Equilibration Pressure and Its Effect on Water Flux in Osmotically Assisted Reverse Osmosis

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When electricity is the only available utility, the current standard in high salinity brine dewatering is mechanical vapor compression (MVC). Such high salinity brines my be encountered in extracted formation water from geologic carbon storage (Arena et al. , 2017b) or produced water from fossil fuel extraction. MVC uses a motor driven compressor to extract steam from a brine fed to an evaporator. Ultimately, the extracted steam is condensed to pure water via heat exchange with the incoming brine. MVC suffer from low efficiency (<10%), which is mostly due to the irreversibility from the temperature gradients across the heat exchangers. For comparison RO has an efficiency of 30-50% and is at present the most efficient commercial technique to desalinate sea water. The applicability of RO using commercially-available RO membrane modules is limited to brines with salinities less than ~90 g/L of total dissolved solids (TDS) (Bourcier et al., 2011) because of the maximum hydraulic pressure that can be applied to the semi-permeable membrane.

One route for more efficient brine dewatering, using only electricity, could be an enhanced RO process. One option, not widely explored, is to engineer the osmotic pressure difference across the membrane by circulating a less-saline sweep solution on the permeate side of a membrane. The salinity and associated osmotic pressure of this sweep solution lowers the bulk osmotic pressure difference across a semi-permeable membrane; therefore, requires less hydraulic pressure be applied to the feed solution. This osmotically assisted reverse osmosis (OARO) process is not a process of direct desalination but one of dilution. Desalination in an OARO process would be achieved by a number of OARO steps. After the sweep solution is diluted by reverse osmosis, it is fed to a second OARO step where would be dewatered and returned to its initial concentration, while another less saline sweep solution is diluted. This sequence would continue until a diluted sweep solution is obtained which could

be dewatered by a conventional reverse osmosis step that produces the product water. An illustrated OARO process is shown in Figure 1.

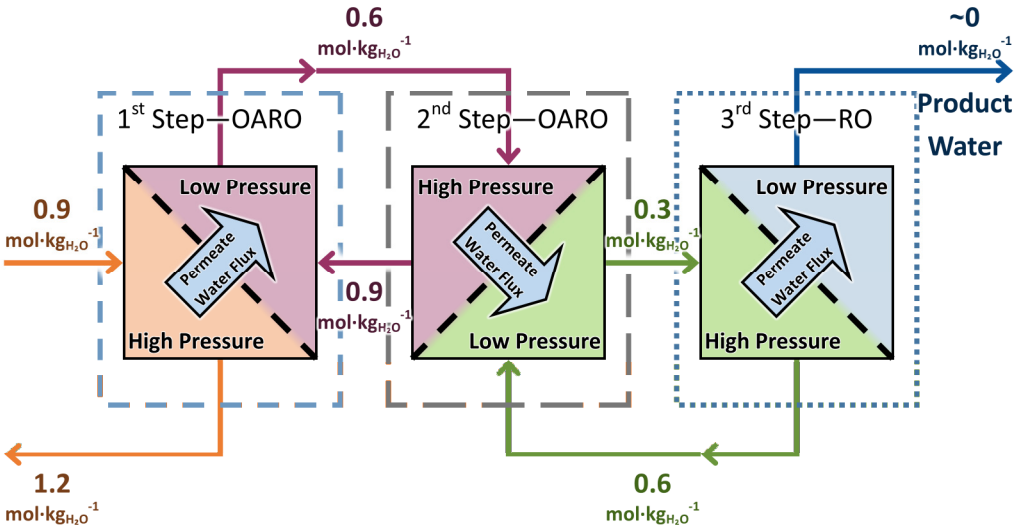


Figure 1. One possible configuration of a multi-stage OARO process to dewater a high salinity brine. Shown here are two OARO stages followed by the requisite final RO stages to produce a low salinity product.

