ENERGY RECOVERY DEVICE PERFORMANCE ANALYSIS

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ABSTRACT

Membrane desalination is a pressure-driven process. Although a thorough analysis of the desalination process must consider all energy consumption points, the chief energy consumer in any membrane desalination plant is the high pressure pump(s). For this reason, the clearest way to measure the effectiveness of an energy recovery device is by quantifying the high-pressure pump energy required to produce a given flow rate of desalinated permeate with an SWRO system equipped with the device. This paper presents the equations and considerations necessary to calculate this energy in SWRO systems equipped with ERI PX Pressure Exchanger technology. Example calculations demonstrate that systems equipped with PX devices can consume less than 2 kWh/m^3 of permeate. Case studies of SWRO plants from which other energy recovery devices were removed and replaced with PX technology are presented.

Key Words: energy recovery, seawater reverse osmosis, SWRO, pressure exchanger

1.0 INTRODUCTION

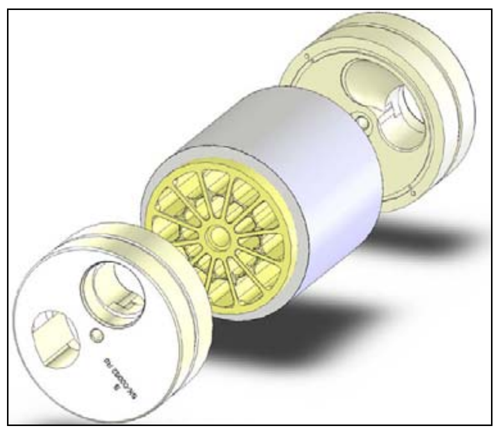
The power required to drive the high-pressure pump(s) is the largest component of the operating cost of most seawater reverse osmosis (SWRO) systems. Most of the energy imparted into the feedwater flowing to the SWRO membranes leaves the membranes in the brine reject water. A number of devices have been developed to recover pressure energy from the brine reject stream. The effectiveness of an energy recovery device can be characterized by quantifying the high-pressure pump energy required to produce a given flow rate of desalinated permeate with an SWRO system equipped with the device.

Energy recovery devices can be divided into two general categories: centrifugal and isobaric. Centrifugal devices capture brine pressure energy with a turbine and transfer it to an impeller(s) spinning in the seawater. Francis turbines, Pelton wheels and turbochargers are examples of centrifugal energy recovery devices. Isobaric devices accomplish a direct transfer of pressure from the brine to the seawater in constant-pressure chambers. The ERI™ PX Pressure Exchanger™ device and a number of piston-type work exchangers are examples of isobaric devices.

2.0 PRESSURE EXCHANGE MECHANISM

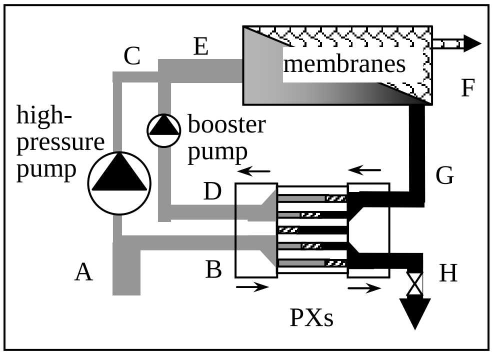
The PX device transfers pressure from a high-pressure stream to a low-pressure stream in a ceramic rotor. The rotor is fit into a sleeve between two endcovers with precise clearances that, when filled with high-pressure water, create an almost frictionless hydrodynamic bearing. These components are illustrated in Figure 1.

Figure 1 – PX Device Cartridge Components



A schematic diagram of an SWRO system equipped with PX technology is given in Figure 2. Pressure energy from the high-pressure brine reject of the SWRO membranes is transferred to filtered seawater with an efficiency that can exceed 97%. Pressurized seawater is conveyed to the SWRO membranes with a booster pump. The high-pressure pump is sized to equal the SWRO permeate flow plus a small amount of bearing lubrication flow, not the full SWRO feed flow. PX technology, therefore, significantly reduces the cost of the high-pressure pump.

Figure 2 – SWRO System with PX



3.0 PX TECHNOLOGY ADVANTAGES

PX technology achieves superior energy transfer performance and reliability because of the following design advantages:

Ceramic: The high-impact-resistant ceramic material used in the PX device is the same material used in bullet-proof sheathing. This material is ideal for SWRO applications because, unlike metals, it never corrodes and it maintains exceptional dimensional stability.

PD: The PX device applies a positive displacement (PD) mechanism. Therefore, its efficiency is very high and constant over a broad range of flows and pressures. This characteristic differs from centrifugal devices whose performance declines as flows and pressures shift away from peak design operating conditions.

Rotor: The rotor is the only moving part in the PX device. Driven by the flow, it floats on a media-lubricated bearing and requires no periodic maintenance. Rotor speed adjusts automatically to maintain constant productivity.

Ease of Operation: Only simple flow controls and pressure limits are necessary for PX operation, no artificial intelligence or adaptive control schemes. There are no pistons or valves in the PX device so startup and shutdown are easy.

