turbo boost. The consequences of an improperly balanced system with too much flux on the front end are fouling, mechanical damage, and too little cross flow for the tail elements on the back end of the system. Implementation of a turbo boost in the Oxnard design dramatically corrects this flux imbalance.

The permeate quality of the Oxnard hybrid design is also balanced between the two stages (Figure 8). The turbo boost not only provides an additional 25-30 psi for the RO's 2nd stage, it improves the permeate quality for the second stage. The permeate TDS of the two stages are similar. Stage 1 produces 34 ppm and stage 2 produces 46 ppm. This is in stark contrast to the high flux design using all ESPA1 in which stage 1 produces 34 ppm, but stage 2 produces 218 ppm.

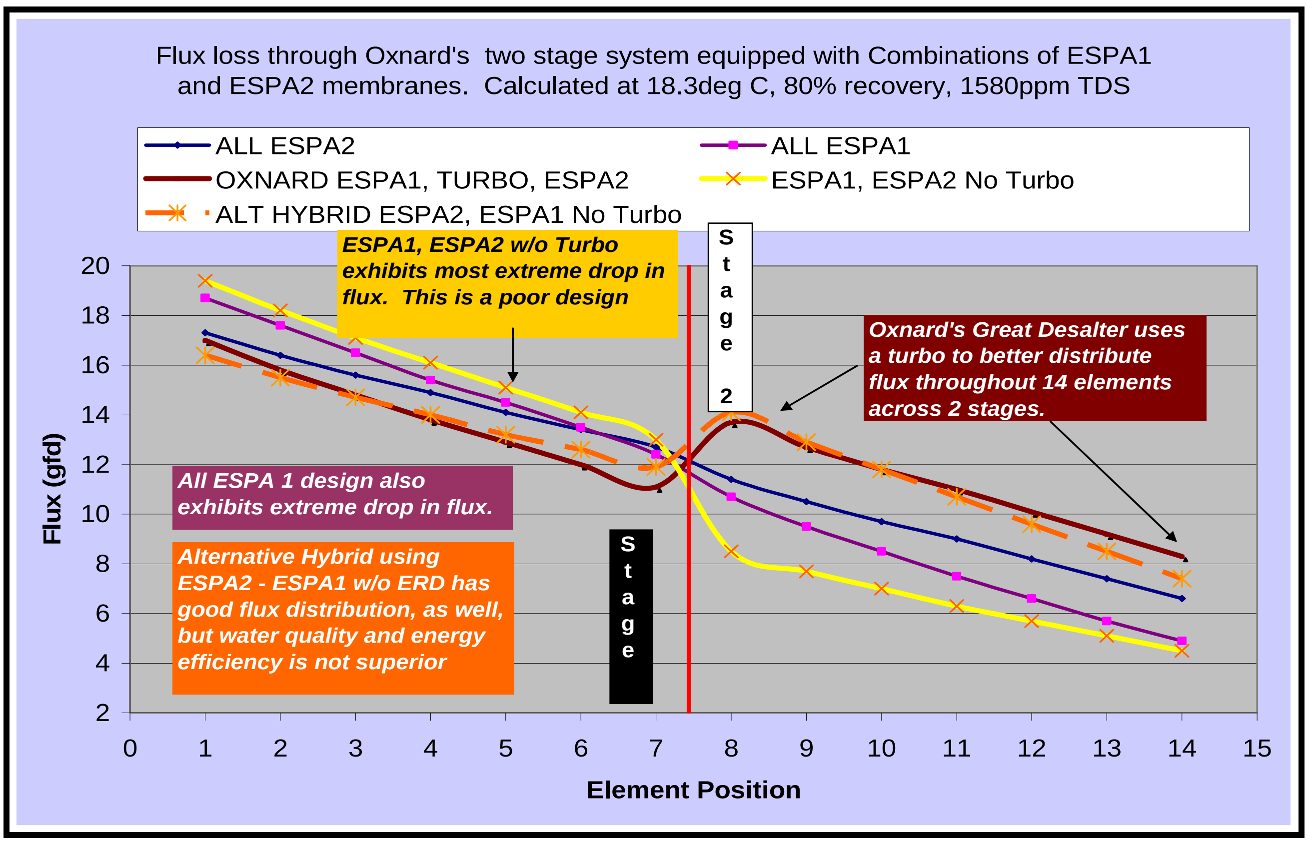

Figure 7: Flux loss in a 2-Stage System with Various Membrane Configurations

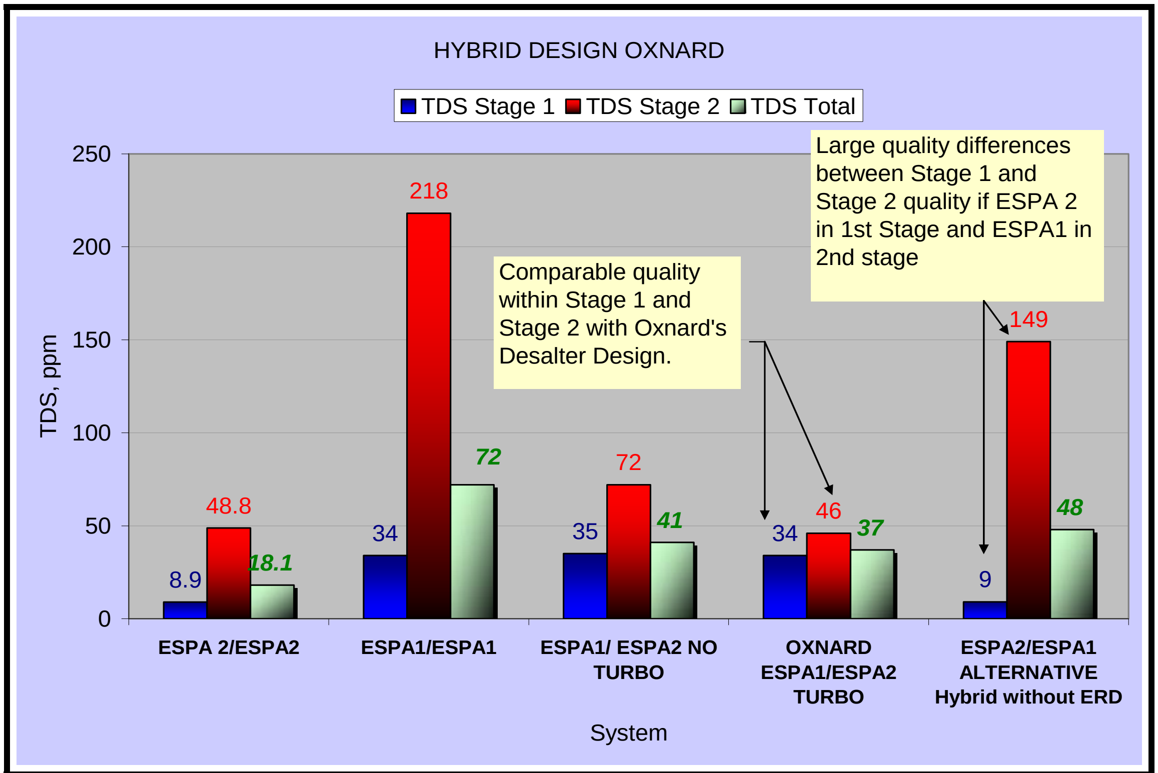

Figure 8: Water Quality Improves for Oxnard's 2nd stage using turbo boost

System Performance

Due to lower than expected demand, the City of Oxnard has not run the plant at the full capacity of 7.5 MGD. The plant operated closer to 5 MGD during most of 2009. The RO has been