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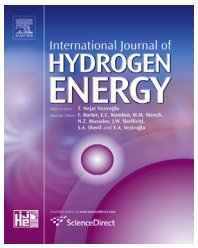

Effect of porosity and pressure on the PEM fuel cell performance

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ABSTRACT

This paper presents a numerical modeling, provides an improved understanding of the fundamental transport phenomena inside the PEM fuel cell. The problem is stated in a steady-state, two-dimensional model and Cartesian coordinates system by using a single domain and a control volume method. The model consists of non-linear, coupled partial differential equations representing the conservation of mass, momentum, species, charges and energy with electrochemical reactions that are valid for gas diffusion electrodes, catalyst layers and membrane region. The modeling of bidirectional, non-isothermal and steady problem of PEMFC provides results concerning the species fraction, potential and temperature distribution in different domain.

1. Introduction

Proton Exchange Membrane fuel cells is an electrochemical devices that convert directly into electricity and heat the chemical energy of reaction of fuel and oxidant (usually hydrogen and oxygen). The PEMFC is considered to be a promising power source, especially for portable electronic applications because of its high energy efficiency, low operating temperature (typically 80 °C), low emission and low noise. Earlier models suggested various ways to predict the electrochemical behavior of PEMFC. Bernardi and Vebrunge [1] developed fundamental studies toward understanding PEM fuel cells.

Chen et al. [2] studied a two-phase transport in the cathode gas diffusion layer (GDL) of a proton exchange membrane fuel cell (PEMFC) with a porosity gradient in the GDL. The results have shown that a gradient in porosity will benefit the removal rate of liquid water and will also enhance the transport of oxygen through the cathode GDL. Wang et al. [3] observed that the cathode GDL porosity has the strongest effect on the cell performance following the cathode CL porosity, while the anode GDL and CL porosities have negligible effect. The optimization of parameters of cathode GDL and CL is more important in improving cell performance than that of anode GDL and CL. Taymaz et al. [4] showed that deformed fuel cell single channel model is imported to three-dimensional, computational fluid dynamics (CFD) model. The latter is developed for simulating proton exchange membrane (PEM) fuel cells. The porosity and thickness of the GDL were decreased by the compression of the assembly pressure. The coefficients of diffusion and permeability depend on the porosity of the GDL; they are decreased by the compression of the assembly pressure.

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Zhang et al. [5] studied the effects of operation temperature, pressure, humidity, and inlet gas stoichiometric ratio on the fuel cell performance under both steady-state and transient conditions. It is concluded that when the operating pressure increases, the cell voltage enhances slightly (with 1.35% increase).

Another theoretical model, accounting for heat, charge, mass transfer, water transport and some transient phenomena in a single cell has been developed by Wohr et al. [6]. A two-dimensional CFD model is developed by Sahraoui et al. [7] which shows that there are two concentration overpotential effects; the slow diffusion effect at the agglomerate level and the smaller porosity of the GDL or CL. This model shows that the optimal catalyst layer thickness is about 0.1 mm.

Obayopo et al. [8] conduct in this study, a numerical investigation to analyze the flow field and reactant gas distribution in a PEM fuel cell channel with transversely inserted pin fins in the channel flow that aimed at improving reactant gas distribution. The channel friction and pressure drop can be significantly reduced with increasing GDL porosity.

A three-dimensional steady-state electrochemical mathematical model is developed by Zhang et al. [9]; where the mass, fluid, and thermal transport processes as well as the electrochemical reaction phenomena are considered. The influences of the parameters of interest, which include on one hand porosity, permeability, and the thickness of the gas diffusion layer, and on the other hand the inlet gas stoichiometric ratio on the performance of fuel cells; are identified. Besides, the optimum values of cathode/anode permeability, porosity, and thickness, and the stoichiometric ratio are obtained.

A larger porosity of the GDL leads to a greater space for the diffusion, which, however, induces a higher contact resistance in the GDL.

Ramousse and Deseure [10] constructed a model by combining independent descriptions of heat and mass transfers in the cell with a third description of coupled charge and mass transfers in the electrodes, considered porous. The results show that thermal gradients in the MEA could lead to thermal stresses at high current densities. The feeding gas temperature influenced on the cell temperature is also important.

Belkhiri et al. [11] developed a two-dimensional and steady-state model of PEMFC. The simulation of this model shows that; the concentrations of reactants depend on the current density and the performance can be enhanced by increasing the pressure differential.

Fuller and Newman [12] showed that temperature distributions depend on mass balance. They emphasized the need to control the membrane hydration and the PEMFC operating temperature well. The model of Alimi et al. [13] presents a steady-state, two-dimensional model which accounts simultaneously for species transport, electrochemical kinetics, current distribution as well as flow dynamics.

The model presented by Ai Suzuki et al. [14] studies the effects of porosity, pore size and Pt content on the polarization characteristics of the PEMFC.

In order to deepen the understanding of the mechanism of fluid dynamics, electrochemical and thermal processes within a fuel cell, this study presents a numerical solution to the complete Navier–Stokes, species, energy and charge conservation equations without counting the two-phase flow effect. The originality of this approach is the combination of two parameters: pressure and porosity. These complete equations are solved using the control volume method. The most attractive feature of this approach is the physical meaning of the full basis of its formulation in terms of fluxes and sources and its ability to use an irregular grid which provides more flexibility in fitting irregular domains.

2. Basic theoretical element

2.1. The PEMFC description

Fig. 1 schematically shows a two-dimensional PEM Fuel Cell and its various components: Anode Flow Channel (AFC), Anode Backing Layer (ABL), Anode Catalyst Layer (ACL), Membrane (MEM), Cathode Catalyst Layer (CCL), Cathode Backing Layer (CBL), and Cathode Flow Channel (CFC). A 2D analysis is sufficient to describe the physical phenomena in the considered single cell with single straight channel geometry [15]. The three-dimensional models account for the effect of the complex geometry, specifically interdigitated flow and serpentine channels. The whole governing equation is solved simultaneously in all seven layers by the control volume method; however, there is a phenomenally discontinuous distribution of numerical solution in the system. That are,

1. Hydrogen mass fraction (or mole fraction) exists only in the three layers AFC, ABL and ACL.
2. Oxygen mass fraction (or mole fraction) exists only in the three layers CFC, CBL and CCL.
3. Electrolyte potential exists only in ACL, PEM, and CCL: (MEA).
4. Solid potential exists only in ABL, ACL, CCL and CBL.
5. Temperature field exists only in ABL, ACL, MEM, CCL and CBL.

2.2. Hypothesis of the model

In the model development the following assumptions have been considered:

- The gas mixture are considered as perfect gases.
- The flow is laminar everywhere.
- The gas mixture flows are incompressible.
- Only the steady-state case is considered.
- Electrodes, catalyst layers and membrane are isotropic and homogeneous.

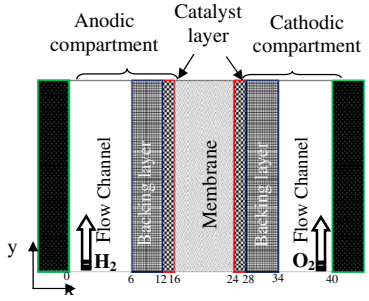

Fig. 1 – Schematic representation of PEMFC compartments.