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Reaction transport phenomena at ion-exchange membranes in DC electric field

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The global challenge of ensuring safe drinking water spans from desalinating seawater and brackish water in coastal regions to treating polluted freshwater sources. Membrane processes are crucial in tackling these issues, with reverse osmosis being the primary method for conventional water desalination. However, electromembrane technologies, particularly electrodialysis, are emerging as viable alternatives, especially for smaller desalination plants and industrial applications focusing on producing ultrapure water rather than potable water.

Despite its promise, electrodialysis is limited by concentration polarization, an intrinsic phenomenon that occurs on membranes under DC bias. Gaining deeper insight into the reaction-transport phenomena behind this effect is necessary for designing and optimizing more efficient electrodialysis systems. Interestingly, solute-induced gravitational convection has emerged as a potential solution to at least partially mitigate the challenges posed by concentration polarization.

Our research aims to enhance the understanding of phenomena occurring on ion-exchange membranes through both experimental and theoretical approaches. To investigate the mechanisms at play, we designed, constructed, and utilized an electrochemical cell for microscopic analysis. Experimental results revealed that gravitational convection initiates immediately in the underlimiting region, significantly influencing mass transfer along the ion-exchange membrane. To support these findings, the second phase of our research involved developing a computational model using COMSOL Multiphysics. We developed a model based on solving the Navier-Stokes, Poisson, and molar balance equations, enabling the prediction of both natural convection and electroconvective vortices. The model demonstrated that natural convection can significantly impact mass transport along the ion-exchange membrane.