Advanced electrodialysis with monovalent-selective membranes

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Motivation

Water scarcity is an increasingly persistent problem, driving the need for desalination technologies with high water recoveries. Reverse osmosis dominates the desalination market, but its water recovery is limited by scaling. Pushing the recovery further produces brines whose disposal creates new environmental challenges. Electrodialysis metathesis (EDM) using monovalent-selective ion exchange membranes (mIEMs) offers a way around this by separating the salts responsible for scaling, while reaching water recoveries up to 95%[1]. These membranes selectively separate monovalent ions (Na^+, Cl^-) from divalent ions (Ca2+, Mg^{2+}, SO_4^{2-}) (Fig. 1) giving valuable control over which ions and salts are removed. This control, however, still has some limiting factors such as transport of divalent ions and selectivity loss as the process progresses. To fully realize the membrane's potential, a deeper understanding of monovalent selectivity is still needed. Most importantly, this requires understanding how membranes and operational conditions can be optimized to maintain selectivity under a wide range of process conditions. This project aims to address that gap by determining when selectivity loss occurs and why (Fig. 2), through experimental investigation of process operation and membrane modification coupled with transport modelling.

Technological Challenges

The main challenges are:

- Monovalent selectivity depends on the interplay between membrane properties, operating conditions and feed water composition. This interaction is complex and not yet well understood.
- Membrane modification can improve selectivity, but it can also change the membrane's properties such as electrical resistance reducing the ion fluxes and increasing energy consumption.
- Real feedwaters contain more complex compositions than synthetic solutions and can subsequently cause fouling or unexpected selectivity loss that was not seen with synthetic solutions.

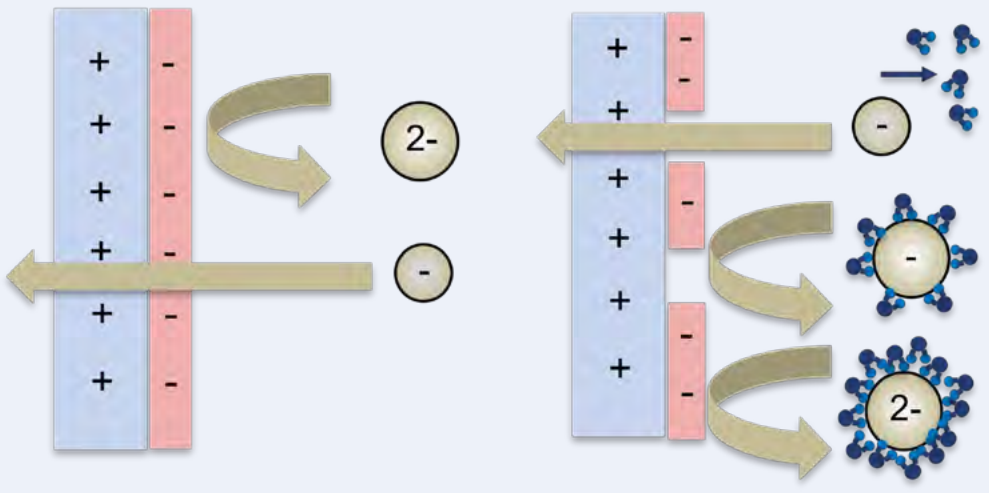

Fig 1. Selectivity mechanisms in monovalent selective ion exchange membranes: Donnan exclusion (left side), size exclusion and hydration/dehydration of ions (right side)

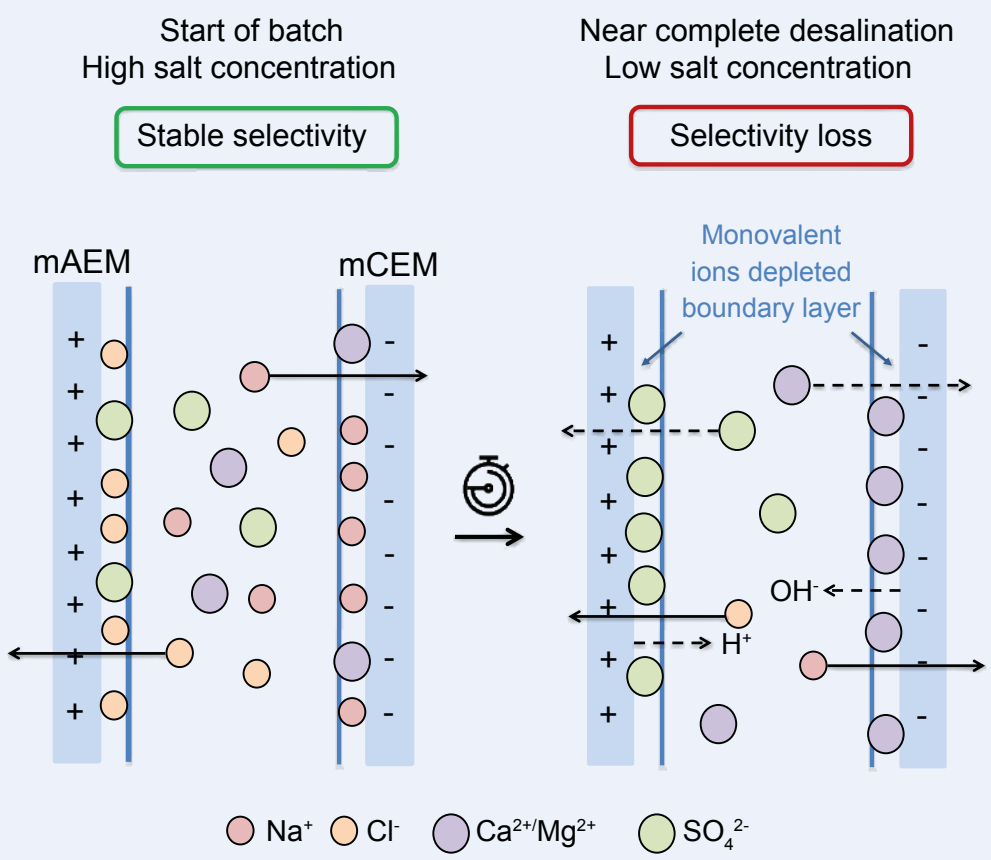

Fig 2. Conceptual diagram of the diluate compartment in a monovalent selective ED cell pair, consisting of a monovalent anion exchange membrane (mAEM) and a monovalent cation exchange membrane (mCEM). The scheme illustrates batch desalination, in which feed concentration decreases over time. As the diluate depletes, the boundary layer becomes increasingly depleted in monovalent ions, driving the system toward and beyond the limiting current, where water splitting occurs. This reduces monovalent selectivity and increases divalent ion transport.

Research goals

This research project studies monovalent selectivity as both a membrane and process property. The research goals are:

- Identify the operational boundaries of monovalent selective ED by investigating different operational parameters for varied feed compositions to determine when and why the selectivity is maintained or lost in multi-ionic feeds.
- Modify commercial ion exchange membranes to improve monovalent selectivity without compromising performance and gain deeper insight into how selectivity and its stability respond to different modification conditions.
- Validate the findings under real industrial feedwaters and integrate them in a process configuration that maintains stable selectivity at high water recovery and current efficiency.

References

[1] K. Li et al., Desalination 604 (2025) 118720.