Reverse Osmosis Brine Treatment: Tech Advancements to Minimize Volume & Cost

Takeaways:

- Reverse Osmosis is considered the workhorse of desalination. Applied correctly, Reverse Osmosis Brine Treatment can be highly effective and lower cost than thermal alternatives:
- RO recovery and RO brine concentration is limited by osmotic pressures or membrane scaling; both limits have been increased by new technology.
- New ultra high pressure RO membranes can achieve pressures of 1800 psi, 50% higher than previous, enabling 50% brine volume reduction if membrane scaling can be managed
- A series of techniques described in this document can be used to delay or mitigate scale, but in many cases only chemical softening truly remove the risk.
- A modernized, compact chemical softening technology – BrineRefine – developed for RO brine treatment can be used to entirely remove membrane scaling risk and realize RO's full brine volume reduction potential.

How does Reverse Osmosis Work?

Reverse osmosis (RO) is the workhorse of desalination. High pressure is used to drive water through specially-engineered semipermeable membranes that reject salt ions. Recovery increases with higher brine concentration relative to inlet salinity, squeezing more freshwater from the salt water. Osmotic pressure also increases with brine concentration, which requires higher driving pressures and reduces freshwater permeate flux requiring larger membrane area. Historically, there are three pressure classes for RO membranes: 300 psi, 600 psi and 1200 psi. The higher the pressure class, the higher the brine volume reduction potential on a nonscaling fluid. RO membrane vendors are innovating ultra-high-pressure reverse osmosis (UHP-RO) spiral wound membranes capable of 1800 psi. UHP-RO enables brine concentrations up to 130,000 mg/L total dissolved solids (TDS), limiting downstream brine disposal or brine treatment costs.

Reverse Osmosis Limitations

RO brine treatment will be limited by either osmotic pressure increase with salinity, which decays permeate flux to an unsuitable level, or scaling ions or organic fouling that can block the membrane. Most industrial RO applications are scale-limited, for example by silica, calcium sulfate, phosphate, fluoride, iron or barium salts. Organic fouling can be managed by pretreatment, a biocide program, automated high-pH washes, or a "kidney organic removal loop."

Ionic scale can affect end users in three ways:

1. Reliability challenges leading to frequent cleaning or shortened membrane life.
2. Recovery left on the table generating more brine than required.
3. RO membrane fouling caused by indirect effects such as coagulants intended to help remove precipitated scale upstream.

The problems are compounded in industrial wastewater where the feed chemistry varies, requiring constant monitoring. The BrineRefine technology introduced below solves these challenges by automatically adjusting and preventing use of membrane fouling coagulants.

Advanced Innovations in Reverse Osmosis Brine Treatment

A series of techniques, as presented below, could be used to delay or mitigate scale, but they do not entirely remove the risk.

Advancements	Process description
Antiscalants	Chemicals developed to delay precipitation of scaling ions, roughly doubling their solubility, so brine can be further concentrated.
Operational	Increase crossflow through the membrane element (fluid velocity) to reduce the boundary layer and "concentration polarization" at the membrane surface, thereby decreasing scale deposition potential.

	Automated permeate flushes and chemical clean to maintain membrane cleanliness, including consideration of trigger points such as decline of permeate flux or increase in concentrate differential pressure.
Flow reversal	Switch the RO inlet flow path on the RO vessel with the RO brine outlet flow path. The last element in a vessel frequently scales first. Therefore, the final membrane element alternates operation in supersaturated conditions with undersaturated conditions.
Batch or semibatch operation	RO permeate is continuously produced while brine circulates in a semiclosed loop. Brine should be bled in small volumes and then batch discharged in larger slugs and replaced with feedwater. This allows for the entire system to alternate between supersaturated conditions and undersaturated conditions, thereby "shocking" scale formation as well as disrupting biological growth through frequent salinity changes.
Hardness removal and high pH (for high silica waters)	Operate at high pH to increase silica solubility to increase brine concentration in silica-limited waters. This requires effective hardness removal through techniques such as ion exchange (IX) to avoid producing carbonate scale at high pH. IX is less effective at higher salinities, so this method is limited to low salinity feedwaters of <5000 mg/L TDS. IX also requires chemical regenerations, resulting in a secondary regeneration waste byproduct.
Saturation relief	Continuous precipitation of scale outside the RO circuit by relieving saturation in large seeded columns, including shifting pH to relieve any antiscalants' effectiveness. After scale is precipitated, fresh antiscalant can be added and a secondary RO process applied. This technique requires large contact areas and vessels to allow sufficient residence time, as well as filtration of the precipitants upstream of the secondary RO.
Disc-tube RO and/or vibratory shear process	Larger spacers between membranes and a nonspiral wound membrane allow for higher flow and turbulence through the equipment, as well as acceptance of higher turbidity and service deionization (SDI) on the inlet (less pretreatment). Specialty vendors innovated "vibratory shear" at the membrane surface aiming to keep the membrane clean.

