OPTIMIZING BRACKISH WATER REVERSE OSMOSIS FOR AFFORDABLE DESALINATION

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Introduction

The Affordable Desalination Collaboration (ADC) represents a unique collaboration of leading government agencies, municipalities, RO membrane manufacturers, consultants and professionals that are working together to improve the designs and technology applied in state of the art desalination systems. The ADC was formed in 2004 to optimize and demonstrate seawater desalination technologies and convey achieved success by desalinating seawater (at the United States Navy's Seawater Desalination Test Facility in Port Hueneme, California) at energy levels between 6.0-6.9 kWh/kgal (1.6-1.8 kWh/m^3).

The objectives of the ADC are to demonstrate affordable, reliable, and environmentally responsible reverse osmosis (RO) desalination technologies, as well as to provide a platform by which cutting-edge technologies can be demonstrated and measured for their ability to reduce the overall cost of the RO treatment process.

Following the previous successes in the seawater desalination arena, the ADC is working with the Texas Water Development Board (TWDB) to optimize brackish water desalination by pursuing the following demonstration scale tasks:

- Phase 1- Demonstrate brackish water energy recovery by testing state-of-the-art isobaric energy recovery technology in an optimized brackish water design.
- Phase 2- Develop and demonstrate new process designs that are possible as a result of the integration of the isobaric energy recovery technologies with the two stage, brackish water desalination system. The pressure exchanger (PX) technology in particular provides the opportunity to develop unbalanced flow schemes to attempt to improve the performance of brackish water RO systems by increasing the overall recovery of brackish water RO systems.

In January of 2010, the ADC demonstration plant was reconfigured from a single stage Seawater RO (SWRO) system to a two-stage brackish water system and was mobilized to the Kay Bailey Hutchison Desalination Plant in El Paso, Texas. The operating protocol established various operating points (vary flux and recovery) in order to determine the most affordable operating point. Two months of demonstration-scale testing was completed to verify the reliability of the most affordable operating point.

The paper will describe the ADC's demonstration-scale pilot's equipment and design criteria. Additionally, the paper will present the demonstration scale data and operating experiences during Phase 1 of the ADC's brackish water RO testing. Preliminary results show an energy savings over typical brackish water configurations and energy recovery systems. Using the ADC demonstration scale operating data, a specific energy comparison will be developed for the operation of the 27.5-million gallon-per-day Kay Bailey Hutchison's Desalination Plant.

TWDB-ADC Demonstration Study Objectives

The objectives of this Texas Water Development Board (TWDB) Brackish Groundwater Demonstration Project are as follows:

- Test and demonstrate state of the art isobaric energy recovery technology in an optimized brackish water design. The ADC expects to achieve 15-30% energy savings over traditional brackish water systems where energy recovery turbines are applied.
- Develop and demonstrate new process designs that are possible as a result of the isobaric energy recovery technologies. As a natural result of the PX technology in particular, there are new kinds of flow schemes that can improve the performance of higher recovery brackish water systems. We will use the ADC pilot system to test and demonstrate these new flow schemes in order to push the recoveries beyond what has been traditionally achievable.

The ADC operated at the El Paso Brackish Water Desalination facility and used the same feed water as the full-scale plant. The desalination plant draws feed water from a number of brackish groundwater wells from the Hueco-Mesilla Bolson (Basin) in El Paso, TX. In so far as possible, the pilot system was designed to mimic the full-scale plant so that comparisons could be made between the pilot system performance and the full-scale plant performance.

While evaluating these brackish water process alternatives, it is important that potable water quality met primary and secondary standards. Potable water quality goals for this ADC TWDB study are summarized in Table 1.

Table 1. Demonstration Scale Test Potable Water Quality Goals

Parameter	Unit	Value	Basis
TDS	mg/L	< 500	USEPA Secondary Standard
Chloride	mg/L	< 250	USEPA Secondary Standard
Nitrate	mg/L as N	< 10	USEPA Primary Standard
Nitrite	mg/L as N	< 1	USEPA Primary Standard
Fluoride	mg/L	< 4	USEPA Primary Standard
Sulfate	mg/L	< 250	USEPA Secondary Standard
pH	pH units	6.5-8.5	USEPA Secondary Standard

Source: EPA 816-F-09-0004, May 2009

Technology and Approach

In January of 2010, the ADC demonstration plant was reconfigured from a single stage SWRO system to a two-stage brackish water system and was mobilized to the Kay Bailey Hutchison Desalination Plant in El Paso, Texas (Figure 1). The startup testing initiated in February 2010, and testing continued through December 2010. The following sections will describe the major equipment that make up the test facility.

