Investigation of Reverse Electrodialysis with Multiphysics Modeling

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Abstract

Salinity gradient represents an interesting renewable energy source (salinity gradient power). Reverse ElectroDialysis (RED) is an ion exchange membrane-based process that converts directly the salinity gradient energy into electric current. In a RED device, two solutions at different concentration are fed in two series of alternated channels, which are formed by piling two alternated series of cation and anion exchange membranes (CEMs and AEMs, respectively) separated either by spacers or membrane profiles. An electric potential difference rises over each membrane due to the chemical potential difference between the two solutions. Selective ionic fluxes across CEMs and AEMs from the concentrate channel towards the dilute channel are converted by redox reactions into an electric current in the two electrode compartments closing the stack. The electric energy is then supplied to an external load.

Various physical phenomena occur in RED units, and affect the process performance. This work presents a novel approach for multiphysics modeling of the RED process implemented in COMSOL Multiphysics® software. Two-dimensional simulations were performed simulating a single cell pair, i.e., the repeating unit of the stack, made by two membranes and two feed channels. The physical models implemented were: (i) Laminar Flow for fluid dynamics inside the channels; (ii) Tertiary Current Distribution describing the electrochemical behavior of electrolytic solutions and membranes based on the Nernst-Plank equation and the local electron neutrality condition. Boundary conditions at the membrane-solution interfaces were set by implementing the Donnan exclusion theory to simulate voltage and concentration jumps. Stack potential, current density and gross/net power densities were computed in a stack of any given number of cell pairs and membrane area.

Different membrane/channel configurations were investigated, including flat membranes, either with or without nonconductive spacers, and profiled membranes. Post processing of simulation results provided perm-selectivity of membranes and ohmic and non-ohmic (due to concentration changes) resistances of the cell pair. A sensitivity analysis of total resistance of cell pair, gross and net power density on the feeds concentration/velocity for the various cell pair configurations was performed. Results showed that the model is a promising tool for design and optimization of RED units.