Applying Ultra-High Pressure Reverse Osmosis in Brine Management

Takeaways:

- New ultra high-pressure reverse osmosis technology can reduce brine management costs by three times relative to evaporators.
- Now rated for 1,740 psi, new UHP RO spiral wound membranes achieve 1.6X brine volume reduction over previous 1,200 psi seawater (SWRO) RO membranes, so long as membrane scaling and fouling are managed.
- Modernized chemical softening technology is available to prevent scaling and enable recovery up to the osmotic pressure limit at 1,200 or 1,740 psi.
- Learn to compare spiral wound vs disk tube (DTRO) systems for ultra high-pressure operation to select the best option for your system.

New ultra high-pressure reverse osmosis (UHP RO) membrane elements are entering the market, rated for 50% higher pressures than previously available. These 1,740 psi (120 bar) membranes raise the practical osmotic pressure and brine concentration limit to 130,000 mg/L total dissolved solids (TDS). This is a 1.6X increase relative to conventional "seawater" RO membranes rated for 1,200 psi (80 bar), which tap out at roughly 80,000 mg/L TDS. However, there are important design and technical considerations, which we review in this article.

Saltworks is one vendor that offers these new membrane systems. Our product, called Xtreme Reverse Osmosis (XRO) delivers the latest UHP RO membrane technology in a reliable, low cost, modularized package. It incorporates all of the important design considerations below, in addition to proprietary enabling features, and expert knowledge.

UHP RO as a Brine Concentrator?

Reverse osmosis is the most widely commoditized, cost effective, and lowest energy desalination technology; however, it has limits. These limits can include sensitivity to organics, oxidants, scaling ions, and declining productivity with increasing salinity (TDS). As the brine concentration increases, flux through the membrane and permeate quality decrease. This is shown below in the curve of Figure 1. The data in Figure 1 was gathered on a Saltworks developed pilot plant, based on 4" membrane elements shown in Figure 2. Two leading manufacturer's membrane products were tested. Similar relationships in flux were observed, however one company produced high quality permeate in a membrane element with more reliable and consistent performance. Saltworks builds this knowledge into our Xtreme Reverse Osmosis systems for our customers.

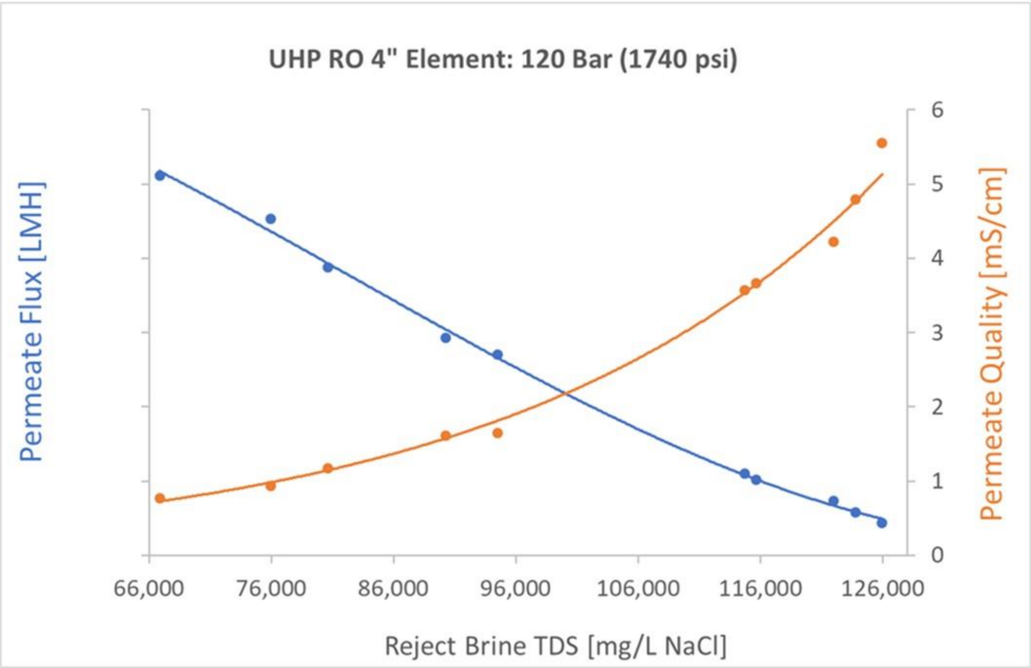

Figure 1: UHP RO flux and Permeate Quality with Reject Brine TDS

The permeate salinity increase with brine concentration is expected. The RO membrane surface rejects a percentage of salt, for example 99.8%. This means roughly 0.2% of salt permeates through the membrane with the water. Naturally, at higher brine concentration more salt gets through the membrane. The slightly higher salinity permeate can be blended with other lower salinity permeates, using a flush source for upstream ROs, or further refined in a low-pressure polishing RO process. The primary objective and cost driver when applying UHP RO should be brine concentration and volume reduction.

