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Title: How to Design and Operate SWRO Systems Built Around a New Pressure Exchanger Device

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ABSTRACT

The new pressure exchanger (PX) device transfers the energy from the concentrate stream directly to the feed stream. This direct, positive displacement approach results in a net transfer efficiency of over 95%. Although application of the PX technology is simple in both theory and practice, in order to get the most benefit from this technology it is important to reconsider the SWRO design and operation approach. Pertinent design considerations include pre-filtration, conversion rate optimization, pump selection, and operating pressures. Some important operating procedures and characteristics are start up, high pressure regulation, conversion rate optimization, flow balancing, and shutdown. Furthermore, it will be shown that these considerations affect the design and operation of SWRO systems counter-intuitively and may possibly reverse given standards that have been developed over the past 20 years of SWRO design.

There has been a recent proliferation of commercially available energy recovery devices based on the positive displacement direct pressure exchange approach. This increased interest is driven by the fact that the technology can reduce the energy consumption of an SWRO system by as much as 60%. Since energy costs are rising and can consume as much as 75% of the total operating costs of an SWRO plant, it is important that the technology be encouraged and disseminated throughout the industry. Although the authors of this paper are directly associated with Energy Recovery, Inc., a leading company in pressure exchanger technology, the principles and theories presented in this paper will be applicable to all devices based on the positive displacement, direct pressure exchange approach.

1.0 INTRODUCTION

The PX is a new pressure exchanger device that transfers the energy from the concentrate/reject stream directly to the feed stream in a cylindrical rotor with longitudinal ducts. The rotor spins inside a sleeve between two end covers that divide the rotor into high and low pressure halves. When designing a seawater RO system using the new pressure exchanger device it is only necessary to reconsider the high-pressure portion of the system. This is because this is the only portion that differs from earlier RO designs. Pertinent design considerations include, conversion rate optimization, pump selection, and operating pressures. Some important operating procedures and characteristics are start up, high pressure regulation, conversion rate optimization, flow balancing, and shutdown. Although application of the pressure exchanger is simple in both theory and practice it is vastly different from typical SWRO design and operation. These differences affect the design and operation of SWRO systems in surprising ways that can be used to improve other aspects of system performance beyond the scope of energy consumption alone.

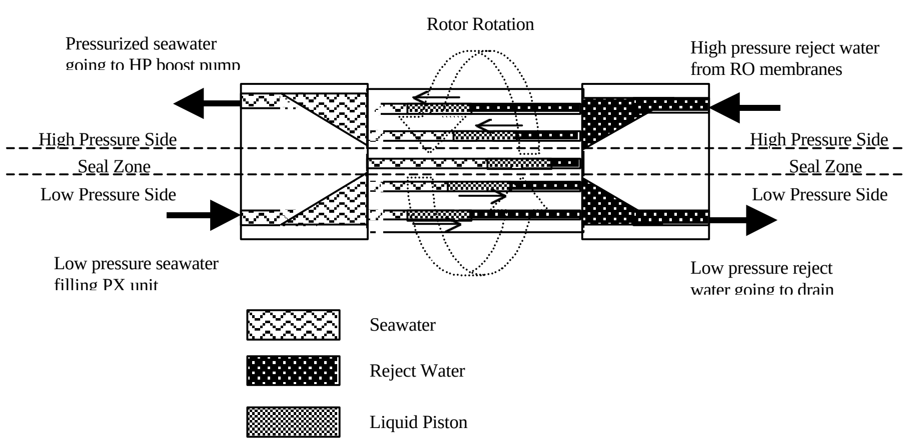
2.0 PRINCIPLE OF OPERATION

The PX unit utilizes the principle of positive displacement to transfer the energy in the reject stream directly to the feed stream. It is interesting to note that the reject stream is continuously and directly connected to the feed stream. This direct connection allows a real net transfer efficiency of energy 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 while the high-pressure side discharges seawater. The rotation simply facilitates the valving mechanism, which is to transport the ducts from one side to the other.