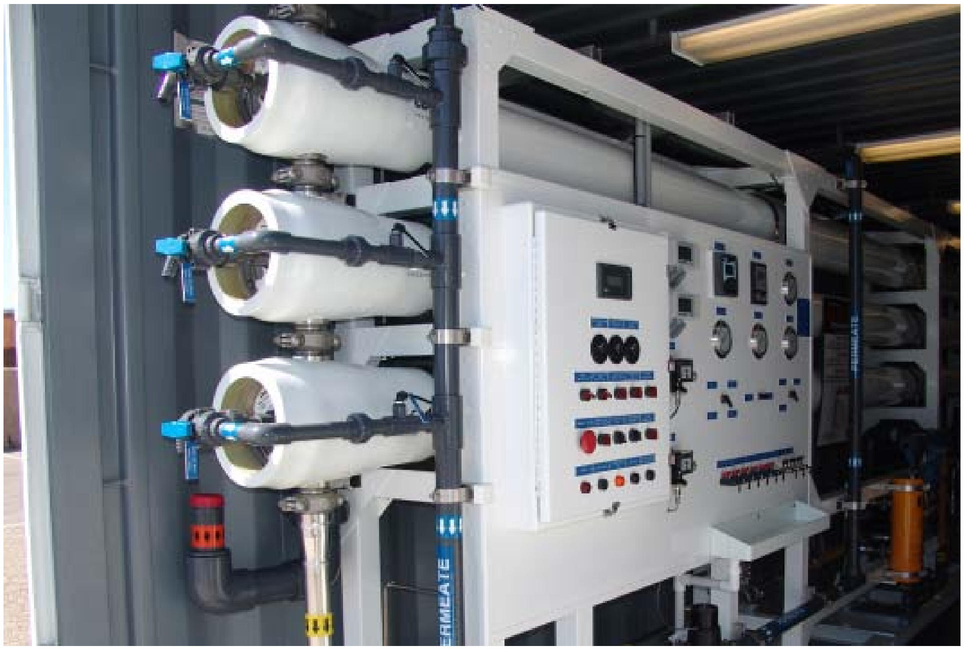

Figure 1. ADC Pilot Demonstration Unit

Pilot Test Facility

The criteria used to size the demonstration scale brackish water RO (BWRO) and cartridge pretreatment equipment are presented in Table 2.

Table 2. BWRO Demonstration Scale Test Equipment Criteria

Parameter	Value
Feed, Flush, Cleaning Pump	
Manufacturer/Model	AMPCO, ZC2 2.5 x 2
Duty Range	170 gpm @ 80 ft TDH
Cartridge Filter	
Manufacturer/Model	Eden Excel, 88EFCT4-4C150
Quantity	22
String Wound Cartridge Specs	#XL1-EP050-PLC40, 5 micron
Pressure Vessels	
Manufacturer/Model	Codeline, 80A100-7
Quantity	3
No. of Membrane Elements per Vessel	7
Membrane Elements	
Manufacturer/Model	Hydranautics ESPA1-7
Quantity	21
Diameter	8 inches
Surface Area	400 ft^2
Total Membrane Area (A_{sys})	8,400 ft^2
High Pressure Pump	
Pump Type	Positive Displacement, VFD
Manufacturer/Model	Danfoss 2 x APP-10.2
High Pressure Pump Flow	40-90 gpm (7-15 gfd)
High Pressure Pump TDH	349 – 2,698 ft H_2O (150 – 1,160 psi)

Parameter	Value
PX Booster Pump	
Pump Type	Multi-stage centrifugal, VFD
Manufacturer/Model	Energy Recovery, Inc. HP-8504
PX Booster Pump TDH	70– 115 ft H_2O (30 – 50 psi)
Energy Recovery Device	
Type	Pressure Exchanger
Manufacturer/Model	Energy Recovery, Inc. PX-70S SW and PX-45S BW
Quantity	2

The Kay Bailey Hutchison Desalination Plant (KBHDP) uses the same membrane pretreatment and membranes (Hydranautics ESPA 1) as the ADC system (Figure 2). The two stage 2:1 array with seven 8-inch elements in each vessel is also identical. The significant differences are the pump type, inter-stage booster pump, energy recovery system, permeate throttling, and motor and pump efficiency. Recovery for the ADC system matched the 80% recovery and higher and lower values of the KBHDP.

