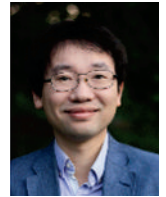


A Novel Electro-Dialytic Crystallizer (EDC) for Energy Efficient Zero-liquid Discharge

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Challenge

The last and often most costly and energy-intensive step in intensified brine management processes is crystallizing salts out from saturated brines. While disposal is often the preferred solution for brine management due to its low cost, in some cases zero liquid discharge (ZLD) is required. Conventional reverse osmosis (RO) can only concentrate the brine to ~ 100 g/L before the osmotic pressure and scaling potential of the brine make further concentration unviable, and it is for these reasons that thermal processes are currently applied for brine concentration. However, thermal processes utilize high temperatures and require exotic metals to contain the hot and corrosive brine, which translates into high operational and capital costs.

Research Approach

This project aims to develop a modular brine concentration/crystallization process that is substantially more energy efficient than the current state-of-the-art thermal processes. The team aims to investigate a new brine crystallization process called electro-dialytic crystallization (EDC), which integrates electrodialysis and crystallization into a single system to enable crystallization without evaporation or large temperature swings, thereby potentially improving the energy efficiency and reducing the cost of crystallization. The core innovation of EDC is the use of the electrodialysis phenomenon to maintain a saturated brine stream for continuous salt precipitation. The team will perform system-scale modeling to guide design and optimization of EDC, perform experiments to validate the concept and, conduct techno-economic analysis, life cycle assessment and market analysis to evaluate the potential of EDC for future practical adoption.

Impact

The proposed project will address major knowledge gap toward the future adoption of EDC. A fully successful project would not only provide experimental proof of EDC's technical capability but also pave the way towards making ZLD more widespread and potentially opening the door to recovering resources from concentrated brines.

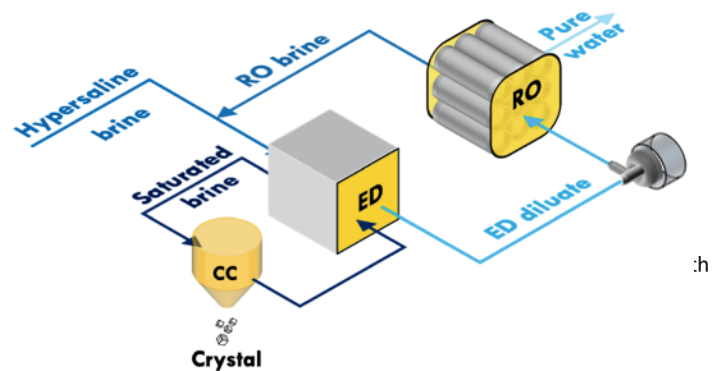


Figure 1. A simplified schematic of the EDC process coupled with reverse osmosis for ZLD without thermal evaporation.

RESEARCH PARTNERS

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REFERENCES

- Tong T. and Elimelech M., Environ. Sci. Technol. 2016, 50, p6846.
 Yaqub, M. and Lee, W., Science of the total environment, 2019. 681, p551.

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Accomplishments & Findings

The project took a novel concept for hypersaline brine treatment (Electrodialysis crystallization – EDC) from first principles through to successful demonstration and engineering refinement, generating significant interest from the semiconductor industry and a cover article in Nature Water. The team built and operated a series of bench-scale pilots from September 2021 to December 2024, and discovered that:

- 1) EDC works well with moderately soluble salts, like sodium or potassium sulfate and many of the nitrate salts. Brines containing these salts typically still require membrane-based concentration and eventually thermal crystallization, but EDC can replace thermal crystallization.
- 2) Water transport across the membranes is the key factor that limits performance of the system. Ions with softer hydration shells (and lower solubilities) permeate across the membrane without dragging H₂O molecules along and are most easily separated.
- 3) Scale formation on the membrane surface was observed to be much lower than with osmotically-driven separations processes
- 4) The team initially worked with an ion exchange membrane that showed good flux but insufficient water exclusion. They then switched to a denser membrane which had somewhat lower fluxes but greatly improved water exclusion. The team concluded their project with a demonstration of Ca-sulfate removal, supersaturation, and crystallization that was featured in Nature Water in January 2023.

Related Accomplishments

NAWI project 6.14 (Novel Bipolar Membrane Assisted Electrosorption Process for the Selective Removal of Boron) illuminated the potential for creating membranes ideal for EDC. But the timing of the two projects was substantially offset so a direct collaboration wasn't possible. Nevertheless, the teams plan on collaborating in the future.

Opportunities for Further Research

Inspired by the work on this project, the research team made an important breakthrough: a novel electrosorption process for ion-specific separations in water called "electrochemical ion pumping" (EIP). EIP overcomes many of the current limitations of electrosorption desalination technologies such as capacitive deionization because it can continuously shuttle ions across a sorption barrier and does not require switching the physical flows of water within the cell.

Publications and Reports

Zhang, X., Yao, Y., Horseman, T. et al. Electrodialytic crystallization to enable zero liquid discharge. *Nat Water* 1, 547–554 (2023).
<https://doi.org/10.1038/s44221-023-00095-4>

