

# Keys to High Efficiency, Reliable Performance and Successful Operation of SWRO Processes

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## **Abstract**

Isobaric energy recovery devices (ERDs) have attained nearly universal acceptance by the seawater reverse osmosis (SWRO) desalting world. These devices are operating in the largest SWRO trains in the world and continue to be an integral component in small, containerized systems. Systems incorporating isobaric ERDs are being installed and supported on all seven continents. This has led to an accumulation of a wealth of knowledge based on practical operating experience.

The purpose of this paper is to bring this information to current and future users of isobaric ERDs to help them be successful. Armed with this practical “hands on” knowledge, it is anticipated that new reverse osmosis professionals will quickly learn reverse osmosis process operation and control and experienced operators will fill in any gaps in their skills.

The authors discuss common system design errors and successful installations, commissioning, startups and operations. Pumping system, train size and energy recovery system configuration alternatives and their impact on operational efficiency, flexibility and uptime are considered. “Lessons learned” from hundreds of successful plant commissions are shared with the goal of promoting SWRO as a reliable and affordable means of fresh water supply.

## **I. ISOBARIC ENERGY RECOVERY DEVICES: AN OVERVIEW**

Energy recovery devices or ERDs recover the pressure energy of the membrane reject stream of a reverse osmosis (RO) process. Turbines were initially applied to use the energy of the reject stream to help turn the shaft of a high-pressure pump. To avoid the efficiency losses associated with the energy-transformation inherent in turbine ERDs, engineers developed positive-displacement isobaric devices for RO. These devices have been deployed widely in seawater RO (SWRO) processes since about 2002.

Isobaric ERDs place the RO concentrate reject and low-pressure feedwater in contact inside pressure-equalizing, or isobaric, chambers. There are currently two commercially-available types of isobaric ERDs including several piston-type work exchangers and the rotary PX Pressure Exchanger device. Piston-type devices have large chambers, pistons separating the concentrate and seawater, and valves and control systems to switch flow between the chambers and limit the travel of the pistons. The PX device has small chambers, no pistons and no direct controls. Piston-type work exchangers were historically considered to be better suited to large SWRO trains because of their relatively large unit size. However, the largest SWRO trains operating today, 25,000 m<sup>3</sup>/day (6.6 million gal/day) in Hamma Algeria, are supplied with PX devices operating in arrays.

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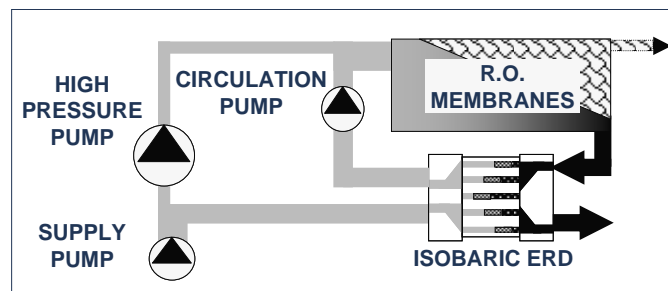
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Like reciprocating pumps, the positive-displacement pressure transfer mechanism used in isobaric ERDs deliver high efficiency despite pressure and speed/flow rate variations. As a result, most SWRO plants being designed and built today utilize isobaric ERDs. Many plants built with turbine ERDs have been retrofitted or are considering the conversion to isobaric devices to reduce energy consumption and increase production capacity.

A simplified flow diagram of an SWRO process with isobaric ERDs is shown in figure 1. Concentrate rejected by the membranes flows to the ERD driven by a circulation pump. The ERD replaces the concentrate with seawater. The pressurized seawater merges with the discharge of the high-pressure pump to feed the membranes. Water leaves the process as fresh water permeate from the membranes or as spent low-pressure concentrate from the ERDs. An energy recovery efficiency of 98% can be achieved with state-of-the-art isobaric ERDs. Isobaric ERDs can reduce the amount of energy required to desalinate seawater by up to 60%, resulting in more economical production of drinking water and a reduced carbon footprint.