4.0 ENERGY EQUATIONS

The energy required to operate the high-pressure portion of an SWRO system equipped with PX technology is the sum of the high-pressure pump and booster pump consumption. This energy is expressed in terms of the specific energy or the energy required per unit output of permeate:

$$\begin{aligned} SE_{PX} &= \left(E_{HP} + E_{BP}\right)/Q_P \\ SE_{PX} &= Q_{HP}\left(P_{HP} - P_F\right)/\left(\eta_{HP}\eta_{HPM}Q_P\right) \quad (1) \\ &\quad + Q_{BP}\left(P_{HP} - P_{BPI}\right)/\left(\eta_{BP}\eta_{BPM}Q_P\right) \end{aligned}$$

where:
SE_{PX} = PX system specific energy
E_{HP} = high-pressure pump energy consumed
E_{BP} = booster pump energy consumed
Q_P = permeate flow rate
Q_{HP} = high-pressure pump flow rate
P_{HP} = high-pressure pump outlet pressure
P_F = high-pressure pump feedwater pressure
η_{HP} = high-pressure pump efficiency
η_{HPM} = high-pressure pump motor efficiency
Q_{BP} = booster pump flow rate
P_{BPI} = booster pump inlet pressure
η_{BP} = booster pump efficiency
η_{BPM} = booster pump motor efficiency

The energy transfer efficiency of a PX device is derived with an energy balance. The hydraulic energy leaving the PX device is divided by the energy entering the device according to:

$$\eta_{PX} = \left(Q_{BP}P_{BPI} + Q_E P_E\right)/\left(Q_B P_B + Q_{F'}P_{F'}\right) \quad (2)$$

where:
η_{PX} = PX efficiency
Q_E = system discharge flow rate
P_E = system discharge pressure
Q_B = membrane discharge flow rate
P_B = membrane discharge pressure
P_B = membrane discharge pressure
$Q_{F'}$ = PX feedwater flow rate
$P_{F'}$ = PX feedwater pressure

Approximately 1 to 2.5% of the brine flow to the PX device is consumed as hydrodynamic-bearing lubrication, depending upon system pressure, temperature and flows. The lubrication flow required by the PX device is supplied by the high-pressure pump.

Since there is no physical barrier between the brine and seawater streams in the PX device rotor, these streams mix slightly. The ratio of the increase in membrane feedwater salinity divided by the system feedwater can be derived by mass balance or very closely approximated with the following equation:

$$SI \cong R \times 6.15\% \quad (3)$$

where:
SI = salinity increase
R = membrane recovery

Equation (3) applies at "balanced flow" when the high- and low-pressure flows through the PX device are equal. No excess low-pressure flow or "overflush" is necessary in a PX device.

5.0 EXAMPLE CALCULATIONS

Hypothetical SWRO system parameters were borrowed from a recently published paper by Irving Moch, Jr., et.al.. Three SWRO system examples are differentiated by their permeate flow rate in cubic meters per day (m^3/d) and feedwater salinity in parts per million (ppm).

- Ex.1: 4,273 m^3/day, 37,000 ppm
- Ex.2: 13,435 m^3/day, 44,000 ppm
- Ex.3: 25,091 m^3/day, 34,000 ppm

A membrane recovery ratio of 40%, 24 degree Centigrade water temperature and 2.8 bar supply pressure were assumed. Pump and motor efficiencies from the best available models were used. A conventional membrane projection program was used to estimate membrane feed pressures as a function of feed salinity. Other assumptions were consistent with those made in the referenced publication.

A summary of PX system operating conditions and specific energy consumption rates for the three examples and are presented in Table 1. It is important to note that the PX device efficiencies and the corresponding flow and pressure performance characteristics presented in Table 1 are guaranteed minimum values for model PX-220 devices.

Table 1 – SWRO System Energy Calculations

	Q_{HP} m^3/hr	P_{HP} bar	Q_{BP} m^3/hr	P_{BPI} bar	η_{HP} %	η_{BP} %	η_M %	***SE*** **kWh/m³**	η_{PX} %
Ex.1	184	63.1	261	60.7	80	78	95	**2.41**	95.3
Ex.2	582	76.3	818	73.5	85	83	95	**2.77**	95.2
Ex.3	1080	57.8	1534	55.3	90	88	96	**1.95**	94.8

The specific energy values presented in Table 1 are significantly lower than published values for comparable systems operating with centrifugal energy recovery devices.

6.0 CASE STUDIES

Because of its superior energy recovery performance, several SWRO system operators have achieved savings by removing other energy recovery devices and replacing them with PX technology. The Club Lanzarote Tourist Complex in Playa Blanca, Canary Islands was retrofitted with model PX-60 devices in 2001. This facility had previously been equipped with turbochargers and was operating at just under 5 kWh/m^3. After replacing the energy recovery devices and upgrading the membranes and high pressure pump, energy consumption was reduced to 2.64 kWh/m^3. The plant has been running efficiently and smoothly ever since.

ERI has also retrofit 4 turbocharger trains with PX technology at the Bonny SWRO plant in Gran Canary Islands. The first of these retrofits started up in 2002 and has a total production of 2,400 m^3/day. Because of the PX, the Bonny organization is enjoying a 48% power savings – down to nearly 2 kWh/m^3 – in addition to cutting the HP pump maintenance in half.

Two trains at the Regents de Mazarron Desalination Plant in Mazarron Spain were retrofitted with model PX-220 Pressure Exchanger devices in August 2005. These trains had been operating with turbochargers. After replacing the energy recovery devices, adding a booster pump and combining the two trains into one, energy consumption reduced by 0.6 kWh/m^3 from its best performance when running with turbochargers.

7.0 CONCLUSIONS

The example systems considered in this analysis indicate that SWRO systems equipped with PX Pressure Exchanger energy recovery technology require very low energy per unit of permeate produced. In addition, the design of the PX device provides the SWRO operator many advantages over other energy recovery devices including no periodic maintenance, consistent performance, and ease of control and operation.

8.0 REFERENCES

"Advanced High Efficiency Energy Recovery," Irving Moch, Jr., Michael Oklejas, Kevin Terrasi, Robert A. Oklejas, International Desalination Association World Congress, 2005.

Additional information about ERI PX Pressure Exchanger energy recovery technology can be found at www.energy-recovery.com or by emailing sales@energy-recovery.com.