Slovak Society of Chemical Engineering
Institute of Chemical and Environmental Engineering
Slovak University of Technology in Bratislava

PROCEEDINGS

52nd International Conference of the Slovak Society of Chemical Engineering SSCHE 2026

Hotel SOREA TRIGAN
Štrbské Pleso, Slovakia
May 26 - 29, 2026

Editors: Assoc. prof. Mário Mihaľ

ISBN: 978-80-8208-177-3, EAN: 9788082081773

Published by the Faculty of Chemical and Food Technology, Slovak University of Technology in Bratislava in Slovak Chemistry Library for the Institute of Chemical and Environmental Engineering; Radlinského 9, 812 37 Bratislava, 2026

Slouka, Z.: Chemical engineering of ion-exchange membranes: from biosensing to electrodialysis, Editors: Mihaľ, M., In *52nd International Conference of the Slovak Society of Chemical Engineering SSCHE 2026*, Štrbské Pleso, Slovakia, 2026.

Chemical engineering of ion-exchange membranes: from biosensing to electrodialysis

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Keywords: ion-exchange membranes, reaction-transport phenomena, biosensing, preconcentration, ion separation, electromembrane processes

Abstract

Ion-exchange membranes are selective materials traditionally employed in electromebrane processes, such as electrodialysis, for the removal of small ions from processed water solutions. However, when viewed as materials that allow one to control the flux of ionic species by externally applying a DC electric field, the range of potential applications significantly widens. The reason for this is the interesting but rather obscure behavior of ion-exchange membranes in the electric field. Especially at the interface between the given membrane and the processed solution, the observed behavior is determined by the complex interplay of various reaction-transport phenomena, such as diffusion, migration, electroconvection, gravitational convection, pressure-driven convection, and acid-base reactions facilitated by a strong local electric field. Depending on the properties of the given membrane and the ionic species in the water solution, those processes can attenuate or amplify, providing a largely unexplored space for chemical engineers.

To unveil and describe these complex systems, we combine experimental and theoretical approaches to understand the spatiotemporal evolution of ion-exchange systems under various conditions. Specifically, we use microfluidic technologies to construct experimental systems that not only allow us to measure integral characteristics, such as polarization curves and the achieved degree of desalination, but also to reconstruct time- and spatially resolved maps of important quantities, such as velocity, concentration, or electric potential. The experimental observations are then explained in the context of numerical simulations of formulated mathematical models, based on conservation of momentum, species, and energy, and the Poisson equation of electrostatics, providing an inspiration for potential applications of ion-exchange membranes. These applications indeed include biosensing, biomolecule preconcentration, molecular separation, ionic separation, and preconcentration or chemical production.

In the talk, we will focus on combining fundamental engineering research on ion-exchange membranes with their potential applications.