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Full Length Article

Assessment of single-serpentine PEM fuel cell model developed by computational fluid dynamics

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ABSTRACT

In this study, a three-dimensional, single-phase model has been established to investigate the performance of proton exchange membrane fuel cell (PEMFC) with serpentine flow fields. The model was operated in the temperature range of 333–353 K, the pressure range of 1–3 atm, gas diffusion layer (GDL) range of 0.3–0.6, both anode and cathode relative humidity range (RH) of 10–100%. The current density and power density of PEM fuel cell was measured according to these varying operation parameters. The V-I characteristic of PEMFC was obtained for these different values of input parameters. The numerical simulation was realized with a PEM fuel cell model based on the FLUENT computational fluid dynamics (CFD) software. The performance of a PEM fuel cell increases with the increase of operating pressure because of partial pressure and diffusivity of reactant gases resulting in decreasing the mass transport resistance. It is also found that temperature has an important effect on the performance of PEMFC by the results of study. Even though after exceeding a definite temperature cell performance decreases. The results showed that the maximum power density was reached with 0.6 GDL porosity, RH_a = 100% and RH_c = 10% and the value of pressure of 3 atm. Also simulation results were compared with the experimental data reported in literature and showed good agreement between the model and experimental results.

1. Introduction

PEMFCs are one of the most promising energy conversion systems in many applications due to their high efficiency, low emissions, fuel flexibility, reliability, low operating temperature, high power density, low noise and cogeneration capability. The performance of a fuel cell is generally expressed by the polarization curve which gives the relationship between the current density and cell voltage and it is known that it is highly affected by reactant distribution, water and heat management and electrochemical properties mainly determined by the catalyst layer and membrane properties. Fuel cell modeling plays a very significant role in determining the new materials developed, the best configuration for the reactant transport and the optimum operating conditions of the fuel cell.

Heidary et al. [1] numerically studied in the paper, the effect of partial- or full-block placement along the flow channels of PEM fuel cells. In this study, a 3D numerical model consisting of a 9-layer PEM fuel cell was performed. The results showed that the case of full blockage enhances the net electrical power more than that of the partial blockage, in spite of higher pressure drop. Performed studies showed that full blockage of the cathode-side flow channels with five blocks along the 5 cm channel enhances the net power by 30%. Caglayan et al. [2] developed a three-dimensional model for a high temperature polymer electrolyte membrane (PEM) fuel cell having an active area of 25 cm^2. Triple mixed serpentine flow channel single cell with phosphoric acid doped polybenzimidazole (PBI) membrane was used in the model that was simulated at different temperatures ranging from 100 to 180 °C to investigate the influence of operation temperature on the performance of the cell. It was seen that there was an improvement in the performance of the cell as the operation temperature increases. Experimental data was used to validate the model both for single channel and triple mixed serpentine flow channel models at 0.6 V and 160 °C. The temperature influence on high temperature PEMFC performance was more pronounced between 100 and 120 °C than between 160 and 180 °C. Quan et al. [3] presented in their work that 3D numerical simulation of water behavior in part of the serpentine micro-channel for a PEM fuel cell cathode performed by use of commercial computational fluid dynamics (CFD) software, the FLUENT package. It is found from the results that the bend area played an important role in determining water behavior inside a U-shaped micro-channel. Also the simulation results showed that the after-bend water distribution might block the reactant supply to the reaction sites, therefore the fuel cell

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Nomenclature

A	area (m^2)
E	voltage (V)
F	Faraday constant (C mol^{-1})
I	local current density (A)
n	number of electrons transferred
P	pressure (Pa)
R	gas constant ($kj\ kg^{-1}\ K^{-1}$)
T	temperature (K)
u	velocity (ms^{-1})
X	mass fraction

Greek symbols

ζ	stoichiometry

Subscripts and superscripts

a	anode
c	cathode
ch	channel
e	electron
H_2	hydrogen
in	inlet
MEA	membrane electrode assembly
O_2	oxygen
ref	reference