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Technology Brief

MINIMUM LIQUID DISCHARGE WITH GRADIANT'S RO INFINITY CFRO

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ABSTRACT

The production of freshwater from alternative sources such as saltwater and wastewater has become a necessity due to the combination of increased demand as well as water scarcity. For inland desalination applications, such as industrial wastewater treatment and ground water desalting, the brine waste produced by desalination processes can be expensive to dispose of and can pose risks of negative environmental impacts. In many seawater desalination plants, expensive or constrained intakes and pretreatment systems limit the ability to increase fresh water production. Concentration or desalination of brine is desired in these applications but has not been feasible for both financial and technical reasons.

While thermal processes can be used for brine treatment, the high capital costs and energy consumption entailed are prohibitive for most applications. Conventional reverse osmosis (RO) is limited by the pressure capacity of standard RO membranes and equipment to brine concentrations of about 70,000 mg/L total dissolved solids (TDS), far below typical saturation concentrations of over 260,000 mg/L NaCl. Disc tube RO and ultra-high-pressure RO (UHPRO) can be operated at pressures of up to 124 bar (1,800 psi), increasing brine concentrations to as high as 130,000 mg/L TDS. However, such high-pressure operation presents potentially prohibitive challenges for equipment sourcing and still does not sufficiently minimize liquid discharge for many brine-constrained application.

A solution to these constraints is Gradiant's RO Infinity CFRO, a novel method for desalinating water with TDS levels of up to 260,000 mg/L NaCl. It operates at pressures of less than 83 bar, enabling use of standard commercially available membranes and components. The system designs and case studies presented in this work make a very strong case of utilizing the CFRO process for a broad range of brine concentration applications.

I. INTRODUCTION

Reverse Osmosis dominates the global desalination industry and has become extremely energy- and cost-efficient. In addition to desalination of seawater/brackish water for drinking water production, RO is used to concentrate wastewater streams for volume reduction to save disposal costs. Stringent regulations on water disposal and increasing disposal costs are forcing industries to consider minimum liquid discharge (MLD) water treatment.

Typically, the maximum brine concentration achievable by conventional RO, corresponding with operating pressures approaching 83 bar, is about 70,000 mg/L. Further brine concentration requires higher operating pressures. With the advent of disc tube RO and ultra-high-pressure RO UHPRO membranes, operating pressures can be raised to 124 bar, facilitating achievement of brine concentration of up to 130,000 mg/L. A significant drawback of such high operating pressures, however, is membrane compaction [1], which reduces membrane productivity. Ultra-high pressure also requires specialty pumps and suitable equipment which can be cost prohibitive.

The CFRO process is a means to concentrate brines to TDS levels exceeding 70,000 mg/L at pressures less than 83 bar. This uses the principle of osmotic assistance in which a saline stream is applied to the permeate side of RO membranes. By lowering the osmotic pressure difference across the membrane, permeate can be produced at feed pressures that are less than the osmotic pressure of the feed.

II. RO INFINITY CFRO

Like conventional RO, Gradiant's RO Infinity CFRO process uses pressure to drive purified water across a semi-permeable membrane against the osmotic pressure difference between the feed and permeate streams. What makes the CFRO process unique is the deliberate application of saline water to the permeate side of the membranes. Compared to conventional RO in which permeate osmotic pressure is negligible, saline permeate reduces the osmotic pressure barrier, which lowers the feed pressure required to drive permeate flow. As a result, ultra-saline feeds can be treated at hydraulic pressures low enough to enable the use of standard RO equipment.

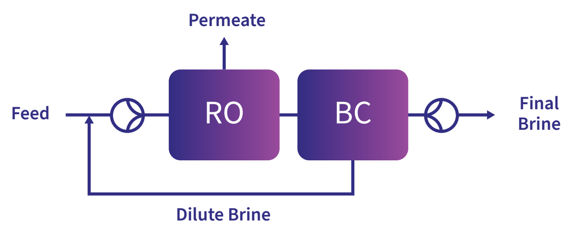

Figure 1. RO Infinity CFRO Process Flow Diagram

RO = reverse osmosis stage(s) and membranes
BC = brine concentration stage(s) and membranes

In the above diagram, feed to the RO stage is desalinated, producing permeate and partially concentrated RO brine. RO brine flows under pressure to the brine concentrator, consisting of one to six stages. Fully concentrated brine leaves the BC stages through a throttle valve or an energy recovery device. Dilute brine from the permeate side of the BC membranes is returned to the feed of the RO or recycled within the BC stages. Because permeate is only produced by the RO stage, its quality is independent of the final brine concentration.

The authors previously introduced the concept of CFRO [2] and presented performance data and experiences from a demonstration unit operating on seawater RO (SWRO) brine [3]. CFRO has been considered for reducing effluent chlorides, for production of potable water from wastewater treatment plant (WTP) effluent [4], as well many other full-scale applications.

