MANUFACTURER'S CASE HISTORY

Exchanger Tests Verify 2.0 kWh/m^3 SWRO Energy Use

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Editor's Note

Energy recovery from seawater reverse osmosis systems has reached new heights with the publication of results from the use of ERI's PX Exchanger in a pilot plant at the US Navy test facility in Port Hueneme. Operating at a conservative recovery rate of 36% and at less than 700 psi, the rig has shown that energy consumption rates of 2.0 kWh/m^3 or even lower are now possible. Decreased recovery does, however, lead to an increase in pretreatment costs requiring an optimum balance to be made between pretreatment, membrane use and energy consumption.

The PX exchanger in the pilot plant

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At the US Navy's Seawater Desalination Test Facility in Port Hueneme, California, Energy Recovery Inc. (ERI) has performed a third party verification test to validate some extremely low energy consumption results for seawater reverse osmosis (SWRO). The company designed a pilot desalination plant around its PX Pressure Exchanger device using all of its unique features and advantages to achieve the remarkable number of 2.0 kWh/m^3 (7.6kWh/1000 gal).

With numbers like these one might assume that the plant must be operating at 70% recovery, and getting its feed water from a beach well that is not really seawater, or maybe they are using some kind of new membrane created by aliens… In fact, quite the opposite is true.

The Port Hueneme plant is operating at the conservative recovery rate of 36% and less than 700 psi using 32,000 tds, cold 15°C Pacific Ocean seawater taken from an open intake. Membranes are industry standard, off the shelf, Koch TFC 2822SS – 8in (200mm) SWRO spirals. It is the new PX energy recovery device and its principle of operation that makes this straightforward approach yield such low energy consumption figures.

Principle of Operation

The PX unit utilises the principle of positive displacement to transfer the energy in the reject stream directly to the feed stream. This direct connection allows a real net energy transfer efficiency from the reject stream to the feed stream of over 95%. The PX device uses a cylindrical rotor with longitudinal ducts parallel to its rotational axis to transfer the pressure energy from the concentrate/reject stream to the feed stream.

The rotor spins inside a sleeve between two end covers with port openings for low and high pressure. The low-pressure side of the rotor fills with seawater and the high-pressure side discharges seawater. A sealing area located between the end-cap and rotor divides the rotor into low and high-pressure halves.

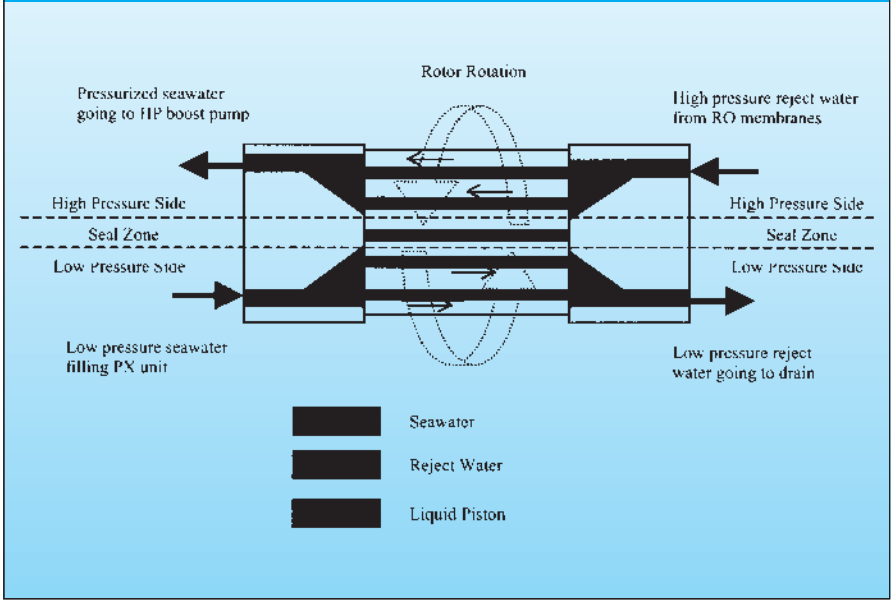
The rotor from the ERI system

By rotation the ducts are first exposed to low-pressure feed water, which fills the duct and displaces the reject water. The rotor continues to rotate past the sealing area and is then exposed to the high-pressure concentrate, which fills the duct and displaces the feed water at high pressure. This rotational action is similar to a Gatling gun firing high-pressure bullets and being refilled with new seawater cartridges. Figure 1 below depicts a sectional view of these dynamics.

The concentrate and reject water are directly connected yet they do not mix because a liquid piston moves back and forth inside each duct creating a barrier that inhibits mixing. One revolution is completed every 1/25 second, and due to this short cycle time, feed water contamination is only 1%–3% (see table 1).

Applying PX Pressure Exchanger technology to SWRO is different from conventional system design, but in practice it is quite simple. The reject brine from the SWRO membranes is passed into the PX unit, where its pressure energy is transferred directly to a portion of the incoming raw seawater at over 95% efficiency. This seawater stream, nearly equal in volume and pressure to the reject stream, then passes through a booster pump, bypassing the main high-pressure pump. This booster pump makes up the pressure losses through the RO membranes (approx. 25psi), the PX

Figure 1 Pressure Exchanger Flow Path



unit(s) (approx. 20 psi) and piping losses (approx. 5 psi). The total pressure differential provided by the boost pump is typically around 45–50 psi 3.4 bar). See figure 2 and table 1 below.