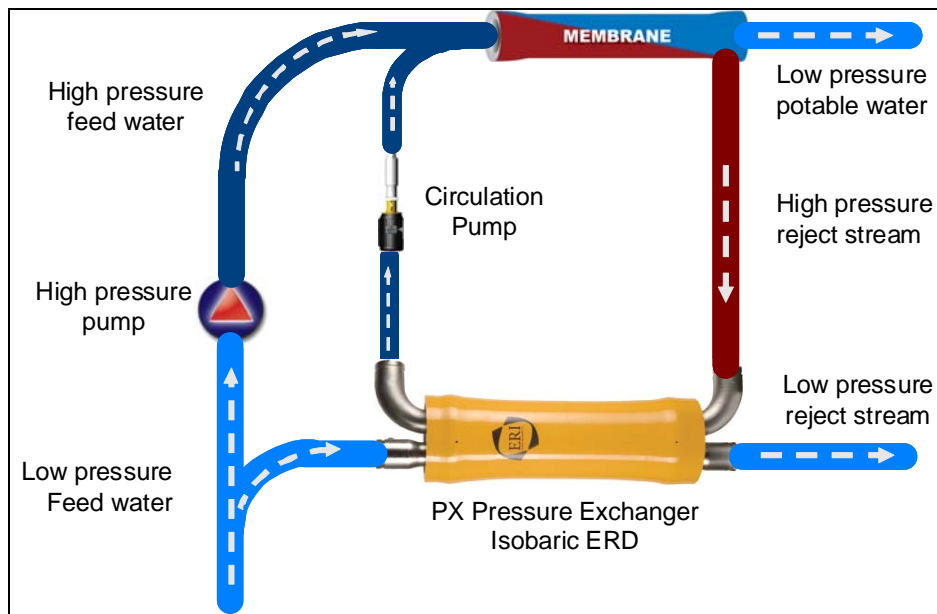


**Figure 1: Simplified Diagram of an SWRO Process with Isobaric ERDs**

## **II. ISOBARIC ERD OPERATION**

One must have a clear understanding of how isobaric ERDs work in order to properly design an effective SWRO system that uses them. This may sound obvious, but it is not always the reality. Often, as work is distributed within an organization, the people tasked with the actual design and operations of the system are not the people who have received the training on the operating theory of the devices.

Isobaric ERDs employ a positive displacement mechanism that incorporates two separate flows. As shown in Figure 2, it allows the concentrate (containing the energy to be recovered) to displace the feed water flowing to the membranes. Controlling the flows insures that the transfer of pressure from the concentrate stream to the feed water stream takes place in the most efficient, reliable, and predictable manner.



**Figure 2: Schematic Showing SWRO and ERD Flows**

In systems that use turbine ERDs, adjusting the high-pressure concentrate flow is the primary means of controlling the system performance. In systems equipped with isobaric ERDs, system performance is controlled by adjusting the low-pressure concentrate flow with a flow control valve and/or adjusting the high-pressure flow by adjusting the circulation-pump speed. For example, slowing the circulation pump will raise the percentage of water recovery by the membranes and increase the membrane array feed pressure. When a centrifugal high-pressure pump is being used, slowing the circulation pump will decrease permeate flow.

## 2.1 Flow Measurement

As isobaric ERDs are positive displacement, flow-driven devices, accurate flow measurements are very important. If designers do not understand how the ERD works or if they are simply trying to cut cost, instruments can be left out of the design. One flow meter is required in the high-pressure (HP) flow circuit and one on the low-pressure (LP) piping.

Flow metering does not need to be extremely accurate to properly operate an ERD. In small plants, rotometers (variable area flow meters) are acceptable. Drawing from experience, paddle wheel type flow meters are the most problematic. At times, end users will require more accurate flow measurement to verify system performance. For this purpose, repeatability and robustness are important. Magnetic and vortex flow meters are successful when a higher degree of accuracy is required. It is important to select instruments constructed of materials able to work in the feedwater and concentrate.

Once meters have been selected, it is critical that they be installed per the flow meter manufacturer's recommendations. Improper installation is a primary cause of flow measurement errors. An expensive instrument installed incorrectly and unable to produce an accurate flow measurement is a wasted investment.

The authors have been seeing ultrasonic “strap on” flow instruments used more often. These instruments are less expensive for high-pressure flow measurement and easier to install than most in-line alternatives. These types of instruments have also been utilized during start ups and for troubleshooting. Some important considerations are outlined below to assist in the selection of ultrasonic flow instruments.

- The accuracy of the ultrasonic flow instrument is completely dependent upon the skill of the technician who installs the hardware and configures the transmitter. Some means of verifying that the indicated flow rate is correct is important.
- There is a big difference in the quality / reliability / accuracy in the ultrasonic instruments available on the market today.
- Because the critical sensing elements of these instruments are exposed to hazards ranging from salt water spray to the operator’s boots when he is climbing on the piping, they are prone to lose accuracy or fail more often than in-line flow instruments. Extra care must be given in protecting these components from hazards, and accuracy needs to be rechecked periodically.
- Ultrasonic instruments can be quite sensitive to entrained air. Until all the air is removed from the system piping; the meter will not read accurately. It can take some time before they settle. This can be problematic if they are to be used in a process control loop. Lots of unobstructed straight pipe upstream and downstream is required to ensure accurate readings.