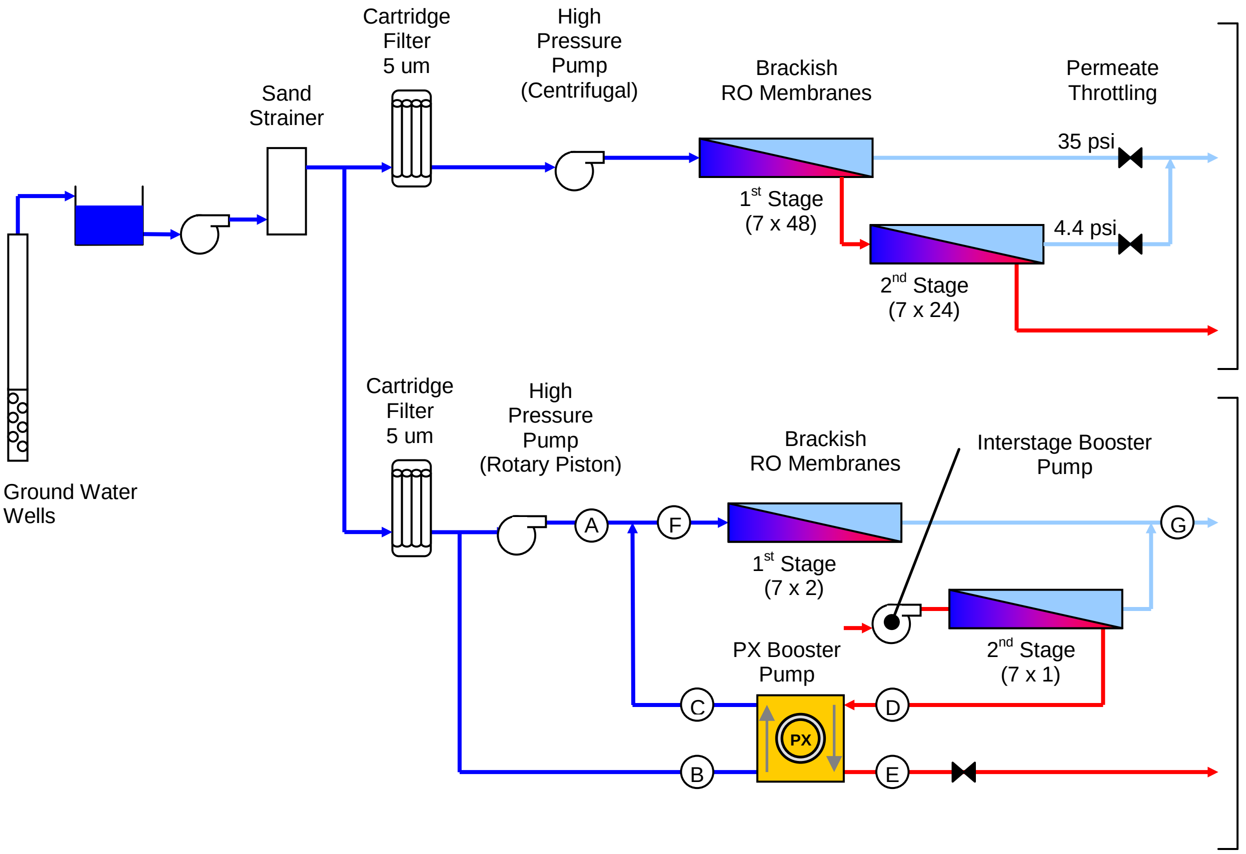

Figure 2. KBHDP and ADC Systems Process Schematic

Isobaric Energy Recovery

Isobaric energy recovery is a technology that has been used in the seawater RO industry since the mid-1990s. It is currently the market leader amongst other energy recovery technologies in the seawater desalination market with over 7,000 installations currently in service worldwide. However, it has not yet been used in the brackish RO market on a large-scale municipal system.