III. PERFORMANCE

We applied CFRO for a demonstration unit which operated on SWRO brine from December 2019 until mid-2022. The trend data documented stable, sustained production of high quality permeate. Final CFRO brine salinity ranged from 110,000 to 130,000 mg/L TDS. It is notable that desalination was carried out at 70 to 80 bar feed pressure despite the brine osmotic pressure being over 92 bar [3]. If conventional RO had been used to produce this brine, feed pressures of up to 130 bar would have been required based on estimations made using RO membrane manufacturer's projection software [5].

IV. CASE STUDIES

1.1 Case 1 – Brine Concentration

The data presented in the previous section was used as the design basis for a full-scale CFRO process for brine desalination. The process is illustrated in Figure 2 below, with flow rates in units of m³/h in plain font, pressure in units of bar in bold font and salinity in units of mg/LTDS in italic font. SWRO brine is pressurized to 60 bar with a high pressure pump, boosted to 79 bar by a turbocharger and fed to an RO stage. The RO stage makes permeate with 300 mg/L TDS. Partially concentrated brine flows under pressure to two CFRO stages where it is further concentrated to 130,000 mg/L TDS. CFRO permeate is returned to the suction of the high-pressure pump. The overall recovery rate is 50% and specific energy consumption is estimated at 5.8 kWh/m³ of permeate. The use of isobaric energy recovery in the system depicted in Figure 2 would lower energy consumption by about 14% to 5.0 kWh/m³ for brine concentration (not to be mistaken for conventional seawater desalination) [6].]

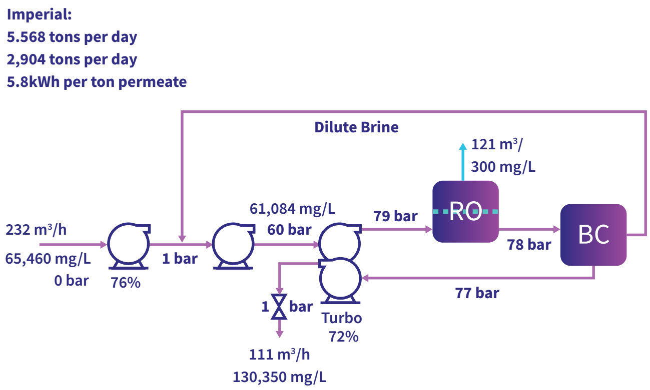

Figure 2. CFRO Process for Brine Concentration

The performance illustrated in Figure 2 above was extrapolated to a large CFRO system treating 15,000 m³/d of brine to a range of final brine concentrations. In Figure 3, we outline the estimated capital cost of the process equipment for such a system, amortized over 20 years at 6% interest. We also include the total cost (sum of capital and operating costs including consumption of $0.048/kWh (USD) energy, chemicals, and spares) as well as the specific energy consumption plotted as a function of final brine TDS. This data indicates that SWRO brine can be desalinated at a specific cost of as little as $0.43/m³ of permeate, making it competitive with greenfield SWRO.

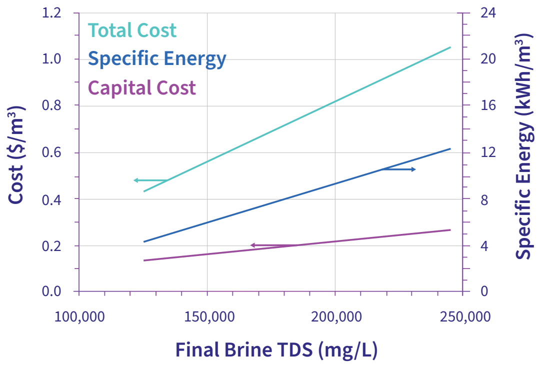

Figure 3. SWRO Brine Concentration – 15,000 m³/d Feed

A similar CFRO system was used as the basis for a cost comparison with UHPRO. Specifically, a 65,000 mg/L TDS feed was considered, desalinated at 48% recovery to generate a brine of 125,000 mg/L TDS and 15,000 m³/day of permeate with less than 500 mg/L TDS. Although CFRO can concentrate saline solutions to 260,000 mg/l TDS or higher, CFRO brine concentration was limited to 125,000 mg/L TDS to facilitate comparison with UHPRO. The results of the analysis are presented in Table 1.

