# Low Energy Consumption in the Perth Seawater Desalination Plant

**Authors:** Miguel Angel Sanz [1], Richard L. Stover, Ph.D. [2]

[1] Degrémont S.A., Ibarrekolanda 19, 48015 Bilbao, Spain. Phone: +(34) 94 4763800, Email: miguel.angel.sanz@degremont.com
[2] Energy Recovery, Inc., 1908 Doolittle Drive, San Leandro, California, USA 94577. Phone: +1 510 483-7370, Email: stover@energy-recovery.com

**Presenter:** Miguel Angel Sanz

## Abstract

The 143,000 cubic meters per day seawater desalination plant in Kwinana Beach (Perth), Western Australia started up in November 2006. As of February 2007, it was the largest SWRO desalination plant in the Southern Hemisphere and the second largest SWRO plant in the world. Built by Suez Degrémont and Multiplex Engineering Pty Ltd., the Perth plant increases drinking water production capacity for the city of Perth where conventional freshwater resources are in very short supply. The plant is entirely powered with electricity generated by a wind farm to minimize greenhouse gas emissions. It operates with twelve seawater reverse osmosis (SWRO) trains in the first pass, each with a production capacity of 13,350 cubic meters per day. Six high-pressure pumps on a common manifold or "pressure center" supply a portion of the high-pressure seawater fed to the SWRO trains. The remainder of the high-pressure seawater is supplied by arrays of PX-220 PX energy recovery devices. All the production is treated again through six low-pressure reverse osmosis trains in a second pass. The plant's hydraulic design provides for cost-effective operation over a wide range of flow and pressure conditions, thereby maximizing operational flexibility.

The energy consumption of the first pass SWRO train is approximately 2.2 - 2.5 kilowatt hours per cubic meter. All pumps of the second pass are equipped with frequency converters to minimize energy consumption in every season. At the nominal capacity and with an overall water recovery rate of 42%, the plant consumes less than 3.5 kilowatt hours per cubic meter including intake, pretreatment, both RO passes, post-treatment, potable water pumping and all electrical losses. This is a remarkably low energy level compared to the best performance reported in 2000.

The authors describe the challenges and solutions of the design, installation and operation of the Perth seawater desalination plant to achieve low energy consumption.

## I. INTRODUCTION

The Perth seawater desalination plant is located 40 kilometers south of Perth at Kwinana Beach in Western Australia (WA). It began supplying municipal drinking water in November 2006. With a capacity of 143,000 cubic meters per day, as of February 2007, the plant is the largest SWRO desalination operation in the Southern Hemisphere and the third largest SWRO plant in the world. The plant was built as a joint venture of Suez Degrémont and Multiplex Engineering Pty Ltd. It is operated by Australian Water Services, a subsidiary company of Degrémont..

As part of Water Corporation's and WA's commitment to promote energy efficiency and reduce greenhouse gas emissions, the Perth SWRO plant is the largest facility of its kind in the world to be powered by renewable energy. The plant buys its power from electricity generated by the Emu Downs Wind Farm, located 200 kilometers north of Perth. The 83 megawatt wind farm consists of 48 wind turbines and contributes over 272 giga-watt-hours (GWhr) per year into the grid, fully offsetting the Perth SWRO Plant's estimated electrical requirement of 180 GWhr per year. In addition, instruments that continuously monitor plant discharges automatically shut down the process in the event of an exceedance (1).

The plant utilizes ERI® PX Pressure Exchanger® (PX®) energy recovery devices to reduce energy consumption. The high-pressure (HP) pumps are sized and operated for maximum efficiency. The supply pumps, booster pumps and second pass pumps operate on variable frequency drivers which provides for flexible operation and low energy consumption. These devices combined with state-of-the-art low-energy membrane elements make the Perth plant one of the highest-efficiency reverse osmosis plants of its size operating in the world today.

This paper describes the Perth process design and the plant startup activities. Process performance data including specific energy consumption is presented and discussed.

## II. PROCESS DESCRIPTION

The Perth plant draws feedwater from an open intake in nearby Cockburn Sound. The six supply pumps draw through screens and discharge to twenty-four dual media filter vessels which in turn discharge through cartridge filters to the reverse osmosis process. Ferric sulfate, coagulant aid, sodium hypochlorite, antiscalant, sulfuric acid and sodium bisulfite are injected as necessary in the pretreatment process. A single pipe conveys treated water to the HP pumps and energy recovery devices. The seawater supply pumps are controlled by variable frequency drivers (VFDs) to save energy and assure constant feed pressure to the HP pumps and energy recovery devices.