An isobaric energy recovery system utilizes the principle of positive displacement to pressurize filtered feed water by direct contact with the high-pressure concentrate stream or reject stream from a RO system. The PX, which is manufactured by Energy Recovery Incorporated (ERI), was selected for assessing the feasibility of incorporating energy recovery devices in brackish water installations. The PX, like all isobaric energy recovery devices, exchanges pressure from the concentrate stream by contacting it directly with a portion of the feed stream. The feed stream and concentrate stream through the PX are equal in flow. A portion of the feed water is fed to the PX after the cartridge filters and the residual concentrate pressure provides enough pressure to the feed stream to meet the hydraulic needs of the first stage while bypassing the RO feed pump. The result is that energy is saved by reducing the flow through the RO feed pumps (by the amount equal to the concentrate flow), and thus reducing the RO feed pump horsepower. This contact between the feed stream and the concentrate stream will inevitably result in some mixing which increases the feed salinity to the RO membranes. This mixing must be accounted for during the RO process modeling to determine the impact to the feed pressure and permeate TDS, which both will increase as a result of the increase in feed water salinity.

In an RO-PX system, the high pressure pump is sized on the basis of the RO permeate flow plus a small volume of permeate for rotor lubrication, not the full RO feed flow. Therefore, the PX significantly reduces flow through the high pressure pump. This point is significant because a reduction in the size of the main pump results in lower power consumption and operating costs. In the standard single stage seawater system the PX auxiliary/booster pump is applied at the outlet of the PX. However, in the 2-stage brackish water system shown in Figure 2, the PX booster pump is installed between the first and second stage. In this optimized two-stage configuration the PX booster pump also acts as an interstage booster pump helping to reduce the required pressure from the main high pressure feed pump by balancing the flux between the 1st and 2nd stages.

Operation Modes

Two operation modes – optimized configuration and underflushing, were conducted in the course of the pilot testing. Figure 3 illustrates the modes of operation.

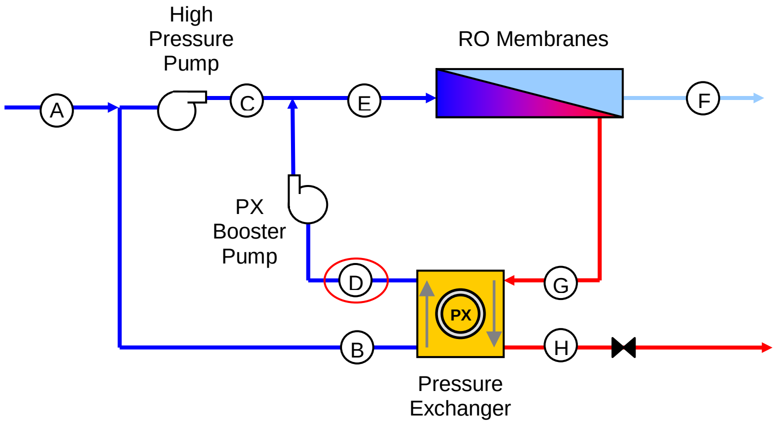

Figure 3. Operation Modes

Optimized Energy Recovery Configuration

To achieve and mimic the 80 percent RO recovery at the KBHDP, the resulting RO concentrate flow from the pilot was insufficient for the PX-45S unit. In order to simulate full-scale PX operation and maintain the manufacturer recommended less than 4 percent salinity mixing at the RO feed, overflushing of the PX system was performed. In this operation mode, low pressure feed flow (B) to the PX was greater than the high pressure outlet (D) flow, hence the RO recovery was greater than the system recovery. Under normal circumstances where the PX is appropriately sized for the operation, overflushing would not be required.

Brine Recirculation Configuration

By incorporating the PX with the RO, brine recirculation to yield an increased overall water recovery can be achieved through unbalancing the flows through the isobaric energy recovery device. In this underflush operation mode, high pressure outlet flow (D) from the PX was greater than the low pressure feed flow (B). The result is the RO recovery will be lower than the system recovery. Recirculation of the RO concentrate with the source water will occur to produce the increase in RO feed flow. The unbalanced flow scheme via brine recirculation is part of the test conditions outlined for this study. The advantages of this mode of operation may include:

- Improved boundary layer conditions by maintaining “high” velocity flows,
- Balanced membrane flux through increased lead element velocities and salinity,
- Minimum brine flow requirements within manufacturers’ specifications, and
- Maximum allowable recoveries within manufacturer’s specifications.

