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High-Recovery & Chemical-free Desalination Using Electrodialysis Metathesis

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Motivation

Ascending water scarcity permits desalination for additional water supply. Membrane desalination is mature and cost-effective. However, its water recovery is limited due to the oversaturation of 2:2 salts (e.g., $CaSO_4$, $CaCO_3$) in the concentrate, eventually leading to scaling. Antiscalant dosing or ion-exchange processes mitigate this limitation, but these measures have negative operational and environmental impacts. Alternatively, studies have proposed Electrodialysis Metathesis (EDM; Fig 1). The EDM process avoids oversaturation of 2:2 salts; instead, it concentrates highly soluble 1:2 (e.g., $NaSO_4$) and 2:1 salts (e.g., $CaCl_2$) separately. However, the process requires the addition of NaCl [1,2].
Our aim is to develop a high-recovery desalination scheme, including EDM, but with electricity and source water as sole inputs (Fig. 2). The process we propose consists of 2 steps. In step 1 monovalent ions migrate from the feed stream to form a 1:1 brine in a monovalent selective ED (mvsED) process. In step 2 divalent ions migrate from the feed to recombine with monovalent counter-ions from the 1:1 brine from step 1, forming a 1:2 brine (Na-type) and a 2:1 brine (Cl-type).

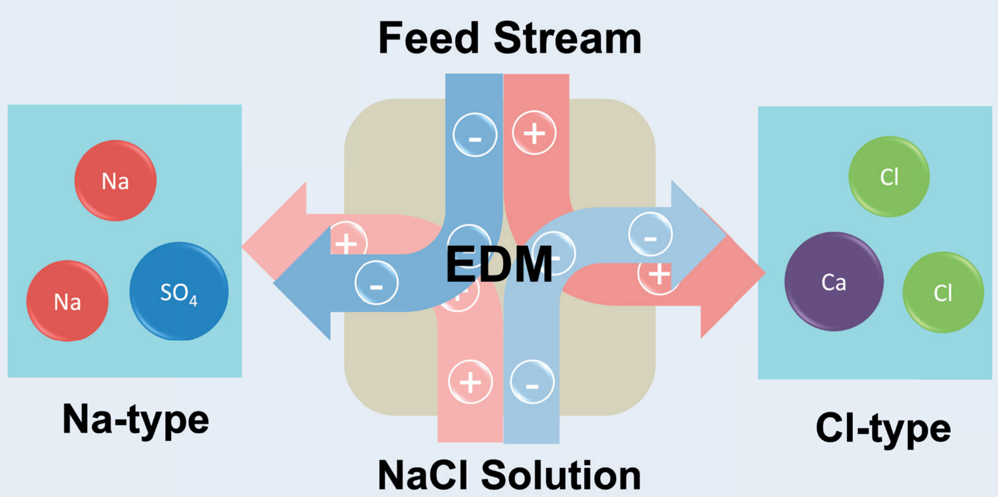

Fig 1 . Desalination with EDM: divalent ions from feed stream rearrange with monovalent ions from NaCl solution

Technological challenges

Regarding development and real-life applications, the main challenges are as follows:

- Without chemical additions, the source water's ionic composition fully defines the ability to rearrange ions into different brines, hence also the water recovery it can obtain.
- The scheme involves at least four types of ion-selective membranes which interact within the process. Essential are the properties of each of these membranes: e.g., counter-ion over co-ion selectivity, monovalent over divalent selectivity, water permeability.
- The process design is complicated since it includes multiple streams (feed, product, recycle, brines).

