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Gas flow field with obstacles for PEM fuel cells at different operating conditions

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ABSTRACT

In proton exchange membrane fuel cells (PEMFCs) laminar flow inside anode and cathode gas channels can be disrupted by using obstacles. By arranging these obstacles near to the exit of the gas channels concentration losses due to hydrogen and oxygen consumption inside the channel will be decreased. Using a three dimensional computational model, numerical simulations are performed to investigate performance of PEMFCs containing obstacles in the anode and cathode gas flow channels. These simulations were conducted at different operating conditions (stoichiometry, relative humidity and temperature) to clarify the effects of the obstacles at specified conditions. The simulations show that the obstacles inside the gas flow channels improve the concentration distribution along the channels and the transport of the reactant gases through the gas diffusion layer (GDL). As a result, the electrochemical reaction is improved and higher cell voltage is obtained at high current densities.

Introduction

Fuel cell (FC) systems are promising candidates for near future and sustainable energy conversion. Developed countries are trying to use fuel cell technology especially in transportation and also stationary applications. FCs are expected to play an important role in future power generation facilities. The differences among the existing categories of FC systems are mainly based on the type of electrolyte and operating conditions. Some of the important features of proton exchange membrane (PEM) fuel cells are: easy start-up, high power density, high efficiency and being usable in mobile applications. The PEM fuel cell may be operated from pressures near ambient to about 6 atm, and at temperatures between 50 and 90 °C. Higher current densities are achievable associated with a voltage gain at higher pressures. For PEMFCs operating parameters are also an important issue, therefore for a new design or a new arrangement, operating parameters have to be taken into account carefully [1,2].

Dong et al. [3] tried to disrupt the laminar flow by locating obstacles in the gas channels of the oxidant flow field. By these obstacles laminar flow is changed to turbulent flow therefore enhancing the transfer of oxygen to the membrane electrode assembly in the fuel cell. As more oxygen enters the reaction, more energy will be delivered. Therefore, the

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performance of the fuel cell will improve. The analysis of the fuel cell performance was done for only one specified operating condition without investigating the effects of different operating conditions for the geometries considered.

H.-C. Liu et al. [4] investigated the application of baffle-blocked flow channels for enhancement of reactant transport and performance of a PEM fuel cell. Their study shows that the local transport of the reactant gas, local current density generation, and the cell performance can be improved by the presence of the baffles. However, the model used was solved in two dimensions and the heat generation by electrochemical reaction within the cell was neglected.

Obayopo et al. [5] presented a numerical study with transversely inserted pin fins in the gas channel flow aiming to improve reactant gas distribution. The effects of the pin fin parameters, the flow Reynolds number and the GDL porosity on the reactant gas transport and the pressure drop across the channel length were explored.

Kuo et al. [6] have also investigated the effects of a novel wave like channel to the performance of PEM fuel cells. Their simulations focus on gas flow characteristics, the temperature distribution, the electrochemical reaction efficiency and the electrical performance of the PEMFCs at operating temperatures ranging from 323 K to 343 K. But in their study the wave like obstacles were located near to the entrance of the gas channel. However, locating these obstacles near to the exit may give better results. In their study, effects of different operating conditions (relative humidity, stoichiometry, etc.) were not investigated.

Biyikoglu and Oztoprak [7] have investigated the effects of baffle blocks in gas channels on the fuel cell characteristics. They showed that the gap between the tip of the block and the gas flow channel wall has an important influence on the current density values. In this study, the optimum gap distance between the tip of the obstacle and the gas flow channel border was analyzed by using one obstacle inside the gas channel. Values of some physical parameters such as thermal conductivity of the membrane used in the analysis are however far away from the values encountered in practice.

The aim of obstacles in gas channels is to decrease the concentration polarization losses at high current densities. When it is needed to run a PEM fuel cell at high current densities, then effects of these obstacles on the cell performance will be important. In this paper, effects of rectangular obstacles inside the anode and cathode gas channels on the performance of a PEM fuel cell is compared with straight gas flow channels. Effects of the different operating conditions (humidity, stoichiometry and temperature) on the performance of the fuel cell have been investigated for these two geometries. The information about operating conditions, used in these analyses, is given in Section 4.

The PEM fuel cell model

The PEM fuel cell model contains one membrane, two catalyst layers (CLs), two gas diffusion layers (GDLs): one for the anode and one for the cathode side. These layers (GDLs, CLs and membrane) together create the membrane electrode assembly (MEA) of the PEM fuel cell. In addition to MEA, gas flow channels are the other parts of the PEM fuel cells.

The membrane has the role of transporting the protons to the cathode side and to prevent the crossover of gaseous hydrogen and oxygen molecules. Each of the gas diffusion layers is coated on one side with a catalyst layer. Hydrogen is provided to the anode side through a flow path created between a current collector plate and the anode side of the MEA. Oxygen or oxidant is provided to the cathode through the flow path created between the cathode current collector plate and the cathode side of the MEA [3].

Model geometry

A 2D schematic illustration of the proposed fuel cell model along the gas flow channel can be seen in Fig. 1. In the anode and cathode gas channels six rectangular obstacles are located near to the channels exit. The first obstacle is located at 20 mm away from the entrance of the anode and cathode gas flow channels. The distance between two centers of obstacles is 5 mm. In Fig. 1 the numbers represent: 1 – anode inlet, 2 – cathode inlet, 3 – anode outlet and 4 – cathode outlet, 5 – anode current collector, 6 – one obstacle in anode gas channel, 7 – anode gas flow channel, 8 – membrane electrode assembly (MEA), 9 – cathode gas channel, 10 – one obstacle inside cathode gas channel, 11 – cathode current collector.

The geometric characteristics of the model are given in Table 1. The membrane electrode assembly (MEA) has an active area of 1.5 cm^2. Physical properties applied in the analysis are summarized in Table 2.

Location of the obstacles near to the exit of the channel, might give better current density values than obstacles near to the entrance of gas channel. Because, if it is examined, the concentration distribution of hydrogen and oxygen, can be easily seen that concentration losses are higher near to the exit of the channel. Therefore, the obstacles are positioned near to the exit of the anode and cathode gas flow channels.

Governing equations

The physical and electrochemical phenomena which occur inside the fuel cell are governed by conservation of continuity, momentum, energy, charge and species [11–15].

The assumptions made in the model are as follows:

1. Steady state, multiphase, 3D model of PEMFC.
2. The membrane is homogeneous and impermeable to the reactant gases.

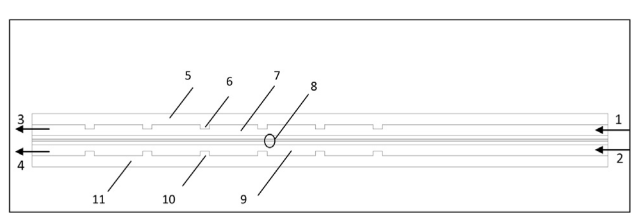

Fig. 1 – 2D view of the model along the gas flow channel with obstacles.