The New Qidfa and Al Zawrah SWRO Plants
Plant Design and Performance with PX Pressure Exchanger Technology

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Country of Attribution: Austria

ABSTRACT

The Federal Electricity and Water Authorities (FEWA) seawater reverse osmosis (SWRO) plants at New Qidfa and Al Zawrah, United Arab Emirates were awarded to Aqua Engineering in late 2004. The New Qidfa plant started up in October 2006 and is producing 13,650 cubic meters per day (m^3/day) of potable water from Gulf of Oman seawater using three identical SWRO trains. The Al Zawrah plant is scheduled to start up in early 2008 and will produce 27,300 m^3/day with six SWRO trains. The plants were designed and built by Aqua Engineering. They employ ERI PX Pressure Exchanger® energy recovery technology, specifically six model PX-220 devices per train, to reduce plant power consumption. The authors describe the design and performance of the New Qidfa plant, particularly those aspects associated with energy efficiency and energy recovery.

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

1.0 INTRODUCTION

The desalination market has grown dramatically in recent years, and seawater reverse osmosis (SWRO) technology is leading this growth. SWRO plants have increased in number and in plant capacity. Several market factors have propelled this growth, and incremental improvements in membrane and pump technology have helped make plant operation more reliable and cost effective. But the technological breakthrough most responsible for reducing SWRO energy costs and enabling large-scale SWRO has been the development of pressure-equalizing or “isobaric” energy recovery devices (ERDs).

Energy Recovery, Inc. (ERI®) has shipped over 2,000 PX Pressure Exchanger (PX) ERDs globally, helping to produce over 1.3 million cubic meters per day (m^3/day) of fresh water and saving customers an estimated 170MW of energy, or $120 million a year in operating costs. The rapid acceptance of PX technology has enabled many public and private institutions to provide affordable water solutions to meet increasing demands. Plants such as Hamma, Algeria (200,000 m^3/day), Perth, Australia (143,000 m^3/day), Skikda, Algeria (100,000 m^3/day), Alicante, Spain (65,000 m^3/day), Murcia, Spain (63,000 m^3/day), Dhekelia, Cyprus (40,000 m^3/day), YuHuan, China (36,000 m^3/day), Maldives (6,000m^3/day) and Dalian, China (5,000m^3/day), along with many others have utilized PX technology as their energy savings solution to SWRO desalination.

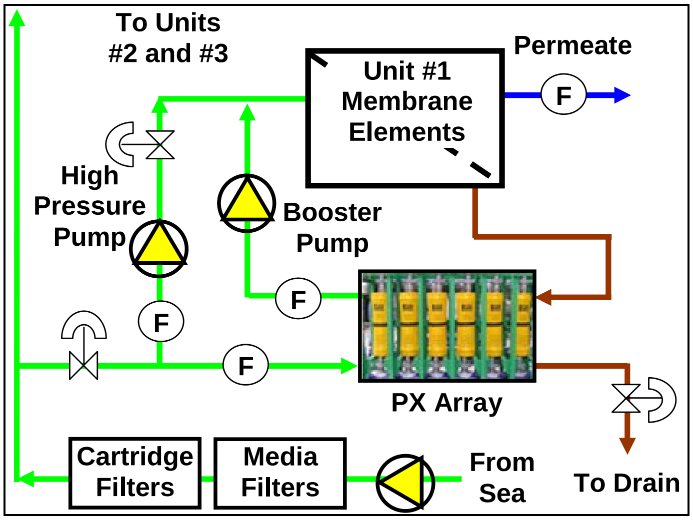
In the Arabian Gulf region, PX Pressure Exchanger devices were introduced for the first time in 2003 by UAE Federal Electricity and Water Authority (FEWA) who recommended use of the Pressure Exchanger as an energy-saving device in their tender specification for the 13,650 m^3/day SWRO plant at Ghalilah, Ras-Al-Khaimah. The contract was awarded to Fisia Italimpianti and the plant started production in the year 2004. Since then it has been running continuously. Before completion of the Ghalilah SWRO plant, the power consumption of the existing SWRO plants using energy recovery turbines in UAE was in the range of 7.5 – 8 kWh/m^3. In the Ghalilah SWRO plant, the use of Pressure Exchangers in place of energy recovery turbines drove down the power consumption to 4 kWh/m^3. It is to be noted that this power consumption is for the whole plant including pre- and post-treatment, product forwarding pumps, as well as plant power and lighting.

