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An Analytical Solution of the Solution-Diffusion-Electromigration Equations Reproduces Trends in Ion Rejections during Nanofiltration of Mixed Electrolytes

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Abstract

This paper develops an analytical solution to the equations governing the solution-diffusion-electromigration transport of the ions from two salts that contain a common ion. The analytical expressions, which rely on constant ion permeances, readily enable simple spreadsheet computations of the permeate ion concentrations in nanofiltration (NF). Despite the model simplicity, calculations of ion rejections as a function of transmembrane volume fluxes, feed-solution compositions, and permeance values reproduce experimental trends, with ion permeances as the only adjustable parameters. For example, with solutions containing dissolved MA and M_2B, when the membrane permeance to B^{2-} is much lower than the permeances to A^- and M^+, plots of A^- rejection versus transmembrane volume flux show the negative minimum that is often characteristic of NF. Moreover, B^{2-} rejection increases with increasing MA in the feed solution, reflecting a decreasing electric field in the membrane. The analytical solution also enables spreadsheet computations of electric fields in membrane separation layers and effectively models experimental data for intrinsic rejections as a function of transmembrane volume flow. Interestingly, the model suggests that with sufficiently high permeances of A^- (relative to M^+), at certain feed compositions the A^-/B^{2-} selectivity may increase without bound as a function of volume flow. Otherwise, this selectivity does not vary greatly with feed composition and quickly reaches a limit as the volume flow increases. Despite the simplifying approximation of constant ion permeances, using only a few adjustable parameters this model readily reveals trends in NF ion rejections and may help to identify the desired ion permeances or solution compositions for specific separations.

Keywords

Nanofiltration, solution-diffusion, electromigration, negative rejection, ion permeance

Introduction