Source Water

The Kay Bailey Hutchison Desalination Plant is supplied by brackish groundwater wells from the Hueco-Mesilla Bolson Basin, where the TDS of the combined feed into the plant averages 2,000 mg/L. Table 3 lists the water quality constituents in the design feed water that the pilot unit will receive.

Table 3. Design Feed Water Quality

Constituent	Unit	Concentration
Calcium	mg/L	135
Magnesium	mg/L	35
Sodium	mg/L	609
Potassium	mg/L	19
Barium	mg/L	0.11
Strontium	mg/L	2
Carbonate	mg/L as $CaCO_3$	0.2
Bicarbonate	mg/L as $CaCO_3$	57
Sulfate	mg/L	187
Chloride	mg/L	1093
Fluoride	mg/L	0.6
Nitrate	mg/L	0.1
Silica	mg/L	32

Constituent	Unit	Concentration
Temperature	^{o}C	26
pH	pH unit	7.2
TDS	mg/L	2183
Turbidity	NTU	< 1

Results and Discussion

Optimized Isobaric Energy Recovery Configuration

Figure 4 illustrates the results of the RO and overall system recovery, and the normalized permeate flows from each stage in the pilot unit in the optimized configuration. The data spans from February 2010 to August 2010. Due to overflushing of the PX, the RO recovery is greater than the System recovery. The 80 percent RO recovery was the baseline of the system (to the right of each vertical dashed line), which was run for at least one week prior to demonstration test points (to the right of each green vertical line) to push the recovery of the system.