By rotation the ducts are exposed to the low pressure feed water, which fills the duct and displaces the reject water. The rotor continues to rotate and is exposed to the high-pressure concentrate, which fills the duct from the opposite direction, and displaces the feed water at high pressure. This rotational action is similar to a Gatling machine gun firing high-pressure bullets and being refilled with new seawater cartridges from the muzzle. A liquid piston moves back and forth inside each duct creating a barrier that inhibits mixing between the concentrated reject and new seawater streams. At 1500 rpm one revolution is completed every 1/25 second. Due to this short cycle time, membrane feed water concentrations typically increase only 1%-2%. See Figure 4-1 below.

Figure 1. Pressure Exchanger Flow Path



Applying PX pressure exchanger technology to SWRO is different from conventional energy recovery device system design, but in practice 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 up to 97% efficiency. This seawater stream, nearly equal in volume and pressure to the reject stream, then passes through a high-pressure booster pump, not the main high-pressure pump. This booster pump is making up the pressure losses across the RO membrane (approx. 2 bar), PX unit(s) (approx. 1 bar) and piping losses (approx. 0.5 bar). The total head provided by the boost pump is typically around 3.5 bar. See figure 4-2 and table 4-1 below.

Figure 2. Typical System Flow Path

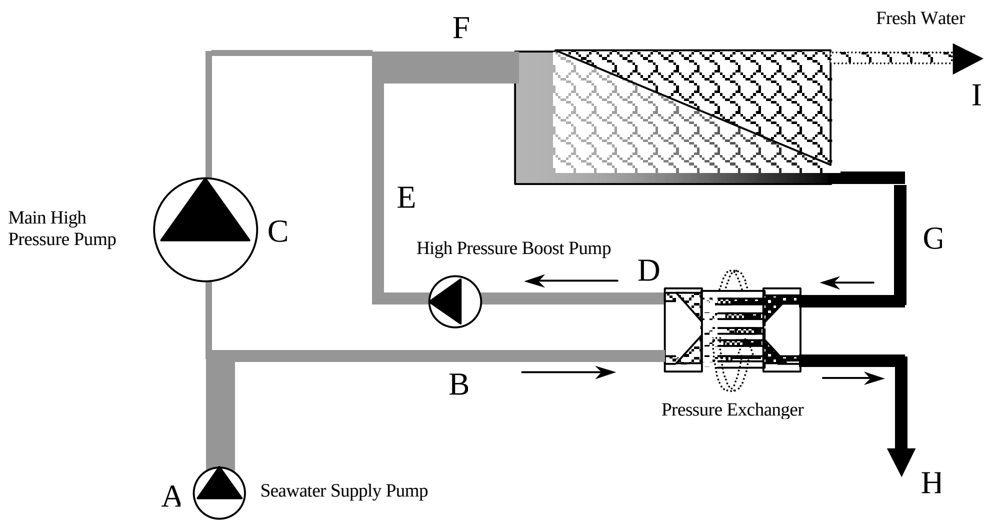


Table 1. Example Flow Rates and Pressures

STREAM	DESCRIPTION	FLOW RATE*	PRESSURE BAR
A	Seawater supply	100	2
B	PX LP Inlet/ Seawater	58.8	2
C	Main HP Pump Flow	41.2	69
D	PX HP Outlet/ Seawater	58.8	66
E	Booster Pump Outlet/ Seawater	58.8	69
F	RO Feed Stream	100	69
G	PX HP Inlet/ Reject	60.0	67
H	PX LP Outlet/ Reject	60.0	1
I	RO Product Water	40.0	0.3

*40% conversion rate RO system independent of units.

It is important to notice that the PX and associated boost pump are handling nearly 100% of the reject flow. The size of the main high-pressure pump has been reduced to a “make up pump” for the permeate flow that is exiting the RO system. Product water flow and reject flow are being provided by two independent pumping systems and therefore are independent of one another.

