Energy xxx (2016) 1–11

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

An investigation of the PEM fuel cells performance with partially restricted cathode flow channels and metal foam as a flow distributor

E. Afshari [a], M. Mosharaf-Dehkordi [a, *], H. Rajabian [b]

[a] Department of Mechanical Engineering, Faculty of Engineering, University of Isfahan, Isfahan, Iran
[b] Department of Mechanical Engineering, Graduate University of Advanced Technology, Kerman, Iran

ARTICLE INFO

Article history:
Received 28 March 2016
Received in revised form
19 October 2016
Accepted 24 October 2016
Available online xxx

Keywords:
PEM fuel cell
Baffles
Metal foam
Current density distribution
Temperature distribution

ABSTRACT

In the present work, the performance of proton exchange membrane fuel cells is studied for three cases; A fuel cell with two parallel flow channels (model A), locally baffle restricted flow channels (model B), and metal foam as a flow distributor (model C). The fully coupled thermal-electrochemical equations are numerically solved in three dimensions, based on the macroscopic, single-domain, and finite-volume approaches. While having no significant effect on temperature distribution, the existence of baffles inside flow channels results in more oxygen penetration into gas diffusion and catalyst layers at the cathode side of the cell. This improves the chemical reaction rate, current density and cell performance. Using metal foam increases oxygen concentration and current density at the cathode catalyst surface, and improves the uniformity of their distributions. Furthermore, a more uniform temperature distribution is achieved, when compared with the other cases. For the considered dimensions, it is observed that decreasing the flow channel depth results to an increase in current density and also in pressure drop along channels (models A and C). Moreover, increasing metal foam porosity can increase the current density value and decrease pressure drop in model C, while it has nearly no effects on temperature distribution.

1. Introduction

Fuel cells are electrochemical devices that directly convert the chemical energy into electrical energy through a set of chemical reactions. The solid oxide fuel cell, molten carbonated fuel cell and proton exchange membrane (PEM) fuel cell are common types of these devices. The high-power density, quick start-up, rapid adjustment to power demands, relatively low operating temperature, and emission-free operation are the most important characteristics of the PEM fuel cells. A single PEM fuel cell usually consists of different parts, including membrane-electrode assembly and bipolar plates. The bipolar plates include approximately 40% of the price of a fuel cell and more than half of its total weight and volume [1].

Optimal design of the flow channels within the bipolar plates has a noticeable effect on the general performance of the fuel cell. Since the gas diffusion coefficients in the cathode-side are smaller than those associated with the anode electrode, the design of the cathode side of the channel is more important. If the amount of output water of the cell becomes out of control, the transfer rate of oxygen into the catalyst layer (CL) will be significantly reduced. This may cause excessive heating and even leads to the membrane dryness. This inappropriate condition increases the internal resistance of the fuel cell and consequently reduces its performance. Therefore, the flow channels should be effectively designed to guarantee a uniform distribution of reactive gases in the catalyst layer. In the past decade, several researchers have attempted to improve the performance of the fuel cell flow field [2–6]. Effects of locally restricted channels on the fuel cell performance were investigated by Liu et al. [2]. By adding a number of baffles (small obstacles) inside the cathode channels, the flow velocity in the regions lie between the baffles and the gas diffusion layer (GDL) is locally increased. It was shown that fuel cell performance can be improved as more reactants penetrate into the GDL and contribute in the chemical reactions [2]. Song et al. analysed a new channel structure by placing baffles in the conventional flow channels [3]. Considering the pressure drop, they showed that the fuel cell performance can be increased by reducing the size of the gap between the baffle and GDL or increasing the number of baffles along the

* Corresponding author.
E-mail address: m.mosharaf@eng.ui.ac.ir (M. Mosharaf-Dehkordi).

http://dx.doi.org/10.1016/j.energy.2016.10.101
0360-5442/

flow channels. The effects of adding baffles into the serpentine flow channels on the performance of the PEM fuel cells were studied by Wang et al. in Ref. [4]. It was shown that the blocked serpentine flow field can generally improve the performance of the fuel cell, due to an increase in the reactants transfer rate into the GDLs and improvement in the current density distribution. By adding some baffles inside the cathode channel, Afshari and Baharloo simulated the locally blocked cathode channel of the fuel cell and studied its effects on the oxygen transfer rate into the cathode GDL [5]. It was shown that the gas flow rate is increased in regions lying between the baffle and GDL. Thus, more gas can penetrate into the GDL and its local concentration and chemical reaction rate in the catalyst layer is increased. All of these studies have shown that the performance of the fuel cell can be improved by adding baffles inside the flow channels through pushing the reactants towards the GDL. Although the existence of baffles inside the channels can generally improve the fuel cell performance, it leads to additional pressure drop and non-uniform distribution of gas concentration in the CL (especially for a large number of baffles).

