A comprehensive multi-scale process model of bipolar membrane electrodialysis (BMED) systems

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Bipolar membrane electrodialysis (BMED) uses electrical energy to produce acidic and alkaline solutions by water dissociation. Its great versatility has increasingly gained the interest in chemical/biochemical industry and in environmental protection. Co-ion leakages through the membranes and shunt currents pose major issues leading to significant drops in current efficiency.

This work focuses on the development of a novel model based on a multi-scale approach. Four different dimensional scales were fully integrated within a comprehensive simulating tool with distributed parameters. The lowest scale, which is represented by the channel, includes two sub-models. The CFD simulations sub-level estimates polarization phenomena and pressure losses, while the other sub-level calculates the physical properties of the solutions. The middle-low level simulates the triplet, i.e. the repetitive unit of the stack, by computing mass balances, membrane fluxes, electrical resistance and electromotive force. The middle-high scale, represented by the stack model, is made up of two sub-levels: one is intended to compute the shunt currents through the manifolds, the other one aims at calculating pressure losses in the whole stack. Finally, the highest level simulates the external hydraulic circuit accounting for external pressure losses and dynamic mass balances in the tanks.

The model was experimentally validated with both an original campaign and literature data, showing a good agreement. A sensitivity analysis was performed in order to assess the behavior of BMED systems. The process performance was evaluated by comparing current efficiency and power consumption in different scenarios. The outcome of the analysis illustrates the influence of operating variables (e.g. current density and mean flow velocity) and of the system geometry. Results highlight the key role of the manifolds features on the process efficiency.

Keywords: Electrodialysis, Bipolar membrane, Ion-exchange membrane, Water dissociation, Acid, Base, Modelling.