Catalysts and cell designs for AEM-based (sea)water electrolysis

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Green hydrogen produced by electrolysis from renewable energy can be a world-changing, low-cost energy carrier. But, making such advances depends on a number of choices – cell chemistry, components, water source, etc. This is particularly true for areas of the world with limited natural resources and/or existing infrastructure and/or access to water. Unfortunately, many of the locations that meet these criteria tend to have a scarcity of fresh water – but nearly unlimited access to seawater, making seawater electrolysis an extremely attractive option. Unfortunately, modern direct seawater electrolyzers have shown insufficient durability due to several negative processes, including electrode corrosion, competitive production of chlorinated products that result from the presence of Cl^- at the anode, and the deposition of alkaline earth metal (hydr)oxides at the cathode. The answer to date has mostly been to do indirect seawater electrolysis, where a deionization step is introduced before electrolysis, but this adds system complexity and cost.

Therefore, the first part of this presentation will focus on the behavior of a passive direct seawater electrolyzer that was designed in our group. The first version used a difference in osmotic pressure to drive water from the seawater compartment into highly concentrated solutions where the electrolysis was carried out. This version had limitations that were overcome in a second generation that shifted to a zero-gap architecture with an anion exchange membrane (AEM) at its core. Several aspects of this device will be discussed, combining electrochemical and theoretical data. The results from a single cell that operated continuously for more than one year will also be shown.

The second part of this talk will shift to catalysts. In AEM-based electrolyzers, anode catalysts for the oxygen evolution reaction have been well-documented and extensively used. However, contemporary high-performance hydrogen evolution reaction (HER) cathodes still rely on platinum-group metals (PGM) catalysts that substantially increase the overall system cost. This has intensified the efforts toward the development of PGM-free HER electrocatalysts, and the literature has literally hundreds of reports claiming to have solved this problem, but implementation in real electrolyzers has been limited, calling these claims into question.

Therefore, our group performed a detailed literature survey to find the most promising PGM-free HER catalysts that have been reported over the past decade. Approximately 400 catalysts were identified, classified, and narrowed down to six “model” catalysts that were synthesized as either self-supported catalysts on PTLs or powders that were subsequently deposited using catalyst-ionomer inks. The resulting electrodes were integrated into MEAs and evaluated in AEM water electrolyzers. Results will show that all six catalysts exhibited much higher activation overpotentials and cell resistances in operating electrolyzers than they did in the reported literature, as well as much higher operating voltages when compared to PtNi/C commercial catalysts. It will be shown that this is most likely due to aggressive iR compensation in the literature that masks true behavior. Lastly, it will be shown that modifications can be made to improve performance of these highly resistive PGM-free catalysts, but they are not yet able to close the gap with PGMs. This work also highlights the importance of collecting and reporting data under realistic conditions with practical importance.

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