Figure 1 also shows the flux decline at higher salinity. Flux numbers in liters per m^2 per hour represent proprietary knowledge only available to Saltworks' customers and partners. Nevertheless, the lower flux trend in Figure 1 is clear and translates into the need for either higher pressure, more membrane area, or both. With the advent of new 1,740 psi UHP RO membranes, designers can apply higher pressures to improve flux at higher TDS, and ultimately concentrate a sodium chloride solution to 130,000 mg/L TDS. If sulfates are present as an appreciable mass fraction, the brine concentration limit increases up to 160,000 mg/L. At these high TDS ranges, flux decreased by three times relative to RO systems operating at 30-60K mg/L TDS. This means more membrane elements, pressure vessels, and pipework in addition to the higher pressure rated equipment.

Ultimately, capital cost of UHP RO systems is notably higher than the cost of brackish or seawater RO systems (SWRO). Although more expensive than SWRO, UHP RO is still much lower cost than thermal evaporators. For this reason, UHP RO can be applied upstream of evaporators, to reduce capacity and energy of more expensive evaporation, or reduce volumes sent to disposal or evaporation ponds. It is important to keep in mind that evaporators can achieve higher brine concentrations than UHP RO, meaning they will produce a lower volume. For larger flow rates, a combination of technologies each operating in at an optimum capacity may be most economic. Typical brine concentration limits and volume reduction ratios are summarized in Table 1 below.

Technology	TDS brine limit (mg/L)	Brine Volume Reduction relative to SWRO
SWRO (1,200 psi)	80,000	1.0 X
UHP RO (1,800 psi)	130,000	1.6 X
Conventional Evaporator (thermal or MVR)	220,000	2.8 X
SaltMaker Evaporator (thermal)	450,000 or solids	5.6 X

Table 1: Typical brine concentration limits and volume reduction ratios

UHP RO vs DTRO

Reverse osmosis systems have been capable of 1,740 psi operation for a number of years as disk tube RO (DTRO) technology. DTRO employs the same membrane material as SWRO, with the membranes arranged as a series of vertically stacked disks in speciality pressure vessels. The primary benefit of UHP RO is that the membranes are spiral wound – the most widely applied RO technology included in every seawater RO desalination plant worldwide. DTRO is a speciality niche manufactured product, while spiral wound RO membranes are widely produced, available and interchangeable from multiple manufacturers. Figure 3 compares spiral wound and DTRO membrane construction.

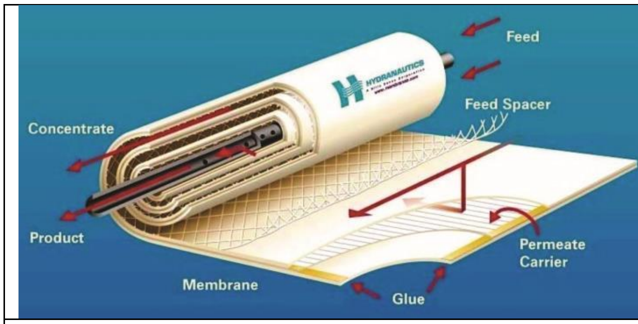

Figure 2: Spiral wound membranes (lateral flow over membrane sheet)

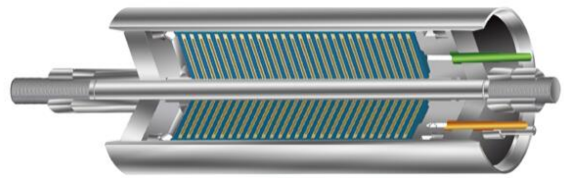

Figure 3: [DTRO membranes] (radial flow over membrane disks)

