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Electrodialysis membrane with concentration polarization – A review

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ABSTRACT

Electrodialysis (ED) is more robust than reverse osmosis in terms of scaling, purity, and control, but its efficiency is dependent on concentration polarization. Concentration polarization is not only inherent in ED, but also commonly found in microfiltration, ultrafiltration, nanofiltration, reverse osmosis, and fuel cells with ion exchange membranes (IEMs). The current meta-synthesis review aims to identify the best approach for reducing concentration polarization, increasing velocity, or maximizing spacer design. Concentration polarization can significantly impact membrane capability and reduce overall performance. To reduce concentration polarization, innovative geometries and configurations of membrane spacers are needed. Carefully designed spacers that increase channel turbulence can help mitigate concentration polarization effects. However, advanced spacers still have negative consequences, such as the shadow effect, which reduces the ion exchange area and increases permeation resistance. Increasing the flowrate can improve membrane performance, maximize recovery/permeate rate, and reduce the limitations of spacer design. However, increasing the flowrate can have drawbacks in certain membrane applications. For example, a higher Reynolds number may improve spacer performance with a higher Sherwood number but at the cost of a greater power number. This review found that the extent of concentration polarization formation is heavily influenced by both spacer design and solution velocity. Convective motions affect mixing, making the concentration domain within the cell highly dependent on spacer design and flow velocity.

1. Introduction

1.1. Background

Electrodialysis (ED) is often touted as a green and sustainable technique that utilizes an electrochemical separation mechanism. ED has gained popularity as a method for extracting dissolved minerals from saltwater, wastewater, and brackish water (Nakayama et al., 2017), but the design and construction of ED stacks can impact its performance. A typical ED stack consists of repeated cells of cation exchange membranes (CEM), anion exchange membranes (AEM), two electrodes (anode and cathode), and mesh/porous filled spacers to maintain the intermembrane gap (Al-Amshawee et al., 2020a).

The function of CEMs and AEMs is to selectively allow the passage of cations and anions while preventing the flow of oppositely charged ions. However, the effectiveness of this selective ion transport can be influenced by factors such as fluid current, which in ED models occurs mostly in flat cells with rectangular cross-sections, where membranes create the borders and spacer material fills the cells. Further research is needed to fully understand and optimize the performance of ED systems (Al-Amshawee et al., 2020a, 2020b).

Concentration polarization is widely recognized as a major problem in membrane operations and electrochemical membrane stacks such as ED and it is important to critically evaluate its impact on power density and productivity (Li et al., 2023a). Multiple studies have demonstrated that concentration polarization, as an obstruction to the hydrodynamic boundary layer, can reduce power density in ED (Gurreri et al., 2016, 2014). However, the extent to which concentration polarization inhibits productivity by forming a thin diffusion boundary film next to IEMs with resistance rates that exceed the resistance of the membrane may vary depending on factors such as membrane design and operating conditions (Balster et al., 2009). Further research is needed to fully understand and mitigate the effects of concentration polarization in ED systems.

It is widely acknowledged that concentration polarization can influence not only electro kinetics but also other contacting phase characteristics (Mishchuk, 2010). Concentration polarization has been shown to impact a range of phenomena, including current density and selectivity through membranes, water dissociation and pH change, interaction of particles, electrochemical reactions, properties of the

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