## **2.2 Air Venting**

Entrained air is destructive to many components in a SWRO system. This is also true for isobaric ERDs. If air, pressurized and compressed, reaches an operating ERD, it will instantaneously expand and may damage the internal components. This risk can be avoided by installing and utilizing air vent valves at the high point of the concentrate header as well as other high points where air can be trapped. If efficient air venting is provided, systems can be started up quickly. Some problems witnessed by the authors include:

- Air venting is not considered when the piping is designed. Piping should be designed to avoid as many air traps as possible.
- Air vents are inaccessible. If the vent valve is difficult to reach, it should be an automated valve. Many smaller plants are designed to operate (start and stop) without operators present. In this case the vent valves need to be automated.
- Some automated vent valves have not been reliable. Some have stuck in the open or closed position. It is beneficial to get a good valve and actuator (pneumatic or electric).
- Vents often spray water everywhere. It is best to be piped to drain. HP vents need to be piped in hard pipe to avoid dangerous plastic piping explosions.

- Pressure can be trapped in the HP circuit after shutdown. Often, the vent valves are used to depressurize the system. Valves should be sized to vent efficiently without depressurizing the membrane system too quickly.

### 2.3 Low Pressure Flow Control

Controlling the LP flow through the ERD can sometimes be a challenge for the designer. For smaller systems, controlling cost is a major factor and for larger systems, multiple train designs can cause complications. If the feed water pressure is steady, LP flow control becomes easier. Some feed pumps have relatively flat performance curves which means that flow changes result in only minimal pressure changes. This is an advantage and can simplify the LP flow control.

When the feed pressure varies considerably, the designer must make some choices. Is it best to try to control the upstream pressure to the ERDs so that a manual LP flow control valve can be used on the discharge? Or, is it best to allow the upstream pressure to the ERDs to fluctuate and install an automated valve downstream that will adjust to control flow? Here are some of the ways we have seen designers control the upstream pressure.

- Use a variable frequency drive or VFD on the low-pressure feed pump. The feed header pressure would be the control loop process variable. Feed pumps are available with integral VFDs that include control logic capabilities.
- Install a pressure regulator upstream of the ERDs.
- Start feed to the ERDs first and feed to the HP pump second. Shut the system down in the reverse order.
- Install a “bypass” loop which re-circulates flow back to the feed water tank when the feed header pressure exceeds the set point. This requires a pressure transmitter, a control valve and a controller.
- Provide a VFD-controlled feed pump dedicated to the ERDs and install a water column at the ERD LP outlet to automatically provide sufficient back pressure.

Control valve options include

- A pneumatic flow control valve – the best choice as pneumatics react quickly to flow changes sensed by the flow meter.
- An electrically actuated flow control valve – OK but some are notoriously slow to react and adjust.
- A pilot operated “flow control valve” – much like a pressure regulator
- A variable orifice flow controller.

The authors recommend that whatever path is chosen, flow control valves should be designed for flow control and not for “on / off” service. The designer of a large plant will usually include an automated flow control valve and often will also include some type feed pressure control. Some large plants with multiple trains will have a separate feed water system for the ERD arrays and another feed water system dedicated to the HP pumps. VFD control of the feed water pumps is common. Ideally, one would have feed water pumps that take suction from a tank downstream of the pretreatment filters and just upstream of the cartridge filters. This would isolate the SWRO trains from upsets and load changes that occur in the filters. More feed water pumps seem to be better than one or two as it is sometimes difficult to turn down large pumps to operate just one or two trains.

## **2.4 High Pressure Flow Control**

Maintaining flow control of the ERD HP flow circuit is usually easier than controlling the LP flow because the HP flows in a circulation loop. The flow rate is usually controlled by adjusting the circulation pump speed using a VFD. ERI recommends using a VFD controlled pump motor, however, in some installations, a flow control valve is preferred. The VFD output to the pump driver or the control valve position will not require adjustment often as the only things that will affect the ERD HP flow rate will be the condition of the membranes and the characteristics of the feed water.

The designer will want to avoid placing restrictions to flow in the ERD HP flow circuit as they will waste energy. Isolation valves, for example, should be full ported and check valves with the most favorable flow characteristics should be chosen.

## **2.5 Designing for Changing Conditions**

If the designer understands that the HP pump controls the permeate flow rate and that the circulation pump controls the concentrate flow rate, designing for anticipated production and recovery requirements becomes simplified. Membranes will age and feed water characteristics and the end user’s requirements may change, so being able to provide for flexibility is a great advantage.

The HP pump must be able to provide the desired flow at the worse case operating conditions if the end user requires a specified permeate production rate. That means that the pump is usually oversized for initial operating conditions and the flow must be controlled. Four methods of HP pump flow control are common:

- A VFD controlled motor is used to directly vary the HP pump speed;
- A flow control valve is installed on the discharge of the pump;
- Backpressure is applied on the permeate;
- A “charging pump” controlled by a VFD is installed upstream of the main HP pump.