		CFRO	UHPRO	
Cost	CAPEX ($/m3)	0.13	0.3	6% Interest, 20 years
	OPEX ($/m3)	0.32	0.5	$0.048/kWh Power, Chemicals, Spares
	Total ($/m³)	**0.45 ± 0.02**	**0.8 ± 0.08**	CFRO: 44% Lower Cost
Process	Energy (kWh/m³)	4.53	4.86	Lower Pressure + Lower Energy
	Pressure (Bar)	70-80	110-120	Lower Pressure = Safer
System	Flow Factor	0.85 (same as SWRO)	0.40 - 0.55	UHPRO: Compaction
	Safety	Same as SWRO	Concerning	UHPRO: Specialty O&M
	Equipment	Standard	Specialty	USHPRO: Specialty Equipment

Table 1. Comparison between CFRO and UHPRO

As quantified in Table 1, the cost of brine treatment with CFRO is up to 44% lower than the cost with UHPRO. By operating at 80 bar or less, CFRO membranes avoid the compaction suffered by UHPRO membranes as indicated by the lower flow factor of the latter. In addition, lower-pressure operation with CFRO avoids the high cost of specialty equipment necessary for 120 bar service, including pumps, pressure vessels, energy recovery devices, couplings, and instruments, while also providing a greater degree of operator safety.

1.2 Case 2 – Minimum Liquid Discharge

While the objective of the brine desalination processes described above is to make low-cost permeate, the goal in other applications is to minimize final brine flow. A broad range of industrial water and inland desalination applications with high brine disposal costs could benefit from reducing liquid discharge volumes. Such sources may have low total salinity but relatively high concentrations of sparingly soluble salts and other potential membrane foulants. For these sources, effective treatment may require multiple unit operations including solids separation, biological treatment, low-pressure desalination, and/or selective mineral removal. An example of a Minimum Liquid Discharge (MLD) treatment train is illustrated in Figure 4 below.

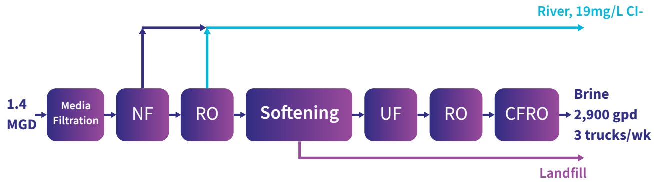

Figure 4. Industrial or Brackish Water Desalination for MLD Operation

The estimated cost of treatment for the above MLD industrial desalination system applied for a range of final brine concentrations is presented below in Figure 5. Specifically, we considered a 1.4 million gallon per day (MGD) system operating at 99.6% overall recovery [4]. Capital costs were amortized over 20 years at 6% interest. Operating costs include softening chemicals and energy at a cost of $0.10/kWh. Changes in the slopes of the lines in Figure 5 are due to the addition of one or more unit operations to the treatment train appropriate for the corresponding brine salinity.

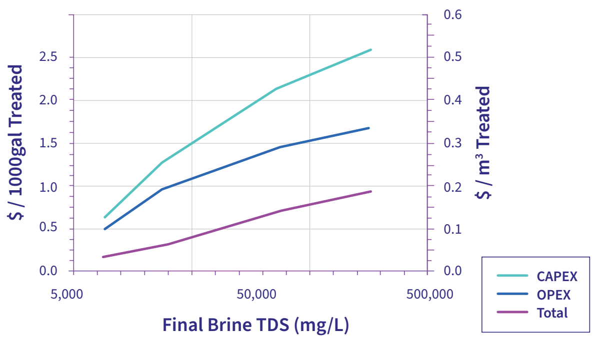

Figure 5. Cost of Industrial or Brackish Water Desalination as a Function of Brine TDS

The only means of brine disposal available to many industrial and inland water desalination sites is hauling and offsite disposal, which costs a minimum of $7.90/m³. Hauling and disposal costs were added to the costs in Figure 5 to produce Figure 6.

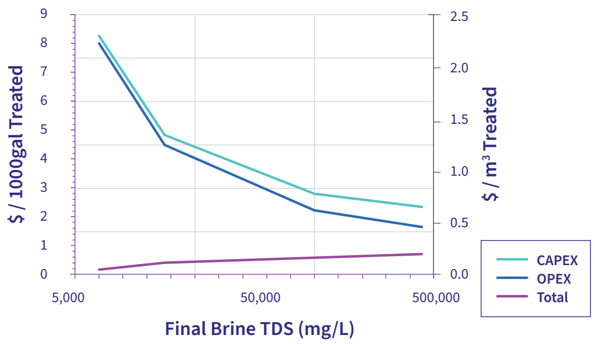

Figure 6. Cost of Water Treatment Including Brine Disposal as a Function of Brine TDS

The total cost of treatment to 200,000 mg/L TDS brine is approximately $0.63/m3. Clearly, minimizing. Without softening and membrane brine concentration, the maximum brine TDS achievable is about 50,000 mg/L, at which concentration the total cost would be over $0.85/m^3. Clearly, minimizing liquid discharge can save significant cost.

V. CONCLUSION

There is strong support for the implementation of CFRO for high recovery water treatment, brine minimization and concentration. The prospect of low-cost membrane brine concentration combined with the broad market acceptance of membrane desalination methods portend a shift away from thermal brine concentration, in the same way that SWRO displaced thermal desalination, while opening new opportunities for the application of membrane technologies.

VI. REFERENCES

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