The first pass has twelve seawater reverse osmosis (SWRO) trains, each with a production capacity of 13,350 cubic meters per day ($m^3/d$) or a total of 160,000 $m^3/d$. Each train uses 1,134 Filmtec™ model SW30HR-LE400 membrane elements housed in Protec™ 7M side-port pressure vessels. They are fed with six Weir split-case centrifugal HP pumps, each with a capacity of 1,144 cubic meters per hour ($m^3/hr$) at 620 meters (m) of differential head, driven by 2,600 kilowatt (kW) motors. The best

---

® ERI, PX, PX Pressure Exchanger and the ERI logo are registered trademarks of Energy Recovery, Inc.
™ Filmtec is a trademark of The Dow Chemical Company
™ Protec is a trademark of Bakaert Progressive Composites Corporation
® Union is a registered trademark of The Union Pump Company

efficiency point of these pumps is approximately 86%. The trains are also fed with twelve Union® vertical booster pumps, each with a capacity of 661 $m^3$/hr at 39 m of differential head, driven by 112 kW motors controlled by VFDs. Energy recovery is provided by twelve arrays of sixteen ERI model PX-220 energy recovery devices, each array with a capacity of 800 $m^3$/hr.

The plant is arranged with six SWRO trains on each side of a central pump aisle. Three HP pumps feed a high-pressure manifold or "pressure center" which in turn feeds a bank of six SWRO trains. Flow from the manifold to each train goes through a high-pressure control valve which allows adjustment of the membrane feed pressure. Each train has a dedicated PX-device array and booster pump. The PX device arrays are situated between the membrane-vessel stacks. A schematic diagram of the SWRO process is given in Figure 1. A photograph of a portion of the SWRO process appears as Figure 2.

**Figure 1 – Schematic Diagram of First-Pass SWRO Process**

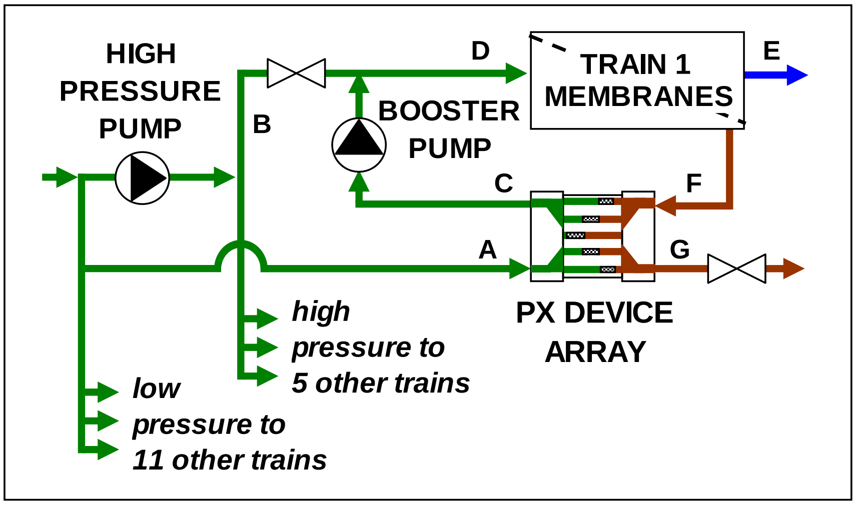

**Figure 2 – SWRO Trains 4A, 5A and 6A**

To further reduce salinity, the first-pass permeate goes to a second pass consisting of six low-pressure reverse osmosis trains. All pumps of the second pass are equipped with VFDs to minimize energy consumption in every season. Post-treatment chemicals include hydrated lime, gaseous chlorine and carbon dioxide. Product potable water flows through a four-hour buffer tank before being pumped approximately 13 kilometers to the fresh water reservoir that supplies the city of Perth with drinking water.

