This bulletin presents process design and operation considerations for PX® energy recovery device arrays in SWRO applications. It explains the advantages of operating multiple PX-units in parallel and provides quantitative guidelines for optimal manifold design. The conclusions presented apply generally to hydraulic manifold design.

How does an SWRO plant designer or operator control flow in a PX array?

Isobaric energy recovery devices (ERDs) such as the ERI PX Pressure Exchanger device transfer pressure from the membrane reject stream to a seawater feed stream with extremely high efficiency. As the scale of seawater reverse osmosis (SWRO) plants has increased, plant designers and operators have sought larger capacity components including membranes and ERDs. Although the efficiency of positive displacement devices generally does not increase with device size, larger devices reduce the number of devices necessary. However, many attempts to implement very large capacity ERDs have failed because of the mechanical complexity and maintenance of the devices, the difficulty of synchronizing and controlling the valves and cycles, and the destructive water hammer and cavitation more prevalent with large chambers.

The ERI PX device circumvents these difficulties by being flow-controlled with only one ceramic moving part and by conducting pressure exchange on a small scale that is compatible with the natural scale of water. The proven performance of PX devices, individually and in arrays, is one reason why hundreds of operators worldwide have adopted PX technology.

Three simple concepts have made an industry successful

The SWRO industry has been built around standard modular components. The scale of many SWRO components, including membrane vessels and elements, has not changed even as the size of the typical large SWRO largest plants has grown by a factor of 30 in as many years. A large 100,000 cubic meters per day (m^3/day, 26 million gallons per day) plant is comprised of over 8,000 reverse osmosis membrane elements housed in nearly 1,200 pressure vessels. The use of small modular components to build large desalination plants has been a popular approach for the following reasons:

1. **Standardization**. Standard membranes and pressure vessels are available “off the shelf.” Delivery times are short, costs are relatively low, and performance is consistent and predictable.

2. **Modularity**. A successful design for a 5,000 m^3/day plant can be scaled up to 50,000 m^3/day without significant technical risk or performance loss. The operator of a properly designed small plant at a hotel complex, for example, can enjoy the same efficiencies as the operator of a mega plant for a large municipality or industry. In addition, small components are easier for operators to handle than large components.

3. **Redundancy**. Large SWRO plants are arranged in trains and the membranes are arranged in racks fed by manifolds. If one train or element fails, the plant can continue to run with the remaining trains or elements until the next scheduled maintenance with minimal loss of productivity.

As SWRO trains become larger and manifolds must distribute flows to hundreds of membrane elements in a balanced fashion, manifolds must be designed with consideration of head loss.

The same three concepts have made the PX technology successful

Like membranes, PX technology has standardized at an optimal unit size. To achieve higher flows, multiple PX units are arrayed in parallel on manifolds. The use of multiple modular components to build large desalination plants has been a popular approach for the following reasons:

1. **Standardization.** Standard PX units to handle anywhere from 5 to 59 cubic meters per hour (20 to 260 gallons per minute) per unit are available "off the shelf." Delivery times are short and costs are relatively low. Because of tough, durable ceramic components, high precision machining, and thorough factory testing, performance is consistent and predictable.

2. **Modularity.** A successful design for a 5,000 m^3/day plant can be scaled up to 50,000 m^3/day plant without significant technical risk or loss of performance.

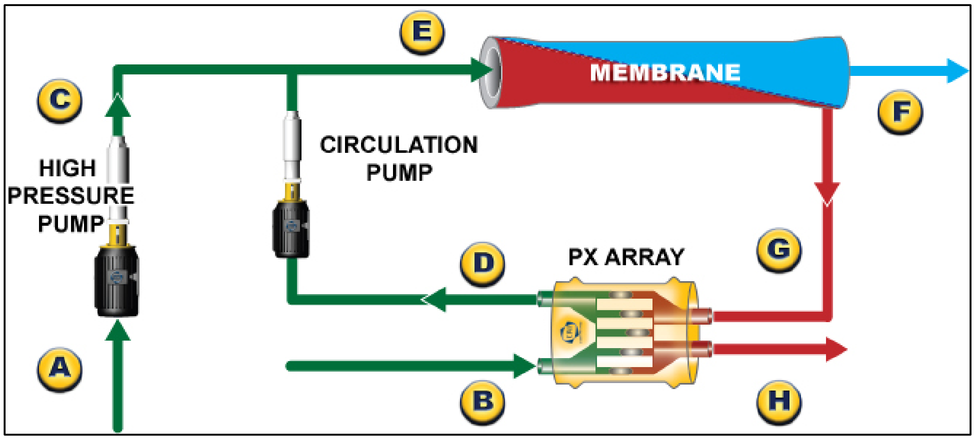
3. **Redundancy**. PX units for large SWRO trains are arrayed in manifolds. If one PX unit's rotor stops for any reason, the train can continue to run until the next scheduled maintenance with minimal loss of productivity.

