

Numerical studies on an air-breathing proton exchange membrane (PEM) fuel cell stack

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Abstract

Air-breathing proton exchange membrane (PEM) fuel cells provide for fully or partially passive operation and have gained much interest in the past decade, as part of the efforts to reduce the system complexity. This paper presents a detailed physics-based numerical analysis of the transport and electrochemical phenomena involved in the operation of a stack consisting of an array of vertically oriented air-breathing fuel cells. A comprehensive two-dimensional, nonisothermal, multi-component numerical model with pressurized hydrogen supply at the anode and natural convection air supply at the cathode is developed and validated with experimental data. Systematic parametric studies are performed to investigate the effects of cell dimensions, inter-cell spacing and the gap between the array and the substrate on the performance of the stack. Temperature and species distributions and flow patterns are presented to elucidate the coupled multiphysics phenomena. The analysis is used to determine optimum stack designs based on constraints on desired performance and overall stack size.

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1. Introduction

Increasing energy requirements around the world have stimulated the interest to develop new reliable clean energy to decrease the dependence on fossil fuels and to reduce atmospheric pollution. To this end, proton exchange membrane (PEM) fuel cells are a strong alternative as a portable power source in widespread applications including automotive, laptop computers, cellular phones and other electronic devices owing to its low operating temperature, quick start, light weight and high power density. Recently, air-breathing PEM fuel cells have gained much interest due to their compact size and fewer components. Since oxygen is drawn directly from the atmosphere by natural convection, humidification and pressurization subsystems at the cathode are no longer required, which forms the basis of the reduced system complexity.

Effective design of air-breathing PEM fuel cells requires a thorough understanding of the interrelated heat and mass

transport phenomena and electrochemical reactions in the cell, which has motivated the studies in the literature. Earlier experimental and numerical investigations on air-breathing PEM fuel cells focused on the performance evaluation and design of a single fuel cell. Several materials and fuel cell designs were explored [1–3], while analytical model and numerical simulations from physics-based models were used to predict the performance of the cell and to obtain detailed species and temperature distributions inside the cell [4,5]. A new design of an air-breathing fuel cell was reported by the authors [6], who also presented detailed computational modeling of the cell performance. The design consists of a dual fuel cell cartridge with a common hydrogen flow channel and two exposed cathode surfaces in communication with the ambient air.

The studies on individual air-breathing fuel cells have shown the practical viability of the designs. Meeting the power requirements of practical applications requires configuring multiple individual air-breathing cells connected either in series or in parallel as needed to form a stack. To the best of the authors' knowledge, relatively scant work on air-breathing fuel cell stacks has been reported in the open literature. Chu et al. [7,8] reported

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