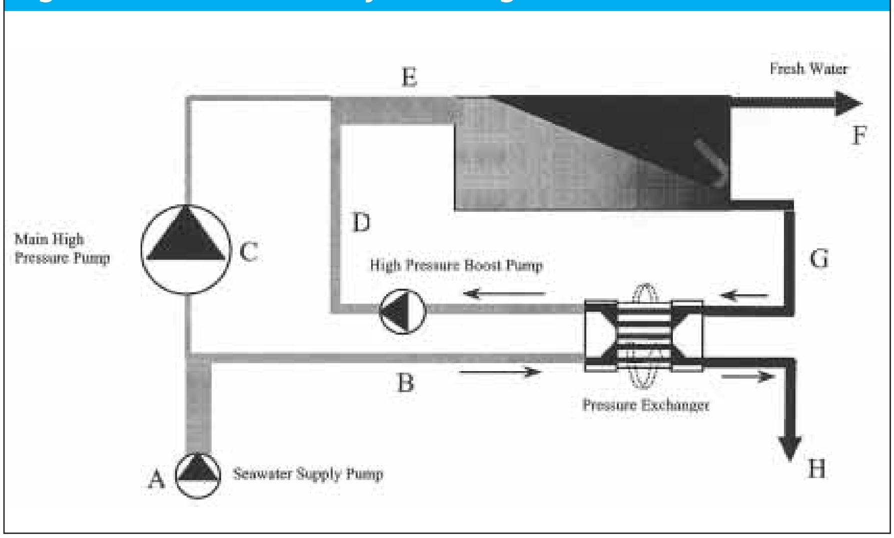
It is important to notice that the PX and associated boost pump are handling nearly 100% of the reject flow. This fact results in reducing the size of the main high-pressure pump to a 'Product Water Make Up Pump' for the permeate flow that is exiting the RO system. From table 1 above you can see that the main high-pressure pump flow equals 9.5 gpm (0.6 L/s) while the product flow equals 9 gpm (0.56 L/s). The product water flow and reject flow are effectively being provided by two separate pumping systems and therefore are independent of one another. These dynamics make system recovery a fully controllable variable, completely changing the traditional struggle between low recovery and high energy consumption.

The Port Hueneme facility with the ERI system to the left

Table 1 Example Flow Rates and Pressures From US Navy Test

STREAM	DESCRIPTION	GPM	PSI	TDS
A	Seawater supply	24.5	15	32,020
B	PX LP Inlet/ Seawater	15	15	32,020
C	Main HP Pump Flow	9.5	690	32,020
D	PX HP Outlet/ Seawater	15	670	33,182
E	RO Feed Stream	24.5	690	32,724
F	RO Product Water	9	5	309
G	PX HP Inlet/ Reject	15.5	680	46,271
H	PX LP Outlet/ Reject	15.5	9	45,734

Figure 2 Port Hueneme System Diagram



Since the PX unit is providing nearly 100% of the reject flow at 95% efficiency, there is very little energy penalty for increasing this flow and thereby lowering the recovery rate of the RO system. At lower recovery the pressure required to produce the same amount of product water is lower, resulting in lower power consumption.

At Port Hueneme the main high-pressure pump is a CAT three-plunger, positive displacement pump with constant flow nearly equal to the product water flow. A significant energy saving is achieved at lower recoveries because the pump is operating at lower pressures.

In plants that incorporate a centrifugal main high pressure pump, the systems strike a balance between slightly lower pressure and more product water as the pumps move out on their respective flow and pressure curves. The power consumption remains relatively constant, but the product production increases creating the same net effect of lowering the kWh/m^3 figure for the overall plant.

There is however a significant energy penalty associated with the inherent lower efficiency of centrifugal pumps, which results in typical energy consumption figures of 2.3 kWh/m^3 when operating under the same general conditions as described above.

Recovery Optimisation

There are many factors that affect recovery optimisation, but none has been more influential than energy conservation, since energy costs can be as much as 75% of the entire operating cost of an SWRO plant.

In the past, recovery has had a major and direct impact on the energy consumption of an RO plant due to the inherent shortcomings of the energy recovery and pumping devices that have been used, such as Pelton wheels, Francis turbines and turbo-boosters. These devices have real overall net transfer efficiencies of 40–75% and are usually designed to pump the entire feed flow of an RO plant. Therefore, at lower recoveries, these inefficient devices are pumping more water.

As seen in figure 3 below, the only way to make these devices pump less water and thereby consume less energy has been to increase the recovery of the RO system. This is all very logical, and, with rising energy costs, it is natural that SWRO systems are still being designed at the 'membrane challenging' recovery rates of 50–60%.