This comparison emphasizes the similarity between membrane racks and PX device arrays, and like membranes, the performance and reliability of PX devices have been proven in SWRO plants worldwide. PX technology has become the standard ERD solution for large and small plants alike.

PX unit operation

The PX device is a flow-driven positive-displacement pump. A typical configuration for an SWRO system equipped with PX technology is provided in Figure 1.

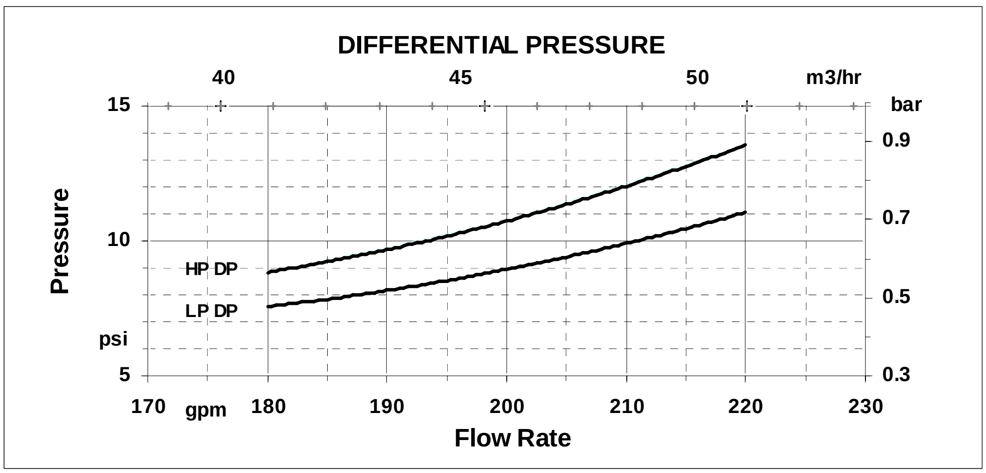
Figure 1 – SWRO System Equipped with PX Technology



Operation and control of a PX unit or PX array in an SWRO system can be understood by considering two parallel pipes; one of high-pressure water and one of low-pressure water flowing in opposite directions. The high-pressure water flows in a circuit through the membranes, the PX unit, the booster pump, and back to the membranes [E-G-D-E] at a rate controlled by the booster pump. The low-pressure water flows from the pretreatment system, through the PX units and to the system discharge [B-H] at a rate controlled by the supply pump and a throttle valve in the brine discharge from the PX unit [H]. The high- and low-pressure flows are independent, so the SWRO-PX plant must be designed for flow monitoring and control of both streams.

The function of the PX rotor is to exchange one volume of pressurized brine from the SWRO membranes for an equal volume of filtered seawater from the pretreatment system. This exchange is done in a ceramic rotor floating in a brine-lubricated hydrodynamic bearing. The speed of the PX rotor is controlled by the flow rate of the streams. There are no shafts, motors, or electronic controls on a PX unit or array. The flow-pressure performance of a typical PX device is illustrated in Figure 2

Figure 2 – Typical PX Device Characteristic Curves

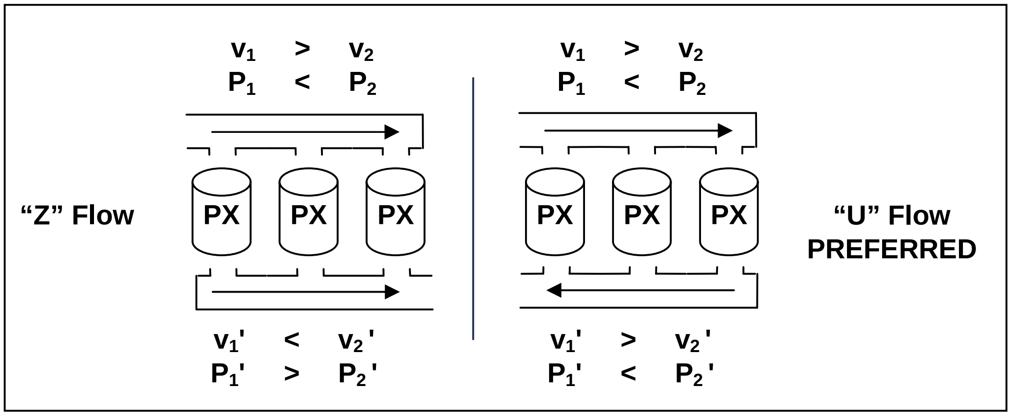


Head loss in a PX unit is primarily the result of frictional losses as the water flows through constrictions in the ceramic components. Figure 2 functions as characteristic curves for the PX device similar to a pump curve. Since each PX rotor is a precision device machined to extremely fine tolerances, PX unit performance varies little from unit to unit and is well-predicted by Figure 2. The PX device stays on its characteristic curves.

