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

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Abstract

The objective of this article is to investigate the performance of an air-breathing proton exchange membrane (PEM) fuel cell operating with hydrogen fed at the anode and air supplied by natural convection at the cathode. Considering a dual-cell cartridge configuration with a common anode flow chamber, a comprehensive two-dimensional, non-isothermal, multi-component numerical model is developed to simulate the mass transport and electrochemical phenomena governing the cell operation. Systematic parametric studies are presented to investigate the effects of operating conditions, cell orientation and cell geometry on the performance. Temperature and species distributions are also studied to assist the understanding of the single cell performance for different conditions. It is shown that the cell orientation affects the local current density distribution along the cell and the average current density, particularly at lower cell voltages. The cell performance is shown to improve with increase of temperature, anode flow rate, anode pressure and anode relative humidity.

Keywords: Proton exchange membrane (PEM) fuel cell; Air breathing; Numerical model; Fuel cell orientation; Passive fuel cell

1. Introduction

Fuel cells are considered as promising candidates of alternative power sources, in which chemical energy is directly converted into electricity. Since water is the only product if pure hydrogen is fed, fuel cells offer high efficiency and emission-free operation. Over the last decade, proton exchange membrane (PEM) fuel cells have gained much attention since they can operate at low temperatures, start up quickly and yield high power density. These characteristics make PEM fuel cells attractive in many applications including automotive, distributed power generation, and portable electronic devices. However, the high manufacturing cost and low reliability and durability of fuel cells have severely limited their widespread commercialization.

The drive to understand the complex and interrelated transport and electrochemical phenomena inside PEM fuel cells has resulted in many numerical simulations and experimental tests being reported in the literature. The earlier work on fuel cell modeling can be traced back to Springer et al. [1] and Bernardi and Verbrugge [2], who developed one-dimensional, isothermal, steady-state models for PEM fuel cells by assuming perfect membrane hydration. More recently, the one-dimensional models have been extended to studying water and thermal management [3], carbon monoxide (CO) poisoning [4] and optimization of operating conditions [5]. The modeling rigor has also grown to include two-dimensional effects [6], transient operation [7], three-dimensional modeling [8–11], and two-phase flow and transport [12,13].

There has also been much interest in developing passive PEM fuel cells designs, which eliminate or reduce the balance of plant such as fans, compressors, etc., and are ideally targeted for portable, light weight applications and as either replacement for batteries or use as hybrid systems [14,15]. One version of the passive design is an air-breathing PEM fuel cell which is exposed to the atmosphere on the cathode side and draws air for its operation entirely

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