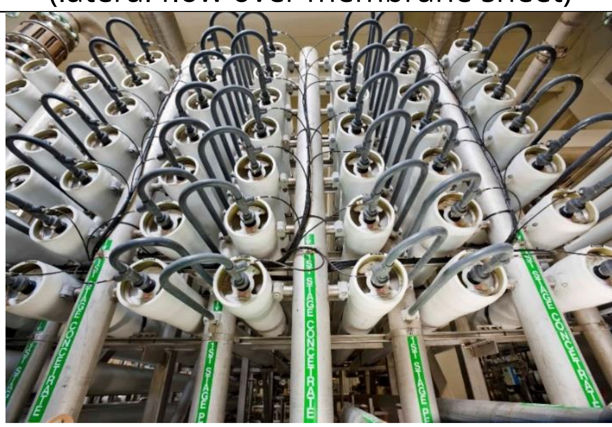

Figure 4: Spiral Wound Membrane System (common)

Figure 5: [DTRO Membrane System] (niche)

Spiral wound membranes have captured over 99% of the global RO membrane market share. Their production has been perfected over the years, resulting in lower cost, high quality, and broad availability. In addition, spiral wound membranes make use of the most common 4” or 8” pressure vessels used in RO, versus a specialty product. Put simply, the end user considering either spiral wound or disk tube RO should consider if they prefer commonplace, or speciality products. Spiral wound membranes are employed in over 95% of all global desalination plants. DTRO offers some claimed shear benefits and the ability to operate on more turbid waters, however a well built spiral wound system with high membrane cross flow can achieve the same. Saltworks builds our Xtreme RO systems with spiral wound membranes in to assure the customer a widely available product not dependant on a single manufacturer. We also build-in chemical, process, and mechanical considerations that are required to maintain membrane longevity.

Realizing UHP RO Full Potential

When reaching for ultra high recovery, scaling ions and organics are concentrated to very high levels. Combined with the ultra high pressure, they can impinge on the membrane surface at a high force. One must be extremely cautious to manage any membrane scaling or fouling risk. Organics may require a combination of pre-treatment, or a Saltworks continuous removal approach that is optionally built-into Xtreme RO. When it comes to scaling ions that can block the membrane surface, there are a variety of both mechanical and chemical methods. First, one must know the scaling ion concentration and its solubility. The solubility of scaling ions can be discovered on our Periodic Table of Scaling Elements. If scaling ions can exceed four times their solubility in the RO brine, even with anti-scalants, they should be reduced to a safe level.

One method to remove scaling ions is to apply a chemical softening technology, such as BrineRefine, to remove or reduce ions such as silica and calcium. When chemical softening is applied before RO, it is important to:

- Adjust dosages to only remove the "right" amount of scaling ions; increased dosages may not increase recovery but will translate into higher chemical cost and increased filter cake waste generation.
- Avoid use of coagulants, since they can foul RO membranes.
- Filter out any precipitant to maintain the RO silt density index specification, and lower pH during RO operation to prevent carbonate scale issues.
- Consider if the upstream chemistry or flow rate could vary, and how the chemical softening will adjust - via automation or human intervention – with reliability of the latter occasionally being questionable.

BrineRefine technology manages all of the above. It was specifically developed to be paired with ultra high recovery RO systems as described in this article. In addition to chemical matters, hydraulics and energy are also important considerations. Hydraulically, designers should aim for high cross flows, which provide high brine velocity to wash away any boundary layers of stagnant water next to the membrane surface where scale and fouling can occur. Steps can be taken to reduce energy. Although energy recovery devices (ERDs) rated for 1,740 psi do not exist yet, an ERD can be avoided and additional benefits realized by including a high-pressure circulation pump as shown in Figure 6 below. The high-pressure recirculation pump recycles and upgrades the pressure of a portion of the RO brine. This prevents breaking all of the brine's high-pressure energy before recirculation, lowering feed pump energy, and also beneficially improves cross flow velocity across the membrane surface. Saltworks' Xtreme RO incorporate all of these considerations. If the reader would like to learn more about RO design state-of-the-art technology advancements, they can in this accompanying article.