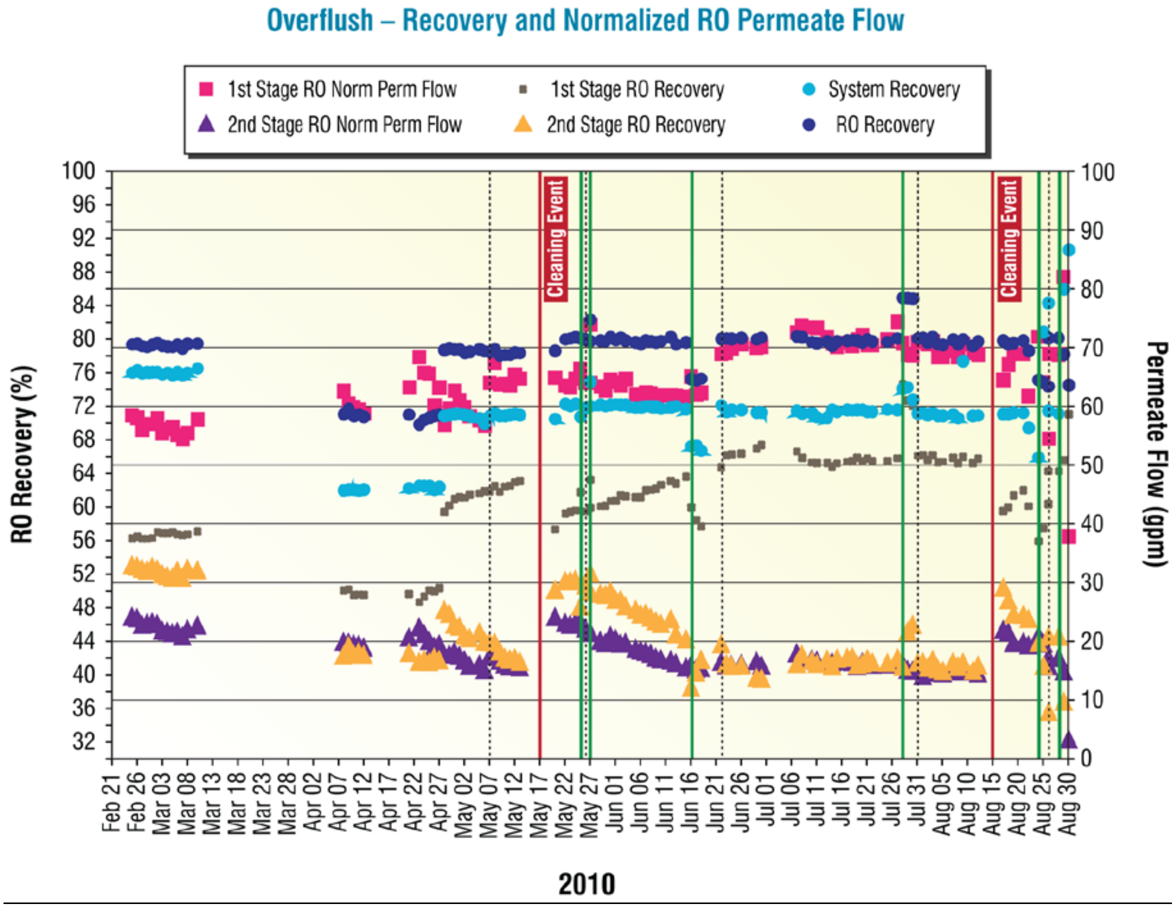

Figure 4. Recovery and Normalized Permeate Flow for the Optimized Configuration

Flux decline was observed during the course of pilot testing, mostly from the second stage. As a result, the flux in the first stage membranes increased to achieve an overall 80 percent RO recovery. Preliminary predictive water quality simulations for the feed water did not indicate the likelihood of mineral scaling. Several membrane-cleaning cycles were conducted using high pH cleaners to remove possible organic fouling on the membranes and recover membrane performance.

Concentrate Recirculation Configuration (unbalance/underflush)

To exceed the 80 percent system recovery, a 2-month long-term test was carried out that included concentrate recirculation by underflushing. The resulting RO recovery in this configuration will be lower than the system recovery. In this unbalanced flow scheme, the system is synonymous with concentrate recycling where the RO concentrate is recirculated through the PX resulting in an increase in RO feed flow. Figure 5 illustrates the results of the RO and overall system recovery, and the normalized permeate flows from each stage in the pilot unit for the underflushing configuration. The data spans from August 2010 to December 2010.

Flux decline was continually observed despite several cycles of high pH cleaning to remove possible organic foulants. Although the RO recovery was returned to baseline conditions after each clean, flux decline continued to affect the optimal operation of the pilot. In September, the lag membrane element in the second stage was sent for membrane autopsy to determine the cause for flux decline and new membranes were installed in the RO unit. Membrane autopsy results in November revealed no visible foulants or mineral scalants on the membrane surface. Energy dispersive X-ray analysis (EDAX)) showed a high concentration of silica (45.8%). Even with silica-specific antiscalant dosing, fouling in the second stage was persistent at system recoveries of 85% due to supersaturation of silica in the concentrate.