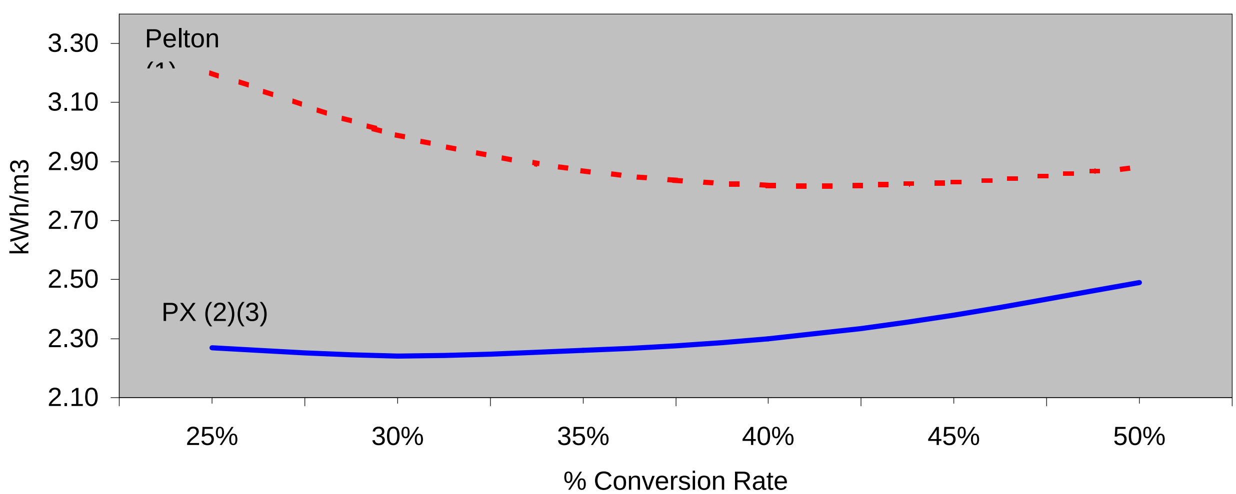
Since the PX unit is providing nearly 100% of the reject flow at over 95% efficiency there is very little energy penalty associated with increasing this flow and thereby lower the conversion rate of the RO system. At lower conversion rate the pressure required to produce the same amount of product water is lower. Since the main high-pressure pump flow equals the product water flow an energy savings is actually achieved at lower conversion rates.

3.0 CONVERSION OPTIMIZATION

There are many factors that effect RO conversion optimization but none has been more influential than energy consumption. This is because energy costs can be as much as 75% of the entire operating cost of an SWRO plant. In the past the sewater to fresh water conversion rate has had a major and direct impact on the energy consumption of an RO plant. This is because of the inherent shortcomings of the energy recovery and pumping devices that have been used such as the Pelton wheels, turbines, and pumps. These technologies have real/overall net transfer efficiencies of 40-70 percent and are designed to pump the entire feed flow of an RO plant. Therefore at lower conversion rates these inefficient devices are pumping more water. The only way to make these devices pump less water and thereby consume less energy is to increase the conversion rate of the RO system. This is all very logical, and with rising energy costs it is natural that SWRO systems are now being designed at the membrane challenging conversion rates of 50-60%.