To overcome the difficulties corresponding to baffle restricted flow channels in the fuel cells, one can replace the flow channels by metal foam. A metal foam, in fact, is as a high porosity porous medium which can be used as a flow distributor to reduce the total volume and weight of the PEM fuel cells. The fluid flow though the metal foam, as a porous medium, can be numerically simulated based on the *macroscopic* or *microscopic* approaches. In the former, the characteristics of fluid flow in the porous media are described by the volume-averaged value parameters, using a representative elementary volume. On the hand, the microscopic approaches [7–10] use the pore-scale details of porous medium to model the fluid flow in the porous media. Comparing these approaches, the microscopic method is generally more accurate and computationally expensive than the macroscopic ones, as they attempted to incorporate the pore-scale details of the medium in the simulation process [11].

Kumar and Reddy in Ref. [12] proposed that using the metal foam as alternative to flow channels can reduce the size and weight of the fuel cells. They also showed that the performance of their single cells with metal foam is relatively good. The performance of different fuel cells with metal foam as a flow distributor was investigated by a set of 3D numerical simulations based on the macroscopic approaches in Refs. [13,14]. In these studies, the steady state and isothermal model is assumed and the effects of heat transfer and temperature distribution on the physical and chemical properties and the performance of the fuel cell were neglected. It was shown that the permeability of the metal foam has a significant and positive effect on the fuel cell performance [13,14]. Tsai et al. in Ref. [15] compared the conventional flow fields in the fuel cell with the flow through the metal foam as a flow distributor. Their experimental results showed that in the fuel cell with metal foam the cell performance is improved due to a better distribution of reactive gases in the CLs. Moreover, the parametric study was constructed to investigate the effects of pressure and input stoichiometric operation on the fuel cell performance [15]. Aristy et al. examined the metal foams flow distributor and GDLs in the methanol fuel cells [16]. The effect of pore size (microscopic approach) and density of the foam on cell performance was also investigated. They illustrated that the performance of the fuel cells with different metal foam (even with similar density) is generally different. Yuan et al. in Ref. [17] reviewed the application of metallic porous materials in the polymeric fuel cell, including manufacturing process and characteristics of the metal foam. A model for the PEM fuel cell was proposed by Wang in Refs. [18,19]. In this work, the effects of heat and electron transfer along with reactant gases on the fuel cell performance was investigated. Carton and Olabi in Refs. [11,20] proposed a representative unit cell structure (RUCS) model for the Open Pore Cellular Foams (OPCF). It was shown that the calculated pressure drop has a good agreement with both experimental and numerical results. Then, the OPCF were used in the PEM fuel cells as the flow plate material in Ref. [21]. In this work, the authors used the CFD results to select the best the housing design for both cathode and anode sides. Furthermore, Carton and Olabi [22] developed a CFD PEM fuel cell model for the OPCF, as an alternative to graphite materials, used as a flow plate. For the isothermal operation and incompressible and laminar fluid flow, the numerical results were compared with experimental results [22]. While they used a RUCS model to microscopically simulate the OPCF, the fluid flow in other porous parts of the fuel cell were modelled based on the macroscopic approach. Comparing to a fuel cell with the dual flow channels, they showed that the fuel cell enhanced with the OPCF has a better performance and more uniform distribution of hydrogen and oxygen through the flow channels [22].

In the present work, the effects of adding baffles inside the flow channels and also use of metal foam instead of common flow channels on the performance of *non-isothermal* fuel cells are investigated. To do this, first three cases for the fuel cell are considered, including the simple parallel channels, flow channels with a number of baffles, and metal foam as a flow distributor. Then, the electrochemical, fluid flow and heat transfer equations are numerically solved in three dimensions, based on the *single domain* and *macroscopic* approaches. Besides the oxygen mole fraction and current density distributions, the temperature distributions for different cases are presented and compared to assess the fuel cell performance. In addition, the effects of flow channel depth and metal foam porosity on the pressure drop, temperature and current density distributions along with the polarization curve are investigated.

2. Different cases of the PEM fuel cell

In the present work, three different cases are considered for a single PEM fuel cell as follows:

Model A: the fuel cell with two simple straight parallel channels shown in Fig. 1a.
Model B: the fuel cell with baffle restricted flow channels shown in Fig. 1b. All the geometric properties of the fuel cell are exactly the same as those for the model A.
Model C: the fuel cell with a metal foam as a flow distributor shown in Fig. 1c. Here, the flow channels and their ribs in the cathode side of the fuel cell of case A are replaced by a nickel metal foam with porosity of 80%.

The humidified air enters the fuel cell by the cathode channels (or the metal foam in the case C) and humidified hydrogen enters the fuel cell through the anode channels. Then, hydrogen diffuses into the CL through the anode GDL. In the anode catalyst layer, hydrogen molecules are decomposed into two protons and two electrons. The produced protons travel through the membrane toward the cathode CL and the electrons travel through the external circuit to the cathode which form an external electrical circuit. In the cathode side, oxygen moves from cathode GDL toward the catalyst surface and reacts with protons and electrons to form water.

In a fuel cell stack, in general, there exists a number of cells with nearly the same performance. Therefore, the fuel cells are commonly modelled as a single cell. This idea can also be applied to the channels of each cell. This means that one channel with its adjacent ribs in a single cell are usually modelled. In the present

Please cite this article in press as: Afshari E, et al., An investigation of the PEM fuel cells performance with partially restricted cathode flow channels and metal foam as a flow distributor, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.10.101