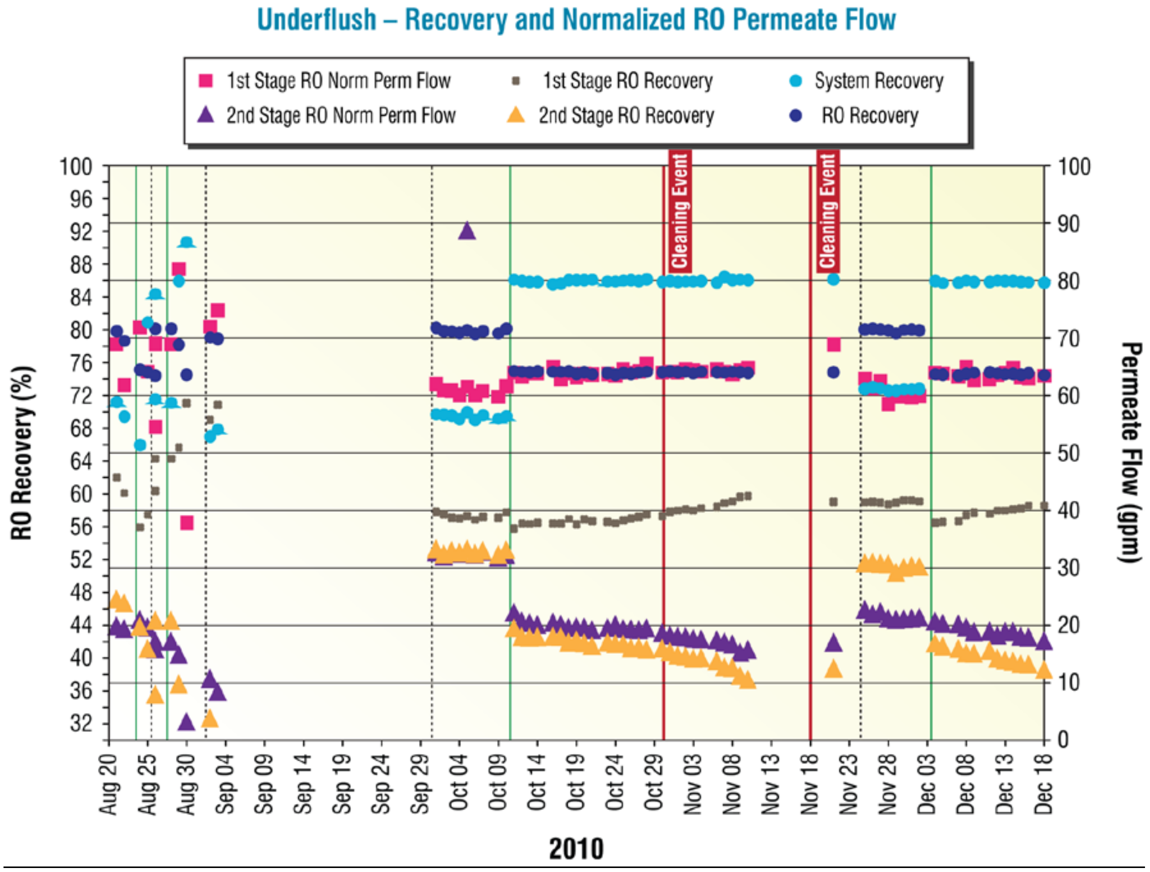

Figure 5. Recovery and Normalized Permeate Flow for the Underflush Configuration

RO Process Specific Energy

In Figure 6, the RO process specific energies were compared. Several scenarios were considered:

1. "<u>KBHDP</u>": Actual conditions at the plant, using assumed pump and motor efficiencies taken from pump curves.
2. "<u>KBHDP + booster</u>": Projections for KBHDP with the addition of a booster pump to balance flux across membrane stages and assumed pump and motor efficiencies from pump and motor curves.
3. <u>"80% Optimized and 75-85 underflush"</u>: Actual ADC pilot specific energy (at optimized 80% RO recovery and also 75% RO -85% system recovery) with pilot pump and motor efficiencies.
4. "<u>80% Optimized w/KBHDP Eff." and "75-85 underflush w/KBHDP Eff</u>": Calculated ADC upsized 3 MGD RO specific energy with assumed KBHDP pump and motor efficiencies, upsized to one full-scale 3 MGD KBHDP RO train.
5. "<u>80% Optimized w/out PX</u>": Calculated ADC upsized 3 MGD RO specific energy without PX, but with an inter-stage booster.

The assumed pump efficiencies are presented in Table 4. At the same feed TDS and system pump efficiency into the system, in decreasing specific energy ranking: KBHDP > 75-85 Underflush Upsized 3 MGD Flow > KBHDP + Booster > 80% Optimized Upsized 3 MGD Flow.

