

Numerical Modeling of Coupled Heat/Mass Transport and Electrochemical Reactions in Fuel Cells

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Abstract

Among various types of fuel cell, the direct methanol fuel cell (DMFC) is one of the most advanced low-temperature electrochemical device that converts chemical energy of liquid methanol directly into electrical energy. Because of its unique advantages, such as higher energy densities, facile liquid fuel storage, and simpler system structures, the DMFC has been identified as one of the most promising power sources for portable and mobile applications. Although promising, the power output of DMFCs must be substantially improved before widespread application to powering different devices is possible. The realization of high power output fuel cell performance depends not only on the development of fuel cell materials with novel properties for ion transport and electrocatalysis, but also on the optimal design of the electrode structure, which critically requires a robust modeling approach in addition to experimental investigations. However, modeling of a fuel cell system is difficult, as heat/mass transport that is coupled with electrochemical reactions occurs in a complex multi-scaled and multi-layered porous structure. Rather than elaborating modeling details, this talk will be focused on presenting our recent experimental observations of coupled heat/mass transport and electrochemical phenomena in the DMFC, which help shed light on understanding of basic transport phenomena, thereby are useful for the development of mathematical models. Examples to be presented include: (i) in the development of passive DMFCs (with neither liquid pumps nor gas compressors), we found that the cell performance improvement with increasing methanol concentration was not because of the reduced anode mass-transport polarization, but because of the increased cell operating temperature as a result of the exothermic reaction between the methanol that permeates from the anode and oxygen on the cathode; (ii) in conventional wisdom, the DMFC is an electrochemical device to generate electricity. However, we recently discovered that the DMFC can also be used to produce hydrogen besides its function of generating electricity; (iii) The DMFC equipped with conventional serpentine fields usually suffers from serious discharging instabilities when the oxygen supply flow rate is low. We invented a so-called convection-enhanced serpentine flow field (CESFF) and found that with this new flow field the oxygen flow rate required to ensure a stable operation was significantly reduced. The application of CESFF enables a reduction in the parasitic power in the fuel-cell system and leads to a higher system efficiency.