Some preliminary estimates on the energy requirements of OARO have shown that the OARO process is a more efficient approach for concentrating a high salinity brine when compared to MVC (Bartholomew et al., 2017). While these early estimates of OARO energy requirements were promising, they used reported literature values for membrane properties (She et al. 2012) that my not exactly reflect OARO operating conditions and omitted salt flux. Subsequent attempts at accurately modeling OARO performance using transport properties extract from modest pressure OARO experiments (Arena et al., 2017a) proved problematic with inaccurate predictions of OARO water flux due to an over-emphasis of RO and pressure retarded osmosis (PRO) data within the dataset, particularly with respect to available salt flux data. These data were also limited in the range of salinities study as they were restricted to the region where sodium chloride concentration and osmotic pressure were linear.

While collecting revised data that included OARO data at higher pressures and salinities it was noted that the salt flux through these CTA FO membranes appeared to increase with pressure. This deviation from solution diffusion indicated possible

damage to the membranes selective layer when a transmembrane pressure of 60 bar was applied to these membranes. Further study that only subjected these membranes to a maximum transmembrane pressure of 45 bar produced significantly different water and salt flux data. A comparison of water flux data for 60 bar and 45 bar maximum pressure tests in shown in Figure 2.

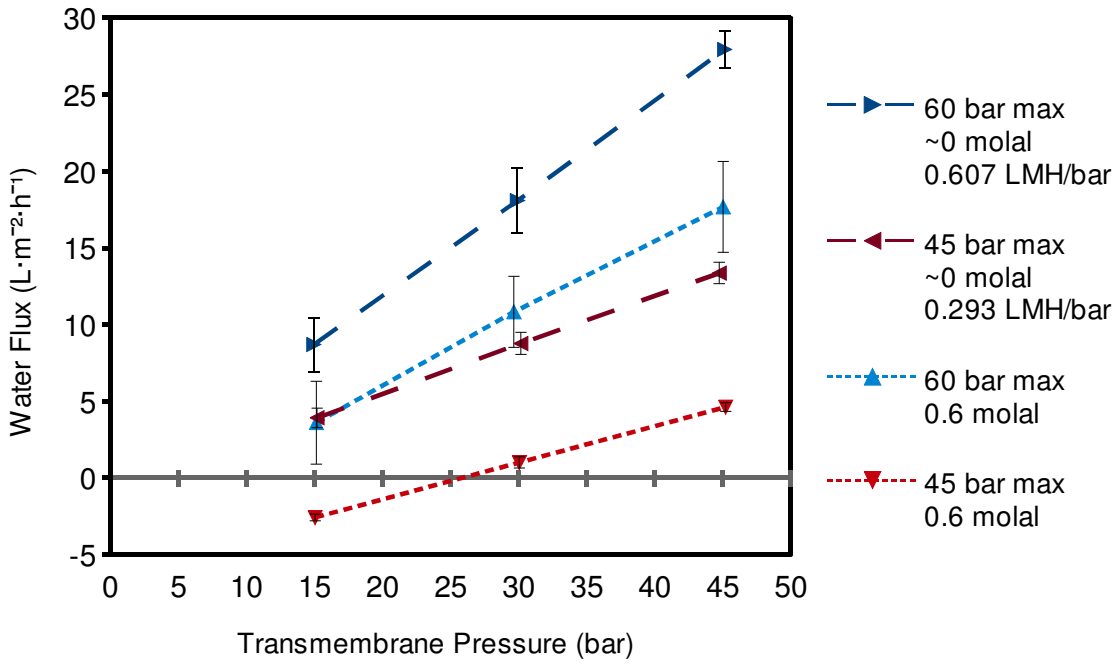


Figure 2. Water flux data for CTA FO membrane subjected to maximum transmembrane pressures of either 60 bar or 45 bar. Data collected at 25°C with samples supported by a permeate carrier recovered from a Dow SW30 membrane module.

Note: For figure clarity water flux data for 60 bar are omitted but are 36 L·m^{-2}·h^{-1} and 23 L·m^{-2}·h^{-1} for feed solutions of ~0 molal and 0.6 molal sodium chloride respectively.

Herein, the revised water and salt flux data for select conditions in RO, PRO, and OARO will be used to extract membrane transport properties and model OARO performance to determine water flux, salt flux, and rejection across a membrane in various steps of an OARO process. As well as discussed differences in OARO membrane performance as a result of excessive membrane pressure.

References

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