Systems designed with the PX device however are markedly different. The PX has a 95% efficiency rate and is pumping the reject water at a rate independent of the product water produced. Because the PX is so efficient, as more water is sent to it, and the recovery rate is reduced, the required feed pressure drops and plant becomes more energy efficient, up to a point.

The overall energy consumption of an SWRO plant using PX technology has a low point typically between 30–40% recovery. Outside of this optimum range, the plant will consume slightly higher amounts of power. Empirical data taken at the Port Hueneme plant shown in figure 4 yields an optimum recovery point for that plant at around 36%.

Another important benefit of low recovery designs is permeate water quality. In the past, system designs had to balance high recovery with good water quality, which are opposing requirements. In higher salinity applications, this presents a particular

Figure 3 Typical Turbine System Recovery vs Energy Consumption

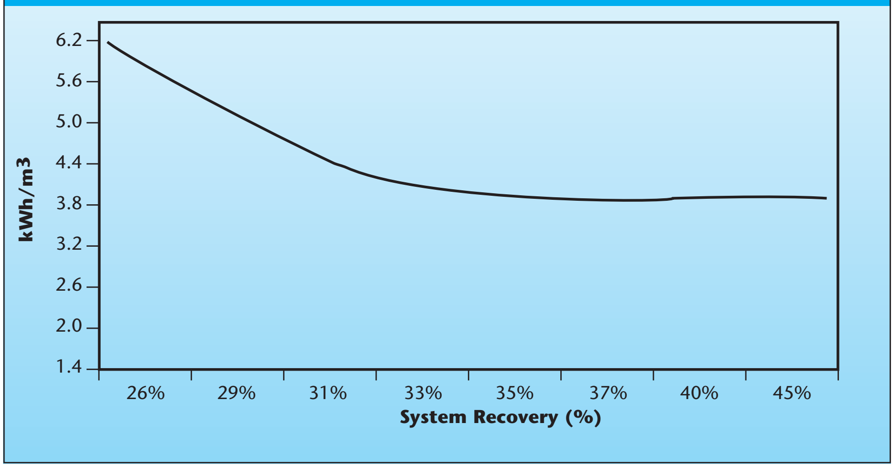
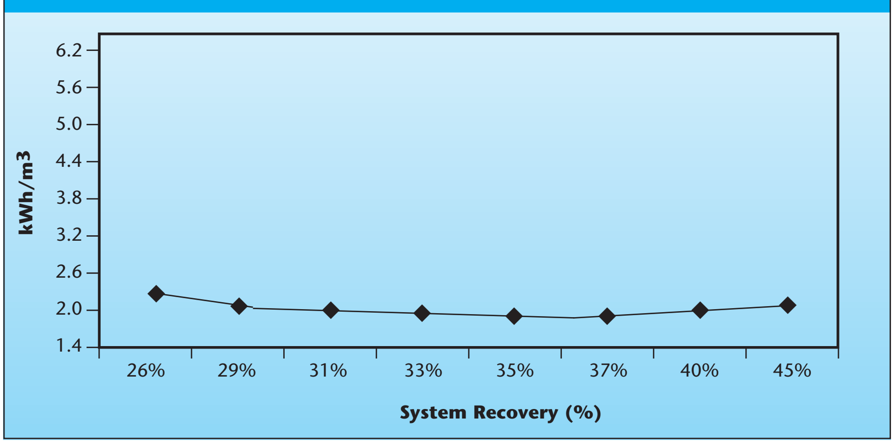


Figure 4 Pt Hueneme Recovery vs Energy Consumption @ Constant 7.2 GFD



challenge where it can be difficult to meet even WHO standards. Figure 5 below shows how low recovery yielded better water quality at the test plant in Port Hueneme.

Logically combining the flat energy curve of Figure 4 with the diminishing water quality curve as recovery increases in figure 5 shows us that there are good reasons now to consider lower recovery SWRO designs. There are also additional benefits associated with low recovery, low flux designs such as ease of operation, lower chemical costs, fewer cleaning cycles and better membrane utilisation.

Of course decreasing recovery does have the disadvantage of increasing the seawater flow and hence the size of the pretreatment system. In smaller systems the effect of decreasing recovery has a small impact on overall capital costs. For example, decreasing the recovery of a 1000 m^3/day system from 45% down to 35% will increase the membrane feed flow from about 400 gpm to 520 gpm. This would typically require 4in (100mm) PVC pipe in either case.

However, on larger applications, a 10% change in recovery could be a substantial consideration that could significantly affect associated capital and operating costs. In these situations a balance is required between pretreatment costs, membrane utilisation, and energy consumption. The optimum point for most plants appears to lie somewhere between 38–45% recovery.

Conclusion

The tests conducted by the US Navy at the Seawater Desalination Test Facility at Port Hueneme, CA have yielded conclusive results. It has been proved that an ordinary commercial SWRO plant, using a low-recovery, low-pressure design and using Energy Recovery's PX Pressure Exchanger, can operate continuously while achieving energy consumption of 2.0 kWh/m^3, and lower. This level of power consumption was previously considered to have been impossible under these conditions.

US Navy test data is available from ERI upon request. ■

Figure 5 Pt Hueneme Recovery vs Product Quality @ Constant 7.2 GFD