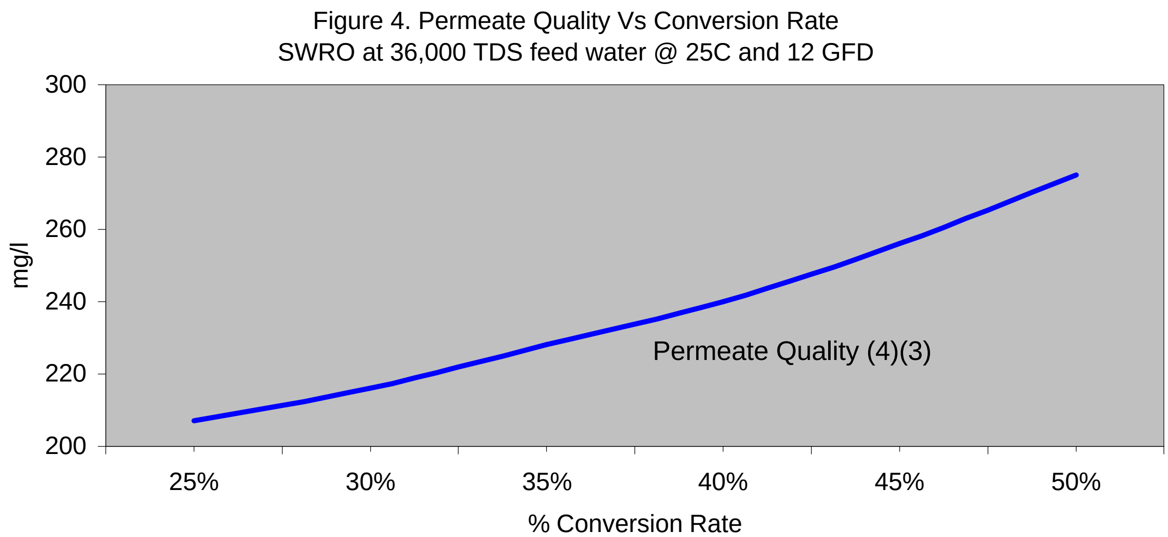
System designs with the PX device are different. This is because the PX, a 95% efficient device, is pumping the reject water independently of the product water being produced. The overall energy consumption of an SWRO plant using the PX device has a low point at conversion rates typically between 30-40%. Outside these conversion points the plant will start to consume slightly higher amounts of power. See figure 3 below.

Figure 3. kWh/m3 Vs Conversion Rate
SWRO at 36,000 TDS feed water @ 25C and 12 GFD



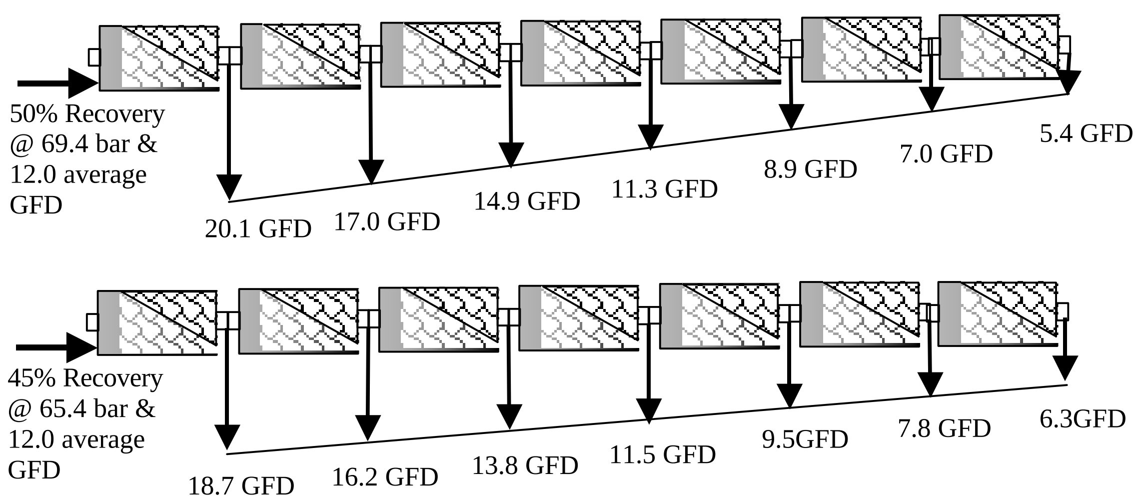
It is important to remember that with the PX device the main high pressure pump flow approximately equals the product water flow. At lower conversion rates it requires lower pressure to produce the same amount of product water. Therefore, the main high-pressure pump will consume less power pumping against less pressure at the lower conversion rates. This phenomenon yields the net energy decrease shown in Figure 3.

Another important point to consider is water quality. In the past, system design had to balance high conversion rate with good water quality. In high salinity applications this has been a difficult challenge. Figure 4 below shows how a lower conversion rate yields better water quality.