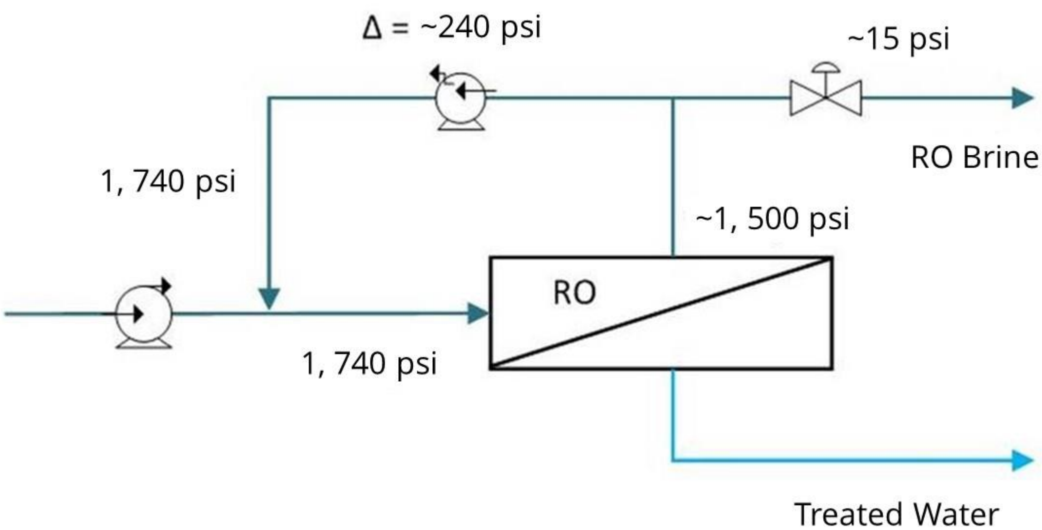

Figure 6: High Pressure Recirculation Pump to Minimize Energy and Increase Membrane Cross Flow

Important engineering considerations also include:

- Pressure vessels: products are emerging capable of 1800 psi operation with an ASME level safety factory, yet the ASME code stops at 1500 psi.

- Reciprocating pumps for 1800 psi operation exist in the market place, but one needs to be conscious of pump metallurgy to avoid corrosion in the ultra high chloride environment of UHP RO.
- All high-pressure pipework must be designed and certified for use.
- Think about membrane cleaning and servicing ahead of time, including consideration of automated flush and chemical cleans in place (CIP).

Saltworks considers all of the above and more, when designing an Xtreme RO system for our clients. We welcome the opportunity to work with partners, including integrating with an upstream lower pressure RO that may release a scaling brine. Figure 2 shows an example system where an existing RO-1 is in place, but additional brine volume recovery is desired. This is accomplished by the integration of BrineRefine and a second RO-2 optionally employing UHP-RO technology. This system has built-in intelligence to continuously adjusts operation to prevent scale formation and ensure peak performance, while also communicating between upstream and downstream treatment assets to deliver value to your entire treatment train. As a result, minimal liquid discharge (MLD) and peak RO brine concentrations of 130,000 mg/L TDS are achieved.

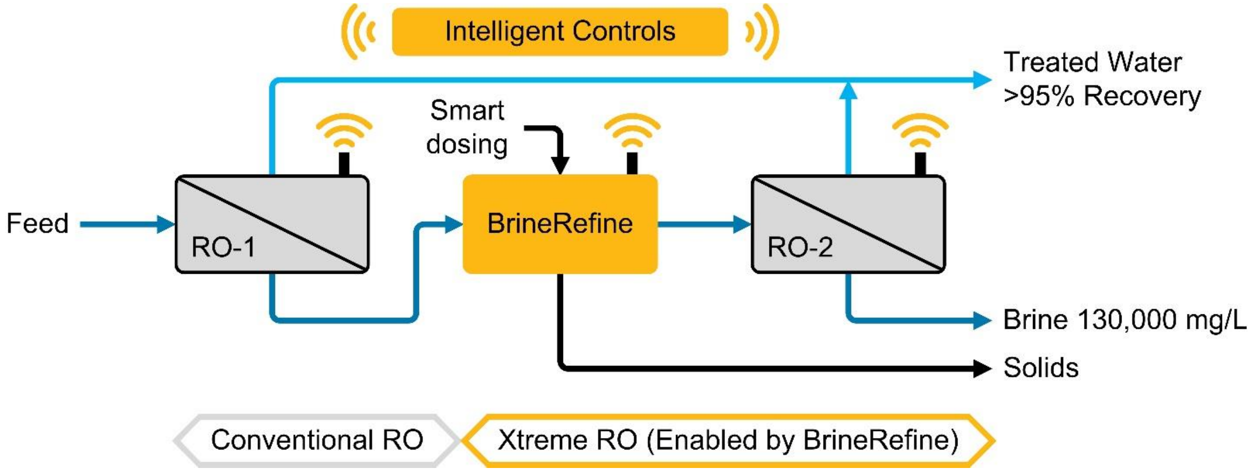

Figure 7: XRO Enable by BrineRefine

Contact a Saltworks Engineer to review options for your project. All we need is your chemistry and capacity, or a live water sample for testing at our lab.