If a centrifugal HP pump is allowed to operate on its curve and the volume of permeate produced is allowed to vary, the membrane recovery can change. This can occur when the feed-water temperature changes. If a constant recovery rate is desired, the designer must provide for adequate concentrate flow (flow provided by the ERD circulation pump). As the ERDs will have a maximum allowable flow rate,

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the ERD array must be sized to accommodate the maximum anticipated concentrate flow. Designers will sometimes provide for additional ERD units in their manifold designs to be able to add units for future expansions.

Adjusting recovery while maintaining the desired permeate flow rate can be accomplished by adjusting the flow rate in the ERD HP circuit. Lowering the recovery will likely mean that additional LP feed water is required. As the operator increases the HP circuit flow rate, increasing the LP flow rate is usually required. The designer should anticipate the need for additional feed water and also the need to be able to supply feed water to the ERD array at a pressure sufficient to maintain the required ERD LP output pressure. Back pressure on the ERDs prevents cavitation in the devices the same way that sufficient suction pressure prevents cavitation in pumps.

## **2.6 Sampling and Pressure Measurement**

Operators are aided by having sample points and pressure indicators installed near all four connections to the ERD array. The advantage these sample points and pressure instruments provide to the operator is important for trouble-shooting, verifying flow meter accuracy and measuring pump and ERD efficiency.

### **III. SAMPLE PROCESS DESIGNS**

#### **3.1 Large Plant Installations**

Large trains usually will have an array of ERD units mounted on a dedicated support frame. The frame will usually carry the ERD units and the associated manifold piping. In cases where the HP piping has been pre-fabricated off site, we recommend that the frame not be secured until the piping has been set in place and the HP manifolds are aligned in their correct positions. This will minimize the amount of reworks required in the field. Empty ERD units, that is, ERD housing and piping connections without the internal components, can be provided to allow the fitters to properly align the manifolds.

Some error in the placement of branch connections on fabricated manifolds can be expected. The LP branch connections are usually fusion-bonded to the manifold and can be broken off at the weld. It is critical, therefore, to prevent strain from being applied to the LP manifold branch connections. One flexible coupling is required to connect each of the four ERD connections to the manifolds. To account for some manifold misalignment and to protect the LP manifold branch connections, we recommend the use of two flexible couplings around a short pipe spool.

Metal piping should be thoroughly inspected to insure that the interior is free from welding slag and other debris created during manufacturing that could separate from the pipe and eventually enter the ERD units. The same precautions should be taken with the LP piping. Pipe fitters need to understand that keeping the piping clean is critical. Regardless of precautions, all piping should be flushed at full flow rates prior to loading the membranes and connecting the ERDs to the system.

While no destructive vibration or hammer can be created by PX ERDs, piston-type ERDs can cause these problems. Also, in any process stream, closing valves suddenly can cause water hammer, while improperly-sized or improperly-installed fittings can cause vibration. If the piping is not properly supported, it may move and damage the ERD units and/or manifold connections. It is critical to properly support the piping.

## **3.2 Small Plants**

On smaller, skid-mounted systems, the builder may need to mount the ERD device on the frame in the factory to insure proper piping alignment. If this is the case, ERI recommends that the PX device internals be wetted, the ports resealed and the devices returned to their original packaging to be shipped to the site.

It is critical that the ERD units are supported independent of the piping. Connections must be free from strain. Plunger-style positive-displacement pumps are sometimes used in smaller systems. These pumps can produce pulsations that can cause piping movement and this movement can damage connections to the ERD units. Proper pulsation dampening and pipe supports are required.

## **3.3 Lessons Learned**

The authors have observed PX ERD systems operating successfully for years where the operators have not received any ERD training. The PX device is a very simple and robust piece of equipment. However, success is most likely with training. In the real world, employee turnover occurs, and as a result, periodic retraining is an important practice. At a minimum, we recommend that the operators understand the consequences of improper operations.

By keeping the ERD units clean and dry, the operator can extend the life of the external non-wetted components. Leaks should be fixed immediately. The ERD units should be rinsed with fresh water periodically. Salt water should not be allowed to accumulate and stand on the devices.

PX ERD units are built with extremely tight tolerances; they are considered “self-cleaning.” In many installations, when the SWRO process is stopped for a short period of time, only a seawater flush is required. However, in some feed waters, biological activity can create a residue within a few hours. In these plants a fresh water flush is recommended at shutdown. This is a site-specific condition and cannot be predicted.

## **IV. CONCLUSIONS**

Isobaric energy recovery devices have attained nearly universal acceptance by the SWRO desalting world. Isobaric ERDs, such as the PX Pressure Exchanger device, can reduce the amount of energy required to desalinate seawater by up to 60% compared to a process with no energy recovery. This savings can result in more economical production of drinking water and a reduced carbon footprint. If designers and operators understand how ERD devices work in RO processes, successful process operation will be intuitive.

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