Coupling CFD simulation with a simplified process model for reverse electrodialysis units

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Salinity gradient between two solutions is a renewable source of energy. Among the technologies able to exploit the salinity gradient, reverse electrodialysis (RED) is an electrochemical process for electrical power generation through direct conversion. Ion exchange membranes, piled alternately and separated by net spacers or membrane profiles, are the key elements of a RED stack. A multiplex phenomenology occurs in RED units; Ohmic and non-Ohmic (due to concentration changes) voltage losses and pressure drop are the main issues, and the membrane/channel configuration is crucial for the stack performance. In this framework, mathematical modelling can be a powerful tool for predictive purposes and for optimization studies.

This work presents a coupled simulation strategy based on combining Computational Fluid Dynamics (CFD) modelling with a higher-scale simplified process model aimed at predicting the performance of RED stacks. Fluid dynamics and mass transport are simulated by solving 3-D Navier-Stokes and continuity equations along with a convective-diffusive transport equation in the periodic domain of the cell pair, including complex configurations with either spacers or profiled membranes. Correlations for the friction coefficient and the Sherwood numbers, related to pumping power losses and polarization voltage losses, respectively, are obtained. Moreover, simple 3-D finite volume methods are used to solve a Laplace equation for the electrical potential, thus providing Ohmic resistances of the cell pair. These results are provided as input data to the process simulator, which includes (i) mass balance equations along the channels, (ii) Nernst's law for the local electromotive force (inclusive of concentration polarization phenomena effect) and (iii) Kirchhoff's law for the equivalent circuit. The voltage-current and (gross and net) power-current curves are obtained as process model outputs.

Preliminary results show that spacers or profiles with large pitch to height ratios yield larger net power densities. The coupled computer-based simulation approach provides a predictive fast-running tool to investigate the potentials of alternative designs, to orient experimental activities and optimize real RED systems.

Keywords: Salinity gradient energy, Reverse electrodialysis, CFD, Process model.

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