

Transport and Physiochemical Properties of Polyether-based Hydrogel Membranes for Ammonia Fuel Cell Applications

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Ammonia production is critical to maintaining global fertilizer supplies. The Haber-Bosch process, the production method used today, led to the quadrupling of the global human population with the increased food production capacity. However, this process requires high temperature and pressure to facilitate reaction kinetics. This leads to massive CO₂ production and energy usage totaling to 1-2% of global energy consumption. Researchers are trying to develop methods to produce ammonia through electrochemistry. Such devices can use electricity instead of heat to facilitate the reaction, and they can operate at ambient conditions. The typical setup for this cell can be seen in Figure 1. The focus of developing these cells has been finding a suitable catalyst. However, the membranes currently used these cells to allow a significant amount of ammonia crossover, leading to the oxidation and loss of products. Better membranes are needed than the current standard, Nafion-117, for electrochemical cells to be more efficient than the Haber-Bosch process. Here, new membrane chemistries are explored for applications in electrochemical ammonia fuel cells, and trends in membrane characteristics such as charge and water uptake are correlated to ammonia transport properties.

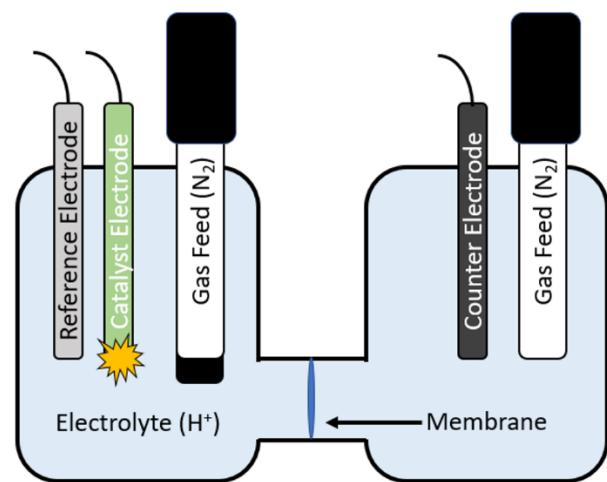


Fig. 1 Ammonia Fuel Cell

The analyzed membranes are composed of three main components in a DMSO solution: a crosslinker (methylenebis (acrylamide)), a negatively charged monomer (2-acrylamido-2-methyl-1-propanesulfonic acid), and a hydrophobic monomer (either phenyl acrylate (PA) or phenyl methacrylate (PMA)). The solutions were thermally crosslinked and solvent exchanged with water to form thin membranes. The membranes were installed in a H-cell similar to Figure 1. One side of the cell was filled with a 1 M ammonium chloride solution, and the other side contained pure DI water. Conductivity was measured on the water side as ammonia crossed over, and this was used to calculate membrane permeability. The membranes were also tested for water uptake by finding the difference between wet and dried films.

Overall, PMA based membranes showed lower permeability to ammonia than PA membranes. This trend matched the trend in relative water uptake. Increased water content in a film typically means there is more free volume in the membrane which allows for molecular diffusion (i.e., ammonia crossover); however membrane density must be measured before this can be confirmed. There was also a trend seen in the amount of charged monomer in the membrane and crossover. Increased charge content led to increased ammonia crossover. Ammonia is positively charged in solution, so the charged monomer has an affinity for ammonia and aided in its transport. Solubility data would help solidify these findings, as it would probe this thermodynamic affinity. Some PMA membranes showed similar permeabilities to Nafion-117, and other membrane chemistries can be tested to improve performance.

These findings have shown manipulating membrane chemistry for ammonia fuel cells could lead to reduced ammonia crossover, and further studies are needed to solidify membrane objectives for this application. Trends found for membrane charge and water uptake give clear direction to how future membranes in this area should be designed.

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Statement of Research Advisor

Brock has synthesized and characterized a series of new, polymer membranes with an aim at improving the operating efficiency of direct ammonia fuel cells by reducing ammonia crossover. Through his study, he demonstrated the relationship between membrane permeability to ammonia and polymer backbone chemistry, where the addition of a single backbone methyl group per repeat unit had a significant impact on permeability. Additionally, he found that the membrane permeability to ammonia could be tuned through the amount of comonomer incorporated into the membrane. He has set the stage for further investigation of structure-property relationships in this class of polymer membrane and my research group is looking forward to building upon his work towards designing new, improved polymer membranes for the sustainable production of ammonia.

- Bryan Beckingham, Engineering

References

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Authors Biography



Brock J. Hunter has recently received his B.S. in Chemical Engineering at Auburn University. He has researched many aspects of nitrogen reduction fuel cells, including membrane design and novel catalysis mechanisms.



Grayson P. Chapman is a junior-year undergraduate studying chemical engineering at Auburn University. He has interests in research pertaining to membrane transport properties.



Bryan S. Beckingham is an assistant professor in the Chemical Engineering Department at Auburn University. He leads a polymer research group exploring polymer chemistry for membranes and 3D printing.