Reliability that Pays: How Energy Recovery Device Availability Drives Profitability in Reverse Osmosis Systems

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SECTION 1: EXECUTIVE SUMMARY

Availability can be defined as the probability that a system or piece of equipment operates satisfactorily at any given time. The availability of the equipment installed in a reverse osmosis (RO) facility directly impacts the cost, quality, and quantity of purified water produced.

There are three critical components in the RO processes: the main high-pressure feed pumps, the RO membranes, and the energy recovery device (ERD) system. This paper focuses on the economic benefits and importance of the availability of ERDs in RO desalination plants.

The largest operating expense for most RO facilities is the power consumed, which accounts for up to 30% of the total expense. For large facilities (>50,000 m3/d), the ERDs responsible for reducing energy consumption are only a fraction of the capital cost (< 2%) of the entire plant but offer significant return on investment through energy savings. Specifically, isobaric rotary-type ERDs, such as Energy Recovery, Inc.'s PX® Pressure Exchanger® (PX) devices reduce energy consumption at RO plants by as much as 60%. In a large RO plant, this performance can save as much as $2.8M in net present value (NPV) over the life of a plant.

Considering that a single day of downtime in a large RO plant can cost over $250,000 in lost profit NPV and $650,000 in lost revenue NPV, the availability of the ERD system is critical to the economics of a plant. ERD downtime results in strict penalties, unplanned maintenance costs, and most importantly, a loss of revenue from diminished water sales and wasted cost of capital investment. In addition to the importance of uptime, considering that RO plants operate nearly continuously for multiple decades, superior performance can result in millions in additional profit.

Clearly both ERD performance and availability are of major importance to RO plant economics.

The role that ERDs play is undeniably critical to the success or failure of an RO facility. Selecting the most reliable and highest performing ERD can save millions over the life of a plant.

This paper considers mechanical and operating variables in commercially available ERDs and quantifies the costs and savings associated with their installation and operation to make a case for maximum availability and highest performance.

SECTION 2: THE IMPORTANCE OF RELIABILITY IN DESALINATION APPLICATIONS

Water is a vital resource for health, sanitation, industry and recreation. Desalination plants are typically designed to run continuously, with only a few days of downtime per year for scheduled maintenance and/or cleaning. Unexpected downtime is similar to a power outage – very disruptive, constituting an emergency situation for the communities and businesses that rely on the plant's water production.

The core components of a desalination plant are the high-pressure pumps, the reverse osmosis membranes and the energy recovery devices (ERDs). These are illustrated in Figure 1.

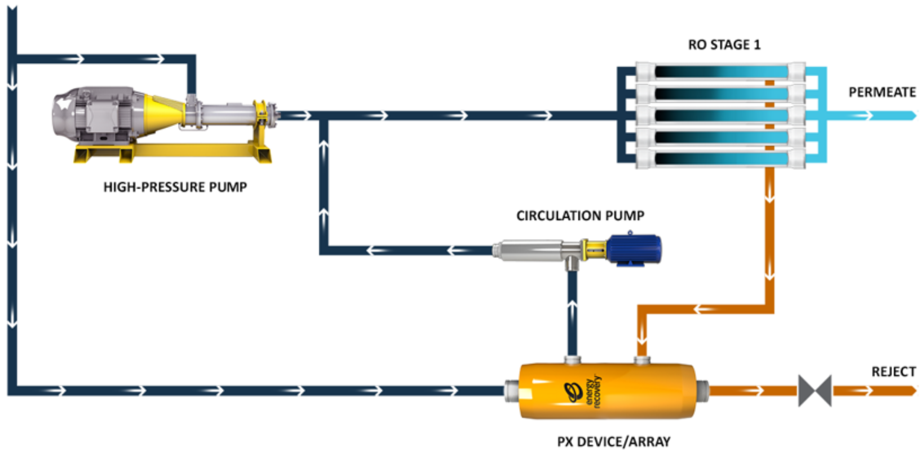


Figure 1: Typical Desalination Plant Equipped with PX ERDs

Energy recovery devices are essential to desalination plant operation. ERD failure can completely shut down the plant. Even planned shutdowns have significant financial ramifications for the plant operator.

This paper discusses and quantifies the importance of ERD availability and the costs of downtime. It compares construction, operation, and performance of PX Pressure Exchangers with competing devices to make a case for maximum availability.

