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Using Membranes with Internal Microchannels to Prevent Drying-out during CO_2 Electrolysis

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Abstract

Scaling up CO_2 electrolysis is a vital aspect in the transition to manufacturing sustainable fuels and chemical compounds, satisfying the demand for chemicals and demand for storing renewable electricity. Depending on the employed catalyst, different products can be produced, such as carbon monoxide and ethylene, by applying a voltage on a CO_2 and H_2O fed electrolyzer. CO is a desirable product according to techno-economic analysis, because it can be produced selectively using a silver catalyst and is a precursor for hydrocarbons in the Fischer–Tropsch process. In a state-of-the-art CO_2 electrolyzer, two electrodes are directly pressed against an ion-exchange membrane – this is called a zero-gap configuration. Therefore, the membrane is a crucial component for the system, since it has the role of providing a conductive medium between the electrodes.

One of the challenges in CO_2 electrolysis is that water is consumed in the reaction. At high current density, this may cause the membrane's surface near the cathode to dry out, lowering efficiency or perhaps stopping the process entirely, since there is no longer a conductive medium. As a result, water management is critical for this process.

In this work, we approach the drying-out challenge by studying the novel concept of a membrane with internal microchannels. These channels allow the circulation of water or an electrolyte inside the membrane, which reduces the water diffusion path and affects the membrane's conductivity.

The effects of channel geometry, location, and concentrations of electrolyte inside on water content, conductivity and overall performance are studied in a 2D COMSOL model. In addition, the effect of internal concentration of electrolyte on the membrane's resistance, on the process performance and the K^+ cross-over to cathode side were investigated experimentally.

Our modeling results prove that the presence of the channels can keep the membrane hydrated. The highest current densities are observed when the channel is closest to the cathode, and with smaller pores. Smaller pores are advantageous due to the trade-off between enhanced membrane conductivity and the lower conductivity of the liquid itself. If water is circulated in a large channel, it increases the membrane's ionomer conductivity due to hydration but the overall conductivity is decreased since water is not highly conductive. Nonetheless, the results also show that a higher concentration of electrolyte inside the microchannels can

significantly increase the total conductivity of the membrane, and therefore the energy efficiency of the process. These effects are most significant at higher current densities.

In the experimental results, we've observed similar effects in terms of membrane conductivity and current density of the process – the higher the electrolyte concentration the higher the current density. Furthermore, a low concentration decreases the amount of potassium which crosses over to the cathode side, inhibiting salt deposition.

We've concluded that a small channel, up to 90 µm wide, close to the pore with an electrolyte with a concentration of up to 10 mM could be very beneficial for the water management and energy efficiency of the process. This helps to keep the membrane hydrated at higher current densities, improves the conductivity of the membrane, and it doesn't have significant impacts on the salt deposition.

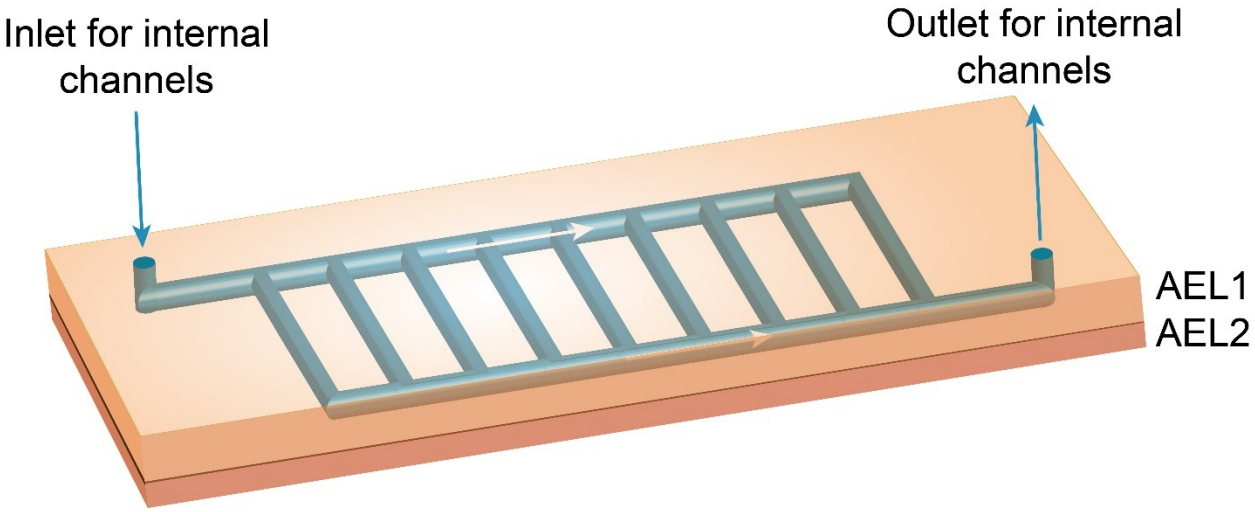

Figure 1