Best practices for examining anion exchange membrane alkaline stability for solid-state alkaline fuel cells

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Abstract

Alkaline fuel cells (AFCs) with an anion exchange membrane (AEM) electrolyte are promising electrochemical energy conversion devices since they can provide power without platinum group metals and they avoid issues, such as carbonate precipitates, associated with traditional AFC technology using a liquid electrolyte. In the past decade, AEMAFC performance has improved substantially due to improvements in electrode binders that facilitate good membrane-electrode contact and AEM ionic conductivity. However, the alkaline (in)stability of AEMs is a long-withstanding challenge to commercializing this technology. To date, there have not been any satisfactory strategies or approaches to adequately assess an AEM's suitability for an AFC. Here, we report a best practices, all-encompassing approach to evaluate a leading AEM candidate (poly(2,6-dimethyl 1,4-phenylene) oxide (PPO) with quaternary ammonium groups) for AEMAFCs. In this work, PPO AEMs were immersed in concentrated alkaline solutions at elevated temperatures (i.e., immersion bath test) and were characterized via functional tests (ion-exchange capacity, mechanical properties, and ionic conductivity) and via sophisticated multi-dimensional NMR correlation techniques (e.g., heteronuclear multiple quantum correlation spectroscopy (HMQC)). Functional tests and interpretation of spectroscopic data revealed that the PPO AEMs suffer from degradation to the quaternary ammonium groups (quaternary benzyl trimethylammonium and quinuclidium) in addition to backbone degradation. However, the backbone degradation was only observed when PPO was functionalized with cation groups to the benzyl position. Non-functionalized PPO was resilient when exposed to identical alkaline solutions at elevated temperatures.

Additionally, the PPO AEMs were fabricated into membrane electrode assemblies (MEAs) and their changes in fuel cell performance versus time were assessed. Testing the PPO AEMs for over 12 hours in an operating fuel cell demonstrated significant system losses that were ascribed to AEM degradation. The MEAs tested underwent post-mortem analysis via multi-dimensional NMR spectroscopy, and the post-mortem results revealed for the first time that the degradation modes experienced in fuel cell matched the degradation modes observed via immersion bath test. Furthermore, this work also reports the highest hydrogen-oxygen single-cell fuel cell performance with an AEM in the peer-reviewed literature (peak-power density of 294 mW cm^{-2}). Initial excellent fuel cell performance was made possible by painting the electrode directly to the membrane since it minimized membrane-electrode contact resistance losses.