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SUSTAINABLE EARTH RESOURCES ENGINEERING

Ion exchange membrane electrodialysis for water and wastewater processing: application of ladder-type membrane spacers to impact solution concentration and flow dynamics

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Abstract

Concentration polarization, which creates a thin boundary layer along the membranes in electrochemical reactors and electrodialysis-related processes, is one of the main issues. Membrane spacers provide swirling motion in the stream and distribute fluid toward the membrane, which effectively breaks the polarization layer and maximizes flux steadily. Membrane spacers and the spacer-bulk attack angle are reviewed systematically in the current study. The study then in-depth reviews a ladder-type configuration composed of longitudinal (0° attack angle) and transverse (90° attack angle) filaments, and its effects on solution flow direction and hydrodynamics. The review discovered that, at the tradeoff of high-pressure losses, a laddered spacer can provide mass transfer and mixing activity along the channel while preserving comparable patterns of concentration near the membrane wall. Pressure losses are driven by a change in the direction of velocity vectors. Dead spots in the spacer design that are created by the large contribution of the spacer manifolds can be reduced using the high-pressure drop. Laddered spacers also permit long, tortuous flow paths, which help to create turbulent flow and prevent concentration polarization. The absence of spacers produces limited mixing and broad polarization effects. A major portion of streamlines changes direction at ladder spacer strands positioned transverse to the main flow by moving in a zigzag manner up and down the filaments of the spacer. Flow at 90° is perpendicular to the transverse wires in *x*-coordinate, no change in *y*-coordinate.

Keywords Concentration polarization · Membrane spacers · Bulk-spacer attack angle · Ladder-type configuration · Pressure drop · Electrodialysis membrane desalination · Mass transfer · Boundary layer · Hydrodynamics · Hydraulic retention time

Introduction

Concentration polarization, which arises during the speedy convective transfer of solutes to the membrane wall, is one of the main issues in electrochemical reactors and electrodialysis-related operations (Schwinge et al. 2004; Balster et al. 2009; Jalili et al. 2018). Concentration polarization affects stack power density and was discussed by numerous scientists (Ahmad et al. 2005; Długołecki et al. 2010; Gurreri et al. 2014, 2016; Jalili et al. 2018). The concentration polarization process takes place at the solution-membrane interface, where the ions become less concentrated in the boundary layer, causing the development of a thin diffusion boundary film along the membranes (Balster et al. 2009; Bai et al. 2018; Jalili et al. 2018).

The counteraction of the boundary layer in the feed at the membrane surfaces is close to or even higher than the resistance of the membrane, adding to the total resistance, posing a barrier to ion transport, and causing concentration gradients to develop (Balster et al. 2009). As a result, the solution-membrane interface experiences salt ion depletion close to the membrane (see Fig. 1).

The effects of concentration polarization reduce the process's technical and commercial viability. For instance,

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