Logically combining the kWh/m3 vs Conversion Rate curve of Figure 3 with the diminishing water quality curve as the conversion rate increases in figure 4 shows us that there are good reasons now to consider SWRO designs with lower conversion rates. There are also additional benefits associated with lower conversion rate designs such as ease of operation, fewer cleaning cycles, longer membrane life and a better balance of flux ("GFD") from the lead element to the end element in an RO pressure vessel. Figure 5 below shows how GFD is balanced as the system conversion rate lowers [5].

Figure 5. GFD Balancing Effect at Lower Conversion Rates



Of course decreasing the system conversion rate does have its disadvantages mainly in increasing the size of the pretreatment system. This effect is less significant in smaller systems under 1000 m3/day because of the less expensive piping materials, pressure media filtration systems and other components typically employed in these systems. However on larger plants using open seawater intakes with largescale gravity feed media filtration systems, and when the chemical additions associated with coagulation are significant operating costs, conversion rates between 45-50% may be more practical.

4.0 START AND STOP PROCEDURES

Starting and stopping an SWRO system designed around the PX pressure exchanger device is actually simpler than with systems designed around other technologies such as regulating valves, turbos and Pelton wheels. This is because of the self-balancing nature of SWRO systems designed around pressure exchanger technologies.

4.2 System start up sequence

Start up of an SWRO plant designed around the PX device is very simple. The first step is to start the raw water supply pump. At this point the system will begin to fill with water and the PX may or may not start to spin. Next, start the high-pressure boost pump. The associated pressure drops through the RO membranes and PX combine with the high-pressure boost pump curve to dictate the reject flow rate into and seawater flow rate out of the PX unit. This means that once the high-pressure boost pump is running and has stabilized the reject flow is now running at or very near the normal flow rate for the plant. Now it is time to start the main high-pressure pump, which will pressurize the RO system. The system will reach the exact pressure required to produce the amount of product water being injected to the RO system by the main high-pressure pump. The membranes create the back-pressure in the system and now act like the pressure-regulating valve. It will take 5-10 seconds for a typical system to pressurize once the main high-pressure pump is started. It may be advisable to install a high-pressure bypass valve at the outlet of the RO membranes that can be closed slowly at start up. This will allow the operator to control of the rate at which the RO system reaches full operating pressure.

4.3 SYSTEM SHUT DOWN SEQUENCE

First stop the main high-pressure pump. After approximately 30 seconds the pressure in the RO system will drop to around 27 bar. At this point it is proper to stop the high-pressure booster pump and raw water supply pump. It should be noted that because the high-pressure side of the PX is sealed from the low pressure side of the PX the high pressure RO portion of the plant can maintain significant pressure for an extended period of time.

4.4 Fresh water flush

If the SWRO system is going to be shut down for an extended period of time it is required to fresh water flush the RO membranes and pressure exchanger in order to inhibit biological growth and fouling. Start by supply the RO system with un-chlorinated fresh water at the normal system feed pressure. Next run the high-pressure booster pump until all of the seawater has been purged from the RO membranes. It may also be desirable to also run the high-pressure pump for a few seconds during this process to ensure that it gets a complete flush as well.

5.0 FLOW CONTROL AND BALANCING THE SYSTEM

Flow rates and pressures in a SWRO plant will vary slightly over the life of a plant. Variations may be due to temperature, membrane fouling, seasonal feed salinity variations, etc. The following designs and procedures should be used to control these variables.

5.1 High Pressure Reject and Seawater Feed Flow Control

In order to control the high-pressure reject and feed flow rates, adjustment of the pressure and flow supplied by the high-pressure booster pump is typically required. Recommended practice is to use a high pressure booster pump with some additional capacity, and control its flow and pressure with a variable frequency drive or control valve. A high-pressure flow meter can be used to determine the amount of reject and feed water flowing through the high-pressure side of the pressure exchanger device. Remember that the high-pressure reject water and feed water are hydraulically connected and are separated only by a water barrier/piston. It is also possible to infer the high-pressure flow rates from the pressure drops across the pressure exchanger and/or high-pressure boost pump. Increasing and decreasing these flow rates is how we decrease and increase respectively the conversion rate of the RO system independently of the product water being produced.