Although the above-mentioned methods mitigate scaling risks, recovery may still be below osmotic pressure limits with brine concentration potential left on the table. Operators may also still be walking a tightrope because scaling compounds are circulating in a sensitive RO brine treatment system.

Chemical softening

Chemical softening is a hybrid solution that removes the tightrope entirely as shown in Figure 1. First, achieve initial recovery through a primary reverse osmosis (RO-1) step, effectively reducing the volume for downstream processes. The techniques explained above are applicable, but do not need to be pushed to their limit. After primary RO-1 recovery, chemically soften the brine to extract the scaling compounds before another secondary RO (RO-2) step that boosts recovery to the osmotic pressure limit of RO. Saltworks has developed an advanced Chemical Softening system called BrineRefine, shown in Figure 1.

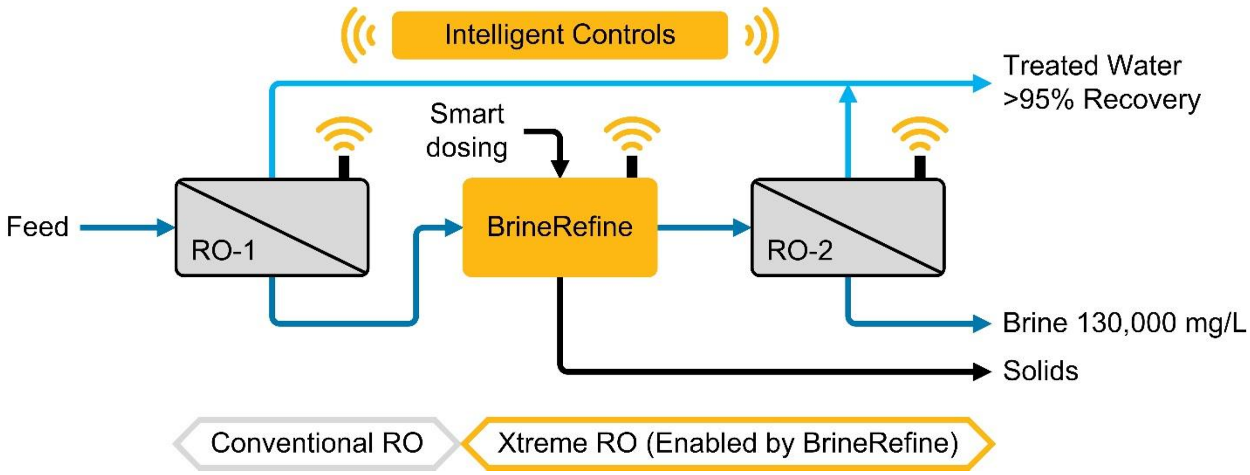

Figure 1: Integration of RO and advanced chemical softening systems to increase RO recovery reliably

Figure 2: BrineRefine Pilot Unit

BrineRefine is a smart and compact chemical softening system that applies modern automation and separation processes to remove scaling compounds. Innovations include:

- Reduced footprint by replacing the reaction tanks and clarifier with an inline processing system.
- Precision dosing by modern automation to prevent overdosing (wasted chemicals and added sludge) or underdosing (scale risk), including the ability to adjust with changing upstream chemistry.
- Elimination of coagulants and floc, which can foul downstream ROs — forming a gel on the membrane that would require frequent chemical cleans.
- Replacement of manually intensive sludge management techniques with semi-automated solids management technology, borrowed from a crystallizer technology – the SaltMaker.

The controls communicate with any upstream and downstream RO to optimize total system performance. Wastewater treatment plants should not be designed or controlled as a linear train of independent unit operations passing water to each other. They should be considered as an integrated system, with each unit operation adjusting to its 'sweet spot' as upstream conditions change. The systems' view enables optimization of total system economics, reliability, energy, chemical consumption, recovery and capacity.

Innovation is driving down the cost of treating industrial wastewater. Membrane systems typically cost 5-10 times lower than thermal brine concentration evaporators and so it is important to maximize membrane recoveries. Contact an expert today to maximize your membrane recovery and prevent scale formation.