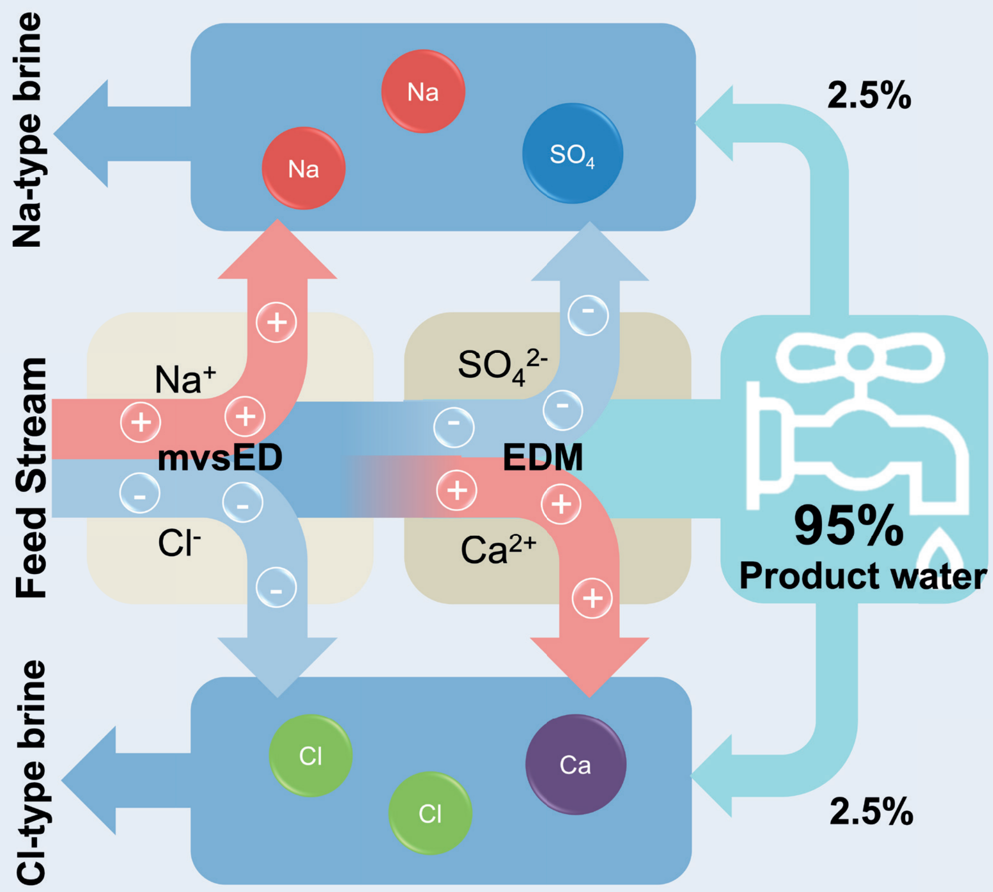

Fig 2. High-recovery (e.g., 95%) and chemical-free desalination: in step 1 Na and Cl are removed from the feed stream by mvsED, in step 2 divalent ions (e.g., Ca and SO4) are removed from the feed and recombined with Cl and Na, resp.

Research goals

The goal is to give an experimental proof of concept and validate the technology in the lab with real water, and for practical use cases provided by our industrial partners. The following research goals schedule the work plan:

- Conceptualizing and modeling the EDM configurations regarding the characteristics: chemical-free, high-water-recovery, and no too concentrated brine discharge.
- Experimentally validating the concepts and investigating the optimum design and operational conditions, including synthetic and real water tests and accurate modeling for fine tunes.
- Identifying and investigating potential practical use cases of the concepts regarding water recovery or regeneration and brine management in various industries (e.g., drinking water, oil, and membrane companies).

[1] [1] Bond, R., Batchelor, B., Davis, T., & Klayman, B. (2011). Zero liquid discharge desalination of brackish water with an innovative form of electrodialysis: electrodialysis metathesis. Fla. Water Resour. J, 63(7).
[2] [2] Chen, Q. B., Tian, Z., Zhao, J., Wang, J., Li, P. F., & Xu, Y. (2022). Near-zero liquid discharge and reclamation process based on electrodialysis metathesis for high-salinity wastewater with high scaling potential. Desalination, 525.

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