## III. PX PRESSURE EXCHANGER ENERGY RECOVERY DEVICES

In an SWRO system equipped with PX Pressure Exchanger energy recovery devices, the membrane reject is directed to the membrane feed as illustrated in Figure 1 above. A rotor, moving between the high-pressure and low low-pressure stream, removes the brine and replaces it with seawater. Pressure transfers directly from the high-pressure reject stream to a feed stream with no intervening piston in the flow path. The rotor spins freely, driven by the flow at a rotation rate proportional to the flow rate, so feed flow rates must be limited to avoid excess rotor speed. However, unlimited capacity is achieved by arraying multiple devices in parallel.

The pressure-transfer efficiency of a PX unit or PX device array can be calculated with Equation (1):

$$\text{PX efficiency} = \frac{\sum(\text{Pressure} \times \text{Flow})_{\text{OUT}}}{\sum(\text{Pressure} \times \text{Flow})_{\text{IN}}} \times 100\ \% \qquad (1)$$

A total energy transfer efficiency of up to 98% is possible, and efficiency is nearly constant over a wide range of flow and pressure variations.

Water flows from high- to low-pressure through narrow gaps that surround the PX-device rotor, creating a nearly frictionless seawater-lubricated hydrodynamic bearing. This flow is measurable in an SWRO process as the difference between the HP pump flow rate and the permeate flow rate. Alternately and equivalently, the lubrication flow rate can be measured as the difference between the low-pressure inlet and outlet flow rates of a PX device array. Lubrication flow is typically about 1% of the high-pressure brine feed rate.

Direct contact between the brine and seawater in the PX device's rotor results in an increase in the salinity of the membrane feed water. This salinity increase can be quantified as follows:

$$\text{mixing} = \frac{(\text{membrane feed salinity} - \text{system feedwater salinity})}{\text{system feedwater salinity}} \quad (2)$$

Mixing in the PX device's rotor is minimized with long, small-diameter chambers and a short brine-seawater contact time (0.05 seconds). The mixing performance can be measured with a sample collected through a plastic sample valve at the low-pressure outlet of each PX unit or at the outlet of the array.

A photograph of one of the twelve PX device arrays at the Perth plant is given in Figure 3. The upper low-pressure manifold supplies seawater to this PX device array from the left. The low-pressure outlet is on the lower right. This flow configuration is referred to as "Z-flow" because of the flow pattern through the manifolds and PX devices. The high-pressure flow configuration is also Z-flow but with the inlet at the lower left. As described elsewhere, more even flow distribution along the PX device array can be achieved with a "C-flow" configuration with bulk flow entering and exiting the array from the same end (2). However, the Perth manifolds are of sufficient diameter to limit flow variation through the PX devices along the array to a range of approximately 10%.

**Figure 3 – PX Device Array Serving SWRO Train 6A**

## IV. PLANT STARTUP

Seawater first flowed through the plant intake in October 2006. Product water from the plant began flowing into Perth's municipal water supply on November 7th. By December, the first six first-pass trains were running. By the end of February 2007, the entire plant was in operation.

The SWRO trains were commissioned and started up two at a time with the corresponding HP pump isolated on the high-pressure manifold. Startup followed a thorough flushing of each train with pretreated seawater at design flow rates to remove any residual construction debris. Plant startup went according to schedule despite several unplanned incidences which could be considered normal in the context of a large plant startup. Most of the PX devices in the plant were exposed to high flow at least once, including one incident where flows rose to 81 $m^3$/hr/PX device (62% higher than the maximum rated capacity) for six hours. The events that triggered the overflows included the loss of control signals, a significant supply pressure increase and a low-pressure control valve failure. These events occurred while the plant's automated control systems and many of the process alarms were suppressed. In addition, fiberglass construction debris stopped the rotors of several PX devices.

A thorough inspection of several dozen PX devices was conducted at the conclusion of startup activities. Only two of the severely overflowed units were damaged. No other damage was found. The general comment of the commissioning team was that the start up of the SWRO trains with the PX devices was very easy and the devices are quite flexible and robust.

## V. PROCESS PERFORMANCE

A representative set of performance data for SWRO Train 1A is presented in Table 1 below. Process locations are indexed according to Figure 1 above. Measured data is indicated in Table 1 in bold font and calculated data is in plain font.