operating in a stable manner since December of 2008. Typically two trains are operated at design conditions. The normalized permeate flow through both stages have been stable for a period of 1 year (Figure 9). The differential pressure loss was also stable during that period, indicating little or no fouling (Figure 10). As of late 2009, no cleanings have been conducted. Permeate quality requirements have been met in all three trains (Table 2). Salt passage has been stable at 2% through the ESPA1 elements in the first stage and 1% through the ESPA2 elements in the second stage. Table 3 shows an ion analysis summary performed at startup.

Table 2: City of Oxnard Startup Permeate Quality

	Requirement	Actual
Permeate Conductivity uS/cm	< 86	49
Hardness (ppm as CaCO3)	<14	4
TDS (ppm)	< 54	32

Table 3: Ion Analysis for City of Oxnard Startup Train1

Sample ID	Na (ppm)	Ca (ppm)	Mg (ppm)	SiO2 (ppm)	K (ppm)	Cl (ppm)	F (ppm)	NO3 (ppm)	SO4 (ppm)	Alk (ppm as CaCO3)
Feed Stage1	134	231	79.5	34.7	6.21	70.7	0.553	62.2	737	258
Perm Stage 1	7.74	0.594	0.212	1.11	0.147	2.22	<0.05	9.65	2.83	
Perm Stage 2	8.93	0.850	0.313	0.82	0.154	2.44	<0.05	9.40	4.90	
Total Perm	8.23	0.654	0.235	1.03	0.165	2.32	<0.05	9.62	3.36	4.0