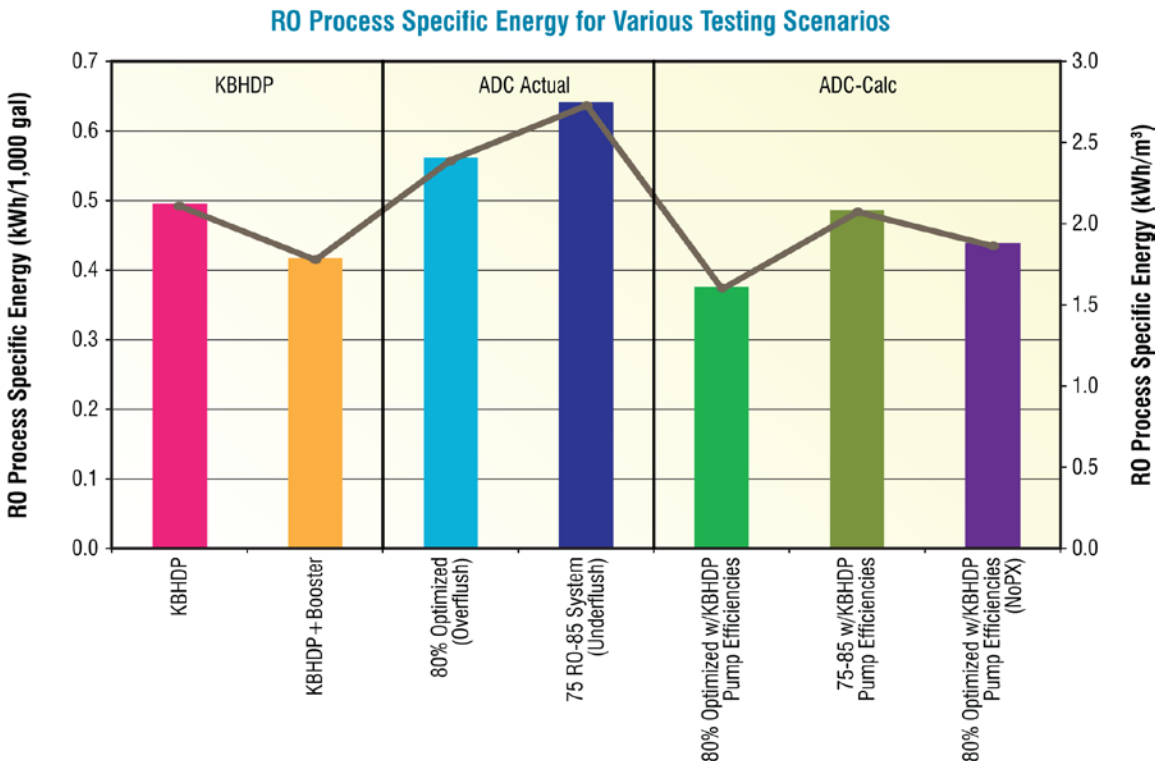

Figure 6. RO Process Specific Energy Comparison

Table 4. Pump Efficiencies for RO Specific Energy Calculations

		HP/Feed Pump			**Interstage Booster**		
VFD Efficiency: 95%		**Flow (gpm)**	**Pressure (psi)**	**Assumed pump/motor efficiencies (%)**	**Flow (gpm)**	**Pressure (psi)**	**Assumed pump/motor efficiencies (%)**
KBHDP	KBDHP	2483	176	81/94	-	-	-/-
	KBDHP+Booster	2525	114	81/94	1104	75	77/95
ADC Actual	80% Optimized	88	138	63/90	33	39	30/95
	75 RO-85 System	89	177	70/90	49	46	37/95
ADC Calc	80% Optimized w/ KBDHP Eff	2083	138	81/94	1036	39	77/95
	75-85 w/ KBDHP Eff	2106	177	81/94	1160	46	77/95

An energy savings comparison was performed for the full-scale 3 MGD flow scenario using the ADC 80-80 configuration. At full-scale flows, the 80-80 RO-PX configuration will save 24% of the energy consumed compared to the current KBHDP, 10% compared to KBHDP +Booster, and 23% compared to the 75-85 underflush configuration. At a $0.10/kWh energy cost assumption, this translates to a $52,500 savings per train compared to current KBHDP, $18,500 savings to KBHDP + Booster, and $48,700 compared to the 75-85 underflush configuration.

Conclusions

The use of the PX and interstage booster pump provided modeled full-scale plant energy savings (using pilot testing results) over configurations without a PX/interstage booster pump and without a PX. However, these savings would be offset to some degree by the increased capital expense of the PX and/or interstage booster pump.

The second pass silica scaling issue at 85% system recovery limited the system recovery to 80% for longer term testing. This was the case for both balanced and unbalanced configurations. It was initially expected that unbalancing the PX to increase the cross flow velocity in a brine recirculation mode would help with this problem, but that was not the case. Increasing the cross flow velocity could potentially help reduce organic matter fouling. Therefore, unbalancing the PX to increase overall system recovery (vs. balanced conditions) does not appear to provide an advantage when silica scaling is the limiting factor.