The FEWA 13,650 m^3/day SWRO plant at the New Qidfa Power Station in the Emirate of Fujairah, United Arab Emirates began operation in October 2006. The New Qidfa plant was designed and built by Aqua Engineering, an engineering, procurement and construction firm based in Mondsee, Austria. The plant is similar in design and operation to the FEWA SWRO plant in Ghalilah, Ras-Al-Khaimah, UAE[1] which has been running continuously since 2004. A new SWRO plant at Al Zawrah-Ajman, also designed by Aqua Engineering, is scheduled to start up in late 2007 and will produce 27,300 m^3/day with six SWRO trains of the same design as the three trains at New Qidfa.

2.0 NEW QIDFA SWRO PROCESS

The New Qidfa plant takes feed water from an open sea intake. The seawater salinity during startup was between 39 and 40 milligrams per liter and the temperature was over 30 degrees Centigrade. Three intake pumps deliver feed water through media and cartridge filters to three SWRO trains via a common feed header. Each SWRO train is equipped with a dedicated high-pressure pump, PX-device array and booster pump. Each train produces 1.2 million gallons per day (4,560 m^3/day) of permeate. A process diagram is shown in Figure 1.

Figure 1 – New Qidfa Train ROA Process Flow Diagram



The following major components are installed on each of the SWRO trains:

- High Pressure Pump: KSB Type HGM-RO-4/6, 198 m^3/hr at 700 meters head, 560 kW Seimens motor
- Booster Pump: KSB Type RPH-D1-150-230B, 276 m^3/hr at 51 meters head, 75 kW drive motor, variable frequency converter
- Energy Recovery: Six ERI model PX-220 devices
- Membrane Elements: 322 Hydranautics SW3C+ in 46 Codeline 7M vessels
- Instrumentation: Endress + Hauser flowmeters

An overview photograph of the plant is shown in Figure 2.

Figure 2 – New Qidfa Plant Overview

3.0 ENERGY RECOVERY

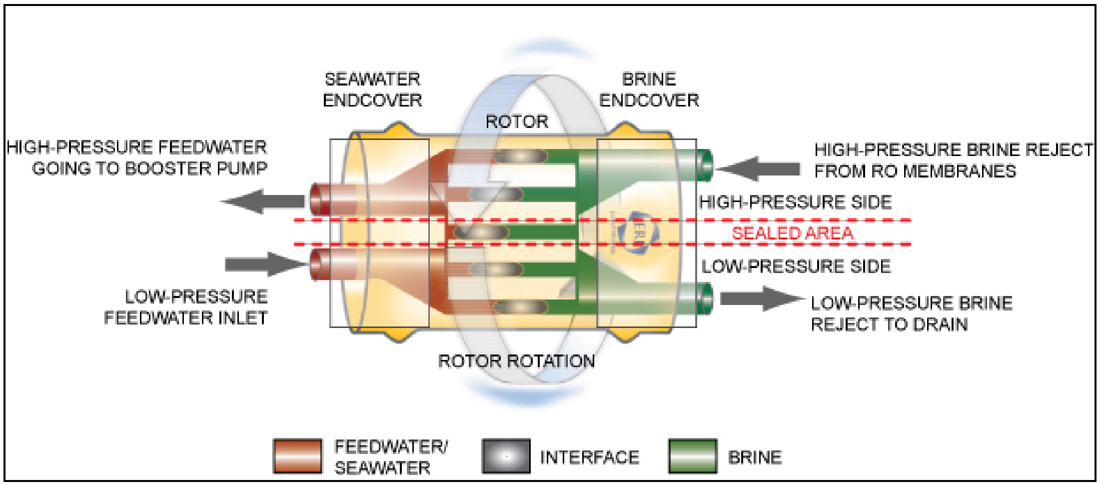
The New Qidfa plant employs eighteen PX-220 PX Pressure Exchanger (PX™) energy recovery devices with six PX units per SWRO train. PX devices can be mounted in any orientation including with the brine end up as at New Qidfa. One PX-device array is shown in Figure 3.

Figure 3 – PX Energy Recovery Device Array

3.1 Principle of Operation

Each PX transfers pressure from the high-pressure brine reject to a portion of feed water by putting them in direct, momentary contact in a rotor. The rotor is fit into a ceramic sleeve between two ceramic endcovers with narrow clearances that create an almost frictionless hydrodynamic bearing. As the rotor turns, the ducts pass a sealing area that separates high and low pressure. A schematic representation of the ceramic components of a PX device is given in Figure 4.

Figure 4 – PX Device Flow Schematic



The PX rotor contains no pistons or barriers. When the rotor is not spinning, flow passes directly through the device making PX operation during SWRO startup and shutdown almost automatic. Mixing between the brine and seawater streams is limited by the aspect ratio of the rotor ducts which are long and narrow. The PX rotor is designed so that the interface between the brine and seawater never reaches the end of the rotor before the duct is sealed.

SWRO systems equipped with PX technology save capital and operating costs by having smaller high-pressure pumps and more flexible water recovery ratios compared to systems equipped with turbines or with no energy recovery devices. With reference to Figure 1, the high-pressure portion of the process is sealed by the high-pressure pump, the membrane elements and the PX devices. The high-pressure pump is sized to supply only the permeate flow at the feed pressure required by the membrane elements. Water is circulated through the reject side of the membrane elements and the ERDs by the booster pump. A small amount of high-pressure water – typically less than 2% of the permeate volume – passes through the seals of the ERD. High-pressure pump flow and permeate flow remain nearly equal regardless of membrane feed pressure or booster pump flow rate. This decoupling of the high-pressure pump flow rate and the membrane-feed flow rate allows the system operator to vary membrane recovery just by adjusting booster pump flow. Such flexibility is important for obtaining optimal performance from each piece of equipment and for maintaining design productivity throughout a plant’s life.

3.2 Efficiency

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

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

The efficiency of a PX-220 is greater than 95% and as high as 98%[2]. In other words, the efficiency loss in the PX-220 is less than 5%. About 1% efficiency is lost to compression of the seawater. Another 2% is lost to viscous friction through the PX. The remaining 2% lubricates the hydrodynamic bearing. This performance is nearly constant over the PX’s operating range, which is typical of a positive displacement device.

In May 2005, ceramic clearances were reduced in the PX-220, resulting in less lubrication flow and a slight increase in differential pressure losses. These changes increased the average efficiency of PX-220s manufactured since then by about 1%.

3.3 Mixing

In all commercially available isobaric ERDs, some contact between the brine and seawater streams occurs inside the device. As a result, these streams mix slightly. The resulting increase in membrane feed salinity is quantified with the following expression:

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

Mixing is a function of the membrane recovery rate and the mixing characteristics of the specific ERD. Mixing can be computed by mass balance or approximated with the following empirical equation[2]:

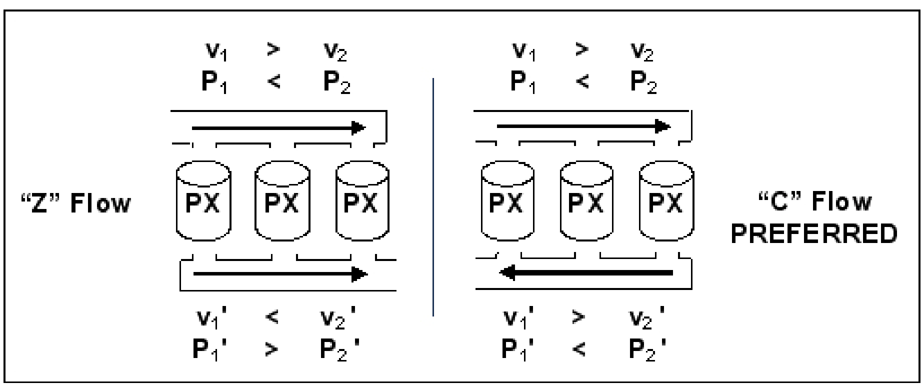
$$\text{mixing} \cong \text{membrane recovery} \times 0.0615 \quad (3)$$

At balanced flow when the high-pressure seawater flow from the PX array equals the seawater flow to the array, mixing is typically less than 3 percent. Feeding the PX array with excess seawater is called applying "lead flow." This decreases the mixing affect by flushing the PX rotor with seawater.

3.4 Multi-PX Arrays

A single PX-220 has a capacity of 220 gallons per minute or 50 m^3/hr. However, PX devices can be manifolded to run in parallel to provide unlimited capacity. As has been demonstrated in many long-running multi-PX arrays, PXs perform as well on manifolds as they do individually with no vibration or resonance problems. The pressure difference between the inlet and outlet manifold determines the flow through the individual PX units. To assure even flow distribution in a PX array, the pressure different between the manifolds should be even along the array. This can be accomplished by using large-diameter manifolds and/or by orienting the inlet and outlet manifolds to provide "C" or counter-current flow as opposed to "Z" or co-current flow as illustrated in Figure 5.

Figure 5 – Manifold Flow Schemes



In a "C" 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 at two arbitrary points in a manifold, assuming equal fluid density at the two points, is derived by energy balance:

$$(P_2 - P_1) + \rho\left(v_2^2 - v_1^2\right)/2 + f = 0 \quad (4)$$

where:
P = pressure,

v = velocity,
ρ = density, and
f = pressure loss due to friction.

Considering Figure 4, velocity in the inlet header 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 the header is relatively short. Friction losses are greater in smaller-diameter headers, however, the velocity change and its impact on pressure is even greater in such systems. Therefore, pressure tends to increase in the direction of flow in inlet headers.

Similar consideration of the flow and pressure in the outlet header leads to the general conclusion that pressure is almost always lowest near the open end of the header where the flow velocity is highest. Therefore, the pressure difference between the manifolds at any PX unit position is more constant in a “C” flow than in a “Z” flow scheme. The resulting conclusion, namely that “C” flow always provides better flow distribution through a PX array than a “Z” flow, 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 arrays are similar to membrane arrays providing the operator with beneficial redundancy. In applications where several rotors are arrayed in parallel like at the New Qidfa plant, one rotor out of service has minimal impact on SWRO membrane performance and the plant can typically keep running until scheduled maintenance corrects the problem.

4.0 NEW QIDFA PLANT PERFORMANCE

Performance data was collected during startup and commissioning in October 2006. A summary of operating data for the two trains for which data was available, ROA and ROB, is presented in Table 1. Also presented in Table 1 is summary data from the Ghalilah plant.

Table 1 – Startup Operating Data

		Al Qidfa ROA	**Al Qidfa ROB**	**Ghalilah 2/05**	**Ghalilah 9/06**
Permeate Flow Rate	m^3/day	**4,608**	**4,560**	**4,526**	**4,512**
Water Recovery Rate	%	40.7	40.4	39.9	39.8
Membrane Feed Pressure	bar	56.3	56.6	64.0	64.4
High-pressure Pump Discharge	bar	76.0	74.0	78.3	77.5
Control Valve Pressure Drop	bar	19.7	19.7	14.3	13.1
PX Efficiency	%	**96.1**	**96.1**	**95.4**	**95.1**
Feedwater Temperature	deg C	33	33	24	33
Applied PX Lead Flow	%	0.4	2.5	0	0.1
PX Mixing	%	1.7	0.6	2.9	1.7
Total SWRO Energy Consumption	**kWh/m^3**	**2.93**	**2.96**	**3.13**	**3.15**

Energy consumed by the SWRO portion of the process per cubic meter of permeate produced does not include pre-treatment or auxiliary consumption and is the actual energy consumption of HP pumps, booster pumps, and control valves as measured at the plant. The total energy consumption of this plant including all electrical devices at the plant as well as lighting, air conditioning, etc. is 3.7 kWh/m^3, which in UAE is regarded as a record in itself. A light increase in power consumption may be anticipated over the years as the membranes foul; feed pressure to the membranes will increase and the frequency of the booster pumps will also increase. But this is normal with any water production plant. A control valve after the high-pressure pump was installed to assure that the high-pressure pump has sufficient capacity to overcome membrane fouling or degradation that may occur in the years ahead, however it consumes a substantial amount of energy.

The PX arrays at New Qidfa were configured with the high-pressure manifolds in C-flow and the low-pressure manifolds in Z-flow. As a result, low-pressure flow is highest through the unit at the end of the low-pressure inlet manifold while high-pressure flow is approximately equal at each PX position along the manifold. This is evident in the measured salinities at the low-pressure outlet of each PX device. Startup salinity data from train ROB was used to estimate the high-pressure outlet salinities and the low-pressure flow rates through the units with a constant high-pressure flow rate of 41.7 m^3/hr per unit. This data is presented in Table 2:

Table 2 – PX Outlet Salinity and Flow Distribution in Train ROB

PX Low-Pressure Inlet-Manifold Position	Inlet					Outlet
Low-Presure Outlet Salinity (mg/l)	60.8	61.3	61.3	61.8	61.8	61.9
High-Pressure Outlet Salinity (mg/l)	40.5	40.0	40.1	39.5	39.5	39.4
Low-Pressure Outlet Flow Rate (m^3/hr per PX)	41.9	43.9	43.8	45.8	46.1	46.3

The data in Table 1 indicates that overall PX device performance at New Qidfa is consistent with the manufacturer's advertised ratings. The performance of train ROA and ROB is identical within the accuracy of the process instruments. Efficiency is greater than 96% and mixing is less than 3%.

SWRO process and PX device performance is better at New Qidfa than at Ghalilah, primarily because of lower membrane feed pressure at New Qidfa related to the lower seawater salinity (38,000 ppm as compared to 42,000 at Ghalilah). PX performance is better at Al Qidfa because the efficiency of the more recently-manufactured PX devices is higher than those installed at Ghalilah. PX-device performance at Ghalilah has not changed in over 18 months of continuous operation – the small difference in PX efficiency attributable to the seasonal change in seawater temperature.

5.0 CONCLUSIONS

The reverse osmosis portion of the New Qidfa plant is running at its design production rate and consuming less than 3 kWh/m^3. The PX devices are running with greater than 96% efficiency and lower than 3% mixing, consistent with the manufacturer's ratings. Energy consumption is lower at New Qidfa than at startup at its sister plant at Ghalilah because of lower membrane feed pressure at New Qidfa. PX-device performance is better at New Qidfa than at startup at Ghalilah because of a design improvement in the PX-220 that was implemented in May 2005.

6.0 ACKNOWLEDGEMENTS

The authors acknowledge the assistance of Mr. Peerzada Kaleem Khan of FEWA for reviewing this work and Mr. Bill Anderson of ERI for collecting and assisting with analysis of the data.

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