Manifold flow schemes for even flow distribution

The performance of PX arrays is identical to the performance of individual PX units. The pressure difference between the inlet and outlet manifold determines the flow through the PX units according to Figure 2. As with membrane manifolds, there at least two ways to assure even flow distribution in a PX array. One is to orient the inlet and outlet manifolds to provide “U” flow as opposed to “Z” flow as illustrated in Figure 3.

Figure 3 – Manifold Flow Schemes



In a "U" flow scheme, flow enters and leaves the array from the same end. In a "Z" flow scheme, flow enters on one end of the array and leaves on the other. The relationship between flow and pressure is derived by energy balance:

$$\left(P_2 - P_1\right) + \rho\left(v_2^2 - v_1^2\right)/2 + f = 0 \qquad (1)$$

where:
P = pressure,
v = velocity,
ρ = density, and
f = head loss due to friction.

Considering Figure 3, velocity in the inlet (upper) manifold decreases in the direction of flow as water diverts into the PX units, causing a pressure increase in the direction of flow. Friction losses in the header and fittings decreases pressure in the direction of flow, however, friction in a PX manifold tends to be small because it is relatively short. Therefore, pressure tends to increase in the direction of flow in an inlet manifold. Friction losses are greater in smaller-diameter manifolds, however, the velocity change and its impact on pressure is even greater in such systems.

Similar considerations apply to outlet manifolds. The general conclusion of this analysis is that the pressure in a manifold is lowest near the open end of the header where the flow velocity is highest. In Figure 3, pressure in the outlet (lower) manifold in the "Z" flow configuration is lowest at the right end, opposite from the highest pressure point in the inlet manifold. The pressure in the outlet manifold in the "U" flow configuration is lowest at the left end, opposite from the lowest pressure point in the inlet manifold.

Therefore, the pressure difference between the manifolds at any PX-unit position is more constant in a "U" flow than in a "Z" flow scheme. As illustrated in Figure 2, pressure difference determines the flow through a given PX unit. The resulting conclusion is that "U" flow always provides more even flow distribution among the PX units of an array than a "Z" flow does for a given manifold pipe diameter. This has been verified with computational fluid dynamics modeling of PX arrays of a wide range of lengths and diameters. More importantly, this conclusion has been verified in a number of long-running multiple-PX arrays.

PX manifolds can also be fed in the center through pipe tees. The resulting "T" flow scheme is hydraulically similar to a "U" flow scheme.

Manifold pipe size specification for even flow distribution

A second way to assure even flow distribution in a membrane array or a PX array is to substantially reduce the ρv^2 terms in Equation (1) by specifying large header pipe diameters. A large header serves as a constant-pressure reservoir regardless of flow orientation. The obvious disadvantage of large header pipe diameters is the greater amount of material required.

Through computational fluid dynamics modeling and evaluation of PX arrays in the field, ERI has come up with general guidelines for manifold sizing. Acceptable flow balance among the PX units in an array will result if the inlet velocity is limited to less than 3.7 m/s (12 ft/s) for a "U" or a “T” flow scheme or to less than 2.1 m/s (7 ft/s) for a "Z" flow scheme. If these limits are adhered to, the high and low pressure sides of the PX units can be considered independently of each other and may be of either flow scheme. PX arrays may be fed from either end of the array as long as the inlet velocities are below the above-specified velocities.

Similar considerations apply to manifold and piping design throughout a SWRO plant. In some cases, pipe diameters can change along a piping run to keep the flow velocity within a design range and thereby provide even branch flow distribution and minimize piping costs.

Summary

The ERI PX energy recovery device is a modular device that performs predictably and reliably in arrays. With precision-machined ceramic components, PX device performance is uniform, and well characterized. In addition to potentially unlimited capacity, PX arrays provide redundancy to assure continuity of plant operations. Good manifold design assures even flow distribution along an array of PX units without requiring excessively large pipe diameters.

Making Desalination Affordable™

For additional information about PX technology, refer to ERI’s website: http://www.energyrecovery.com. For technical questions or sales inquiries, contact ERI at sales@energy-recovery.com or call +1 (510) 483-7370.