SECTION 3: COMPETING ENERGY RECOVERY DEVICES

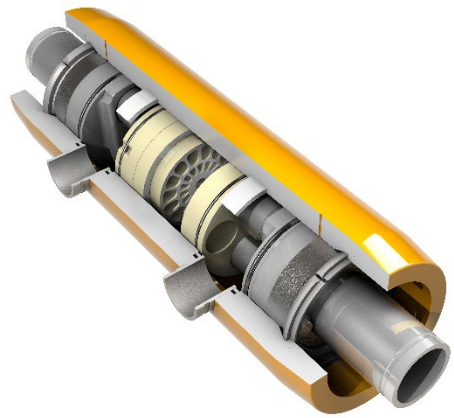
The clear need for ERDs in RO processes has spurred the development of at least 20 device types in the last 25 years. Only four device types are still in production. Isobaric ERDs are those that transfer pressure directly from the RO brine reject stream to the feed stream with efficiencies exceeding 95%. This category includes the PX® Pressure Exchanger®, a recently introduced rotary isobaric ERD, and a motor-driven isobaric ERD. In addition, less efficient turbocharger-style ERDs are available, but they fall outside the scope of this paper.

Of the isobaric technologies evaluated here, the PX Pressure Exchanger has the longest track record in large-scale deployments. In contrast, both the rotary and motor-driven isobaric ERDs, collectively referred to here as emerging isobaric ERDs, have only recently entered commercial production. These newer devices have yet to be proven at full-scale plant capacities and have mostly been installed in retrofitted systems for field validation purposes. Consequently, their long-term reliability and durability remain uncertain.

This analysis compares the performance, cost, and availability of the three commercially available isobaric ERD technologies. Where empirical data for the emerging isobaric ERDs is limited, reliability projections are based on available manufacturer specifications and limited field trial observations.

SECTION 4: MINIMAL MOVING PARTS

Simplicity, efficiency, and uptime are important features when comparing energy recovery technologies for energy intensive desalination plants. PX Pressure Exchangers contain a single moving part: a free spinning rotor driven only by flow. The rotor moves on a seawater hydraulic bearing that is constantly refreshed, such that there is no direct contact with the moving rotor. The rotor contains no pistons, such that PX devices never block flow. Unlimited capacities can be achieved by arraying multiple devices in parallel.



Fewer moving parts means reduced likelihood of failure.

In contrast, the competing motorized ERD contains dozens of moving parts plus a separate electric motor on every device. These devices are subject to periodic maintenance requiring plant shutdown. Several specific motorized ERD models contain pistons that, upon failure of any component, block flow, resulting in an immediate plant shutdown.

If a PX device does require maintenance, the internal components can be accessed without removing the device from the high-pressure connections or the rack. In contrast, both the emerging isobaric ERDs need to be nearly completely removed for service. Ease of service contributes to availability over long-term operation.

SECTION 5: MATERIALS OF CONSTRUCTION

Because RO applications are very demanding, with exposure to constant corrosive and abrasive conditions and intense cavitation energy, the materials that make up an ERD play a major role in the overall reliability and uptime. Minor defects that may not be detected during manufacturing or initial operation can further degrade over time, resulting in major problems.

The core of a PX device is composed of extremely durable, high-purity alumina (ceramic). Alumina has proven to be critical to long-term and trouble-free ERD device performance. Alumina is known for outperforming plastics such as PET, Acetal, UHMW, which can become relatively soft and dimensionally unstable. In addition to material stability, trapped debris can cause problems in sliding polymeric components such as pistons, sliding vanes or poppet valves, features found in other ERDs. Studies have shown that PX devices provide a 30-year design life. No maintenance is required for the entire life span of PX devices in seawater applications.

The core components in a PX device are made of alumina – one of the hardest and most durable materials available.

In contrast, the motorized isobaric ERD is made of stainless steel with optional ceramic coatings or inserts. Wear parts in the device require periodic maintenance, estimated at once per year, and the device requires a major overhaul every three years.

PX housings are designed and produced following the American Society of Mechanical Engineers (ASME) Code, the most respected international safety standard regulation for fiber reinforced plastic pressure elements, written specifically for fiber reinforced plastic pressure vessels. This contrasts with the alternative, non-motorized rotary ERD that is housed in a metallic vessel that is not fabricated according to any international safety standards.