**Table 1 – Typical Performance Data for SWRO Train 1A**

**TRAIN 1A, 18-JAN 2007**

| | | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| **FLOW** | **$m^3$/hr** | **674** | 559 | **666** | 1225 | **552** | 673 | **681** |
| **PRESSURE** | **bar** | **2.6** | **63.8** | **57.2** | **58.9** | - | 58.2 | **1.7** |
| **SALINITY** | **g/l TDS** | **34.0** | **34.0** | **35.6** | 34.9 | **0.435** | **63.5** | **61.1** |

**MEMBRANES**

| | | |
|---|---|---|
| Membrane Differential | bar | **0.70** |
| Water Recovery | % | 45.0 |

**HIGH PRESSURE PUMP**

| | | |
|---|---|---|
| Voltage | V | **11,000** |
| Line Current | A | **142** |
| Power Consumption | kW | 2,705 |
| Total Flow | $m^3$/hr | 1,127 |
| Specific Energy Consumption | kWh/$m^3$ | 2.40 |

**PX DEVICES**

| | | |
|---|---|---|
| PX Array Lubrication Flow | $m^3$/hr | 7 |
| Volumetric Mixing | | 5.1% |
| Mixing at Membranes | | 2.4% |
| Nominal PX Efficiency | | 95.7% |
| PX Efficiency at PX Array | | 96.7% |

**BOOSTER PUMP**

| | | |
|---|---|---|
| Power Consumption | kW | **45** |
| Specific Energy Consumption | kWh/$m^3$ | 0.07 |

| | | |
|---|---|---|
| **SWRO SPECIFIC ENERGY** | kWh/$m^3$ | 2.47 |

The data in Table 1 shows that lubrication flow through the PX devices was approximately 1% of the brine flow to the array. The train was operating with 1.2% more seawater being fed to the PX device array (process location "A") than what was being discharged from it (process location "C"), and at this condition the salinity increase at the membranes was 2.4%. If these flow rates were set equal by adjusting the booster pump VFD, mixing would increase slightly to about 2.5%.

The pressures of the high-pressure and low-pressure streams to the PX device array (process locations "B" and "G") were measured far upstream of the array. PX-device efficiency computed with these pressure readings was 95.7%. However, using pressure data collected at the inlets and outlets of the PX device manifolds, a transfer efficiency of 96.7% was computed.

At the time the data in Table 1 was collected, Trains 1A and 2A were being fed with one HP pump. The specific energy consumption of the HP pump and the two booster pumps was 2.22 - 2.47 $kWh/m^3$. The high-pressure flow rate was being throttled with the high-pressure control valve. Supply pump performance data was not collected, but the design energy consumption of the pumps for the conditions shown in Table 1 was about 0.3 $kWh/m^3$. Energy consumption data for the second reverse osmosis pass, post-treatment and product-water pumping were not collected, but the design energy consumption was 0.7 $kWh/m^3$ for these processes. Therefore, the estimated total energy consumption for the plant was 3.2 – 3.5 $kWh/m^3$.

Although the data presented in Table 1 is a "snap shot" indicating how one train was running at one point in time, three additional complete data sets collected on the same day and complete data sets collected on five other days from Trains 1A through 6A indicated very similar performance. In addition, trend plots of key process parameters throughout plant operations were consistent with Table 1.

## VI. CONCLUSIONS

The PX energy recovery devices used in the plant are operating at the highest efficiency ever reported for such devices at this scale. Accidental operation of the devices at nearly double their normal flow rates with minimal damage proved that these devices are extremely robust. Plant performance is consistent with the design goals. The Perth plant represents a significant milestone for the development of large-scale SWRO technology by operating on renewable energy at a very low energy consumption level.

## VII. REFERENCES


(1) G. Crisp and M. Rhodes, Perth Seawater Desalination Plant – Blazing a Sustainability Trail, Proceedings of the International Desalination Association World Congress, Gran Canaria, Spain, 2007.

(2) R. Stover, J. Martin and M. Nelson, The 200,000 m3/day Hamma Seawater Desalination Plant – Largest Single-Train SWRO Capacity, Proceedings of the International Desalination Association World Congress, Gran Canaria, Spain, 2007.


## VIII. ACKNOWLEDGEMENTS


The authors acknowledge ERI's Mr. Bill Anderson, the staff of Pro Alliance (Multiplex-Degrémont joint venture) and the staff of Australian Water Services for their assistance compiling data and information for this paper.