5.2 Low Pressure Reject and Seawater Feed Flow Control

In order to control the flow rates of the low-pressure feed and reject water, adjustments to the low-pressure seawater inlet pressure to the PX should be made. Recommended practice is to install a valve at the low-pressure seawater inlet of the PX unit(s). Remember that the low-pressure seawater and reject water are hydraulically connected and are separated only by a water barrier/piston. The low-pressure seawater and reject flow rates can be determined by installing a flow meter at the low-pressure seawater inlet of the PX.

5.3 Balancing the pressure exchanger using flow meters

All flows in and out of the Pressure Exchanger must be approximately balanced. The following equation applies to this process:

High pressure seawater outlet flow = Low pressure seawater inlet flow

Determine the desired amount of high-pressure seawater outlet flow, which is approximately equal to the reject flow for your system. Adjust the variable frequency drive or control valve on the high-pressure booster pump until that flow rate is achieved as seen at the high-pressure flow meter. In the absence of a high-pressure flow meter it is also possible to infer the flow rates from the pressure drops across the boost pump and/or pressure exchanger(s).

Adjust the low-pressure seawater inlet valve until the low-pressure seawater inlet flow equals the high-pressure seawater outlet flow.

If the low pressure seawater inlet flow is less than the high pressure seawater outlet flow excessive intermixing of reject with the feed will occur which will result in lower quality permeate, increased feed pressure and higher energy consumption. If the low-pressure seawater inlet flow is greater than the high-pressure seawater outlet flow, treated feed water is being wasted and dumped to the low-pressure reject drain.

6.0 CONCLUSION

The PX is a new pressure exchanger device that promises to revolutionize SWRO design. The device affects the design and operation of SWRO systems in several counter-intuitive ways. As we have discussed, lower conversions rates in the order of 30-40% actually yield lower energy profiles than higher conversion rates. Furthermore, these systems operate at lower pressures and produce better water quality.

The fact that the main high pressure pump flow equals the permeate flow means that we can now achieve SWRO systems with nearly 100% conversion rates when considering the pumping power that is being applied. This fact also means that for any given high pressure pump, systems that are 2-3 times larger can be achieved with that same pump.

The PX device now makes it possible to adjust the conversion rate of an SWRO plant independently of product water production. This means that the conversion rate can now be simply and directly used to optimize the efficiency of the RO membranes rather than having to balance it against energy consumption, product quality, membrane pressure limits, and so on.

It is clear that this device is an extremely efficient approach to energy recovery, and that the SWRO systems of today and the future will consume far less energy than those of yesterday. However, the impact that this device will have on design concerns such as the conversion rate, water quality, and operating pressures will surely surprise us all.

References:

(1) Pelton curve generated using Fluid Systems ROPRO Version 6.1, TFC 2822SS-360 membrane, 0 years and 0 fouling, 15,970 m3/day system @ 25-50% conversion rate, 88% efficient Pelton wheel, 86% efficient main high pressure pump, 96% efficient electric motor, 1.7 bar feed pressure and 0 bar discharge/reject pressure.

(2) PX curve generated using Fluid Systems ROPRO Version 6.1, TFC 2822SS-360 membrane, 0 years and 0 fouling, 15,970 m3/day system @ 25-50% conversion rate, 1.4 bar differential across PX, 85% efficient main high pressure pump, 96% efficient electric motor, 1.7 bar feed pressure and 0.3 bar discharge/reject pressure. Also see reference 3.

(3) The International Desalination and Water Reuse Quarterly, Manufacturers Case History, Exchanger Test Verify 2.0 kWh/m3 SWRO Energy Use, Pg 42.

(4) Quality vs. Conversion Rate curve generated using Fluid Systems ROPRO Version 6.1, TFC 2822SS-360 membrane, 0 years and 0 fouling, 15,970 m3/day system @ 25-50% conversion rate. Also see reference 3.

(5) Flux figures generated using Fluid Systems ROPRO Version 6.1, TFC 2822SS-360 membrane, 0 years and 0 fouling, 15,970 m3/day system @ 45 and 50% conversion rate.