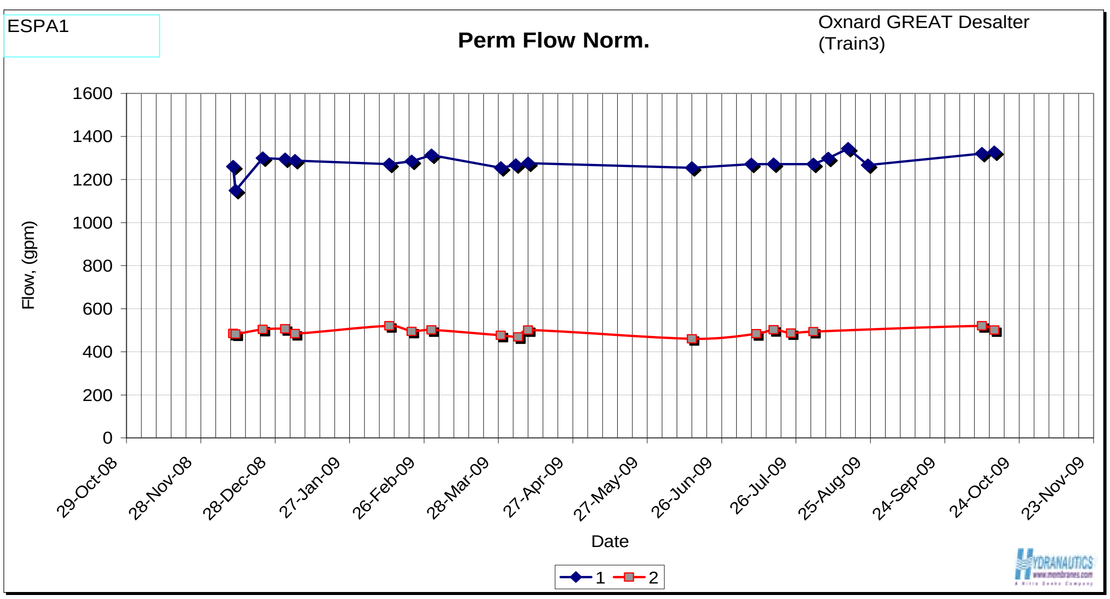

Figure 9: Stable Normalized Permeate Flow over 1 year of operation

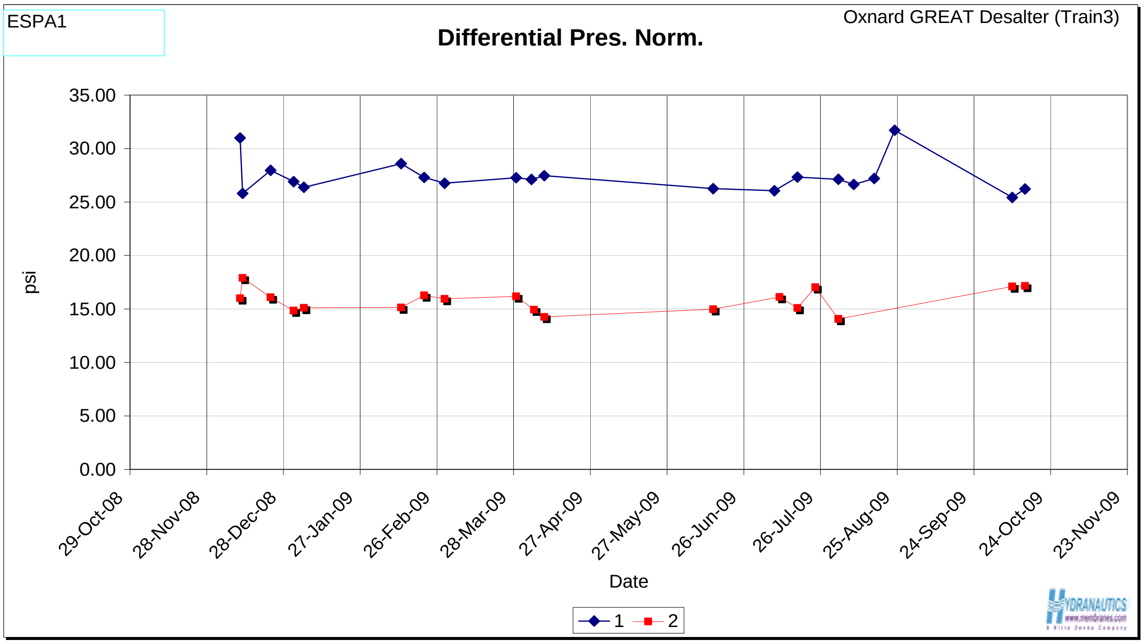

Figure 10: Differential Pressures of Oxnard Desalter Stage 1 and 2

Conclusion

Oxnard's Desalter uses the latest in RO technology and design to treat Southern California groundwater to produce high quality potable water which is blended with local water supply before its distribution throughout the community. The RO employs several design techniques, such as a simplified delivery system and 7M pressure vessels, to reduce operating and capital costs. Furthermore, the design of the RO successfully combines advancements in membrane technology and energy recovery technology to meet water quality targets at reasonable cost. The use of a combination of high flow and high rejection RO membrane achieves a balance between low pressures and enhanced permeate quality. The implementation of the energy recovery device improves flux distribution between the two stages which further improves permeate quality. The use of a hybrid design and turbo boost reduces power consumption by 20%, relative to a conventional design using all high rejection membranes. The permeate TDS is also reduced by 50%, from 75 ppm to 35 ppm, relative to a conventional design using all high flow membranes. The Oxnard RO continues to run stably since startup in December 2008. The plant capacity of 7.5 MGD and its proposed expansion to 15 MGD are expected to supplement the City of Oxnard's water supply through the year 2030.