SECTION 6: HYDRAULIC DESIGN

The hydraulic design of an ERD is as important as the materials of construction for assuring reliable performance. Hydraulic stress phenomena, such as cavitation and erosion, can destroy even the most durable materials. Figure 2 illustrates high and low velocity streamlines in an ERD. High flow rates result in local pressure reductions that increase risk of cavitation. High flow rates can also produce impinging flow that increases the risk of erosion. Acceptable flow rates are indicated by blue and green streamlines. Excessive flow rate streamlines are illustrated by the red and yellow lines. High noise levels often accompany high hydraulic stress.

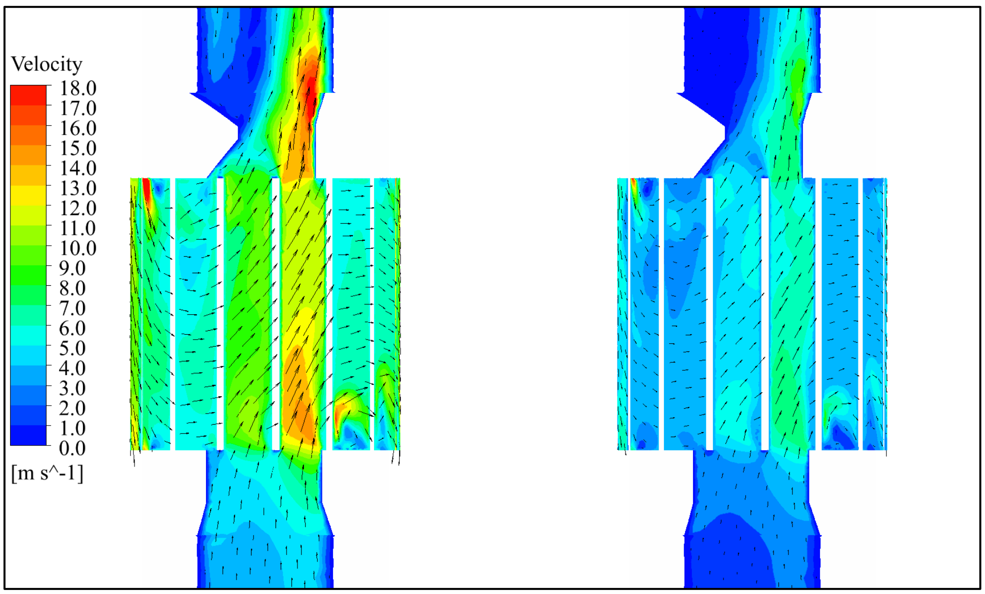


Figure 2: Velocity Contours at 150% (left) and 90% (right) of Rated Maximum Flow

Energy Recovery specifies maximum flow rates for PX devices that are well below hydraulic stress thresholds, providing for a long 30-year design life. The recently introduced competing non-motorized ERD features similar cross-sectional flow areas but is rated for up to 50% higher flow rates, nominally making these devices more economical on a per-unit-of-water-pressurized basis. However, accentuated hydraulic stress can shorten the life of these devices to five or fewer years. Indeed, field reports have consistently noted that these competing devices produce levels of noise that can exceed plant safety standards. Noise is an immediate indication of hydraulic stress.

SECTION 7: FAIL SAFE

Operating PX Pressure Exchangers in arrays of multiple devices in parallel provides users with built-in redundancy. In the unlikely event that a PX unit rotor stops, the system can continue to operate until the next scheduled maintenance takes place, with minimal loss of productivity. Flow passes through the stopped PX device, allowing continued operation of the RO system. In larger arrays, operation can continue with up to 20% of the devices stopped.

While it is highly unlikely, if a PX unit's rotor were to stop for any reason, the train can still continue to operate until the next scheduled maintenance, with only minimal loss of productivity.

In contrast, several motorized ERD models do not pass flow if the motor stops, resulting in an immediate RO system shutdown in the event of device stoppage or failure.

SECTION 8: FINANCIAL IMPLICATIONS

Desalination plant designers and owners consider both capital expenses (CAPEX) and operating expenses (OPEX) when selecting equipment. CAPEX is amortized over the life of the plant and combined with OPEX to compute the total cost per unit of water produced.

The following table was developed considering a RO plant of 100,000 m3/d permeate production capacity and a $0.10/kWh power tariff. List-price costs of PX Pressure Exchangers, combined with typical costs of manifolds and racks necessary to support them, are compared with the corresponding costs of competing ERDs. It is assumed that the motorized ERD is 33% lower cost than the PX or other isobaric rotary energy recovery devices. It is also assumed that periodic maintenance or premature failure of competing ERDs will necessitate their overhaul every five years for the non-motorized isobaric rotary device and every three years for the motorized ERD while PX devices will require no maintenance. Other performance parameters are per manufacturer's published data sheets.

CAPEX & OPEX

	Motorized ERD:	**Rotary Isobaric:**	**PX:**	
Capital Cost (ERDs, Manifolds, Racks)	1,498,000	2,245,000	2,245,000	USD
Operating Cost (Power, Spares)	10,359,000	9,962,000	9,711,000	USD/y
Capital Cost (25 years, 8% interest)	0.004	0.006	0.006	USD/m³
Operating Cost	0.284	0.273	0.266	USD/m³
Total Cost	0.288	0.279	0.272	USD/m³
Total Cost	10,498,000	10,170,000	9,919,000	USD/y
Switching to PX:				
PX Savings (NPV)	**6,251,000**	**2,710,000**	**Baseline**	**USD**
Simple Return on Investment	**1.2**	**0.0**	**Baseline**	**years**

Compared to the motorized ERD, the savings provided by more reliable operation and better average energy efficiency of the PX more than compensates for the assumed higher cost of the PX in this analysis. The NPV savings with PX is over 6 million USD for this plant size or $0.016 per m^3 of permeate produced, resulting in a 14-month payback. Because the competing rotary isobaric ERD requires more frequent maintenance, even if only at 5-year intervals, the PX provides 2.7 million USD savings or \$0.005 per m^3. The capital cost of the PX and the non-motorized competing devices are very similar, so the lower maintenance requirements of the PX make the return on investment instantaneous.

Downtime in a desalination plant results in loss of revenue and profit. Consider a RO plant with 100,000 m^3/d permeate production capacity. Assuming typical plant life, financing interest rate, water sale price and operating costs (including power, labor, chemicals and spares), the following table computes the losses associated with downtime, either planned or unplanned. Losses are computed as net present value (NPV) over the life of the plant for a single day of downtime per year.

REVENUE AND PROFIT LOSS		
Life of Plant	25 years	
Interest Rate	8%	
Plant Size	100,000	m^3/d
Overall Water Price	0.60	USD/m^3
Revenue	60,000	USD/d
Operating Costs	0.37	USD/m^3
Gross Profit	0.23	USD/m^3
Gross Profit	22,771	USD/d
Profit Loss - 1 Day Downtime (NPV)	**245,856**	**USD**
Revenue Loss - 1 Day Downtime (NPV)	**647,823**	**USD**

Internal research and data collected from a range of RO desalination plants worldwide were used to assess the availability of PX Pressure Exchangers compared to competing ERDs. These facilities, located in regions including the Caribbean, the Middle East, and Australia, vary in production capacity from 1,000 to 900,000 m^3/day. On average, it was found that competing ERDs experienced up to three (3) days of unplanned downtime per year. When factoring in lost revenue from downtime, along with capital (CAPEX) and operational (OPEX) savings due to the superior reliability and efficiency of PX technology, the total net present value (NPV) savings amounts to 8.2 million USD versus the motorized ERD or 4.7 million USD versus the PX-like ERD—3.7x or 2x the estimated capital cost of a typical PX installation, respectively.

SECTION 9: SUMMARY

Energy recovery device (ERD) system availability and performance are critical economic factors in the selection of ERDs for reverse osmosis plants. Among available technologies, the Energy Recovery PX® Pressure Exchanger offers superior inherent reliability, availability, and operational efficiency compared to alternative devices. These advantages translate into significantly lower operating costs and reduced unplanned downtime. Over the system's lifetime, the net present value of these savings is more than twice the initial capital investment of a typical PX installation, making it a highly cost-effective solution for maximizing plant profitability and resilience.

All statements assume proper operation of PX designed for pressures of 1,200 psi (82 bar) or less in seawater reverse osmosis applications.

Actual results may vary based on multiple factors, including system design, RO membrane model and conditions, and operating conditions.