Heat Transfer Considerations in a Tubular Carbon Fuel Cell

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Introduction

As the developing world is modernizing along with growing concerns about greenhouse gas emissions, there is an increased need for mitigating emissions during power generation. It is clear that in the foreseeable future renewable energy technologies will be unable to eliminate fossil fuel dependence, and hence efforts to reduce the environmental impact of carbon-based fuels are required. Carbon Fuel Cells (CFCs) have the double benefit of efficient utilization of a carbonaceous fuel such as coal or biomass, and the production of a concentrated stream of CO_2 that can be easily stored or sold as a marketable product.

Previous work in our lab has demonstrated solid oxide-based CFC for efficient electricity production from various types of carbons **[1-3]**. The CFC utilizes an yttria-stabilized zirconia electrolyte (YSZ) for oxide ion transport with solid carbon fuel at the anode and air at the cathode. Carbon dioxide enters the anode compartment and reacts with the carbon to produce CO via the Boudouard reaction.

$$C + CO_2 \rightarrow 2CO \qquad (1)$$

As shown in Figure 1, the cell oxidizes CO to generate electricity, producing an outlet stream of CO_2, part of which can be recycled to the anode and the reminder sent for storage.

Modeling Heat Transfer for the Tubular Carbon Fuel Cell Geometry

Heat transfer considerations are important for various reasons, and we provide in this presentation a comprehensive model that couples heat transfer with chemical and electrochemical processes as well as mass transport in a tubular carbon fuel cell. In the carbon bed, the Boudouard gasification reaction of the solid carbon fuel is endothermic, while CO oxidation at the anode surface is exothermic. Performance of the air carbon fuel cell depends on the rates of these reactions in several regards. First, the two reactions may result in a non-uniform temperature distribution in the cell due to differences in their enthalpies of reaction. As the kinetics of both reactions is temperature dependent, it is important to understand the coupled relationship between reaction rates, heat release and local temperature. Thus, consideration of heat transfer effects is necessary to develop a realistic understanding of the overall cell operation. Second, the operation of the cell results in an anode exhaust containing largely CO_2 with the remaining balance of unreacted CO. Carbon dioxide formed at the anode can diffuse back into the bed and further gasify the solid carbon. The CO from this gasification can then diffuse back to the anode, or it can diffuse through the carbon bed and leave the cell. Any CO in the exhaust is carbon fuel that is not fully oxidized, still capable of undergoing the oxidation reaction to produce electricity at the cell. Thus, fuel utilization improves with the ratio of CO_2/CO, and this influences the overall efficiency measured from the cell.

A model for operation of a tubular CFC was developed that takes into account heat transfer and temperature distributions within the cell. The parameters in the model were determined experimentally. The model was then used to map out the operating space for power density and cell efficiency. Furthermore, geometrical parameters such as fuel bed height and tubular placement can be tuned to minimize the mole fraction of CO in the exhaust. The model was implemented for multiple tubular geometries and spacing between tubes in order to determine how these parameters affect overall fuel cell performance.

This presentation will address the dependence of cell efficiency and power density on the cell and carbon bed geometries, which will then aid in the optimization of tubular cell design for the air-carbon fuel cell. Optimal operation conditions are identified for maintaining high efficiencies while also achieving realistic power densities.

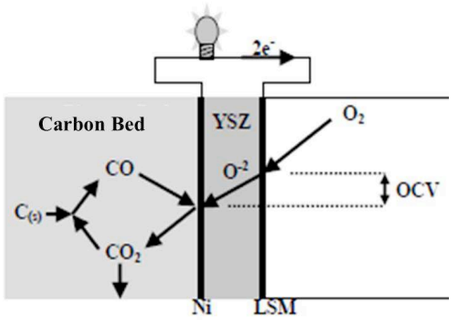

Figure 1: Boudouard reaction and CO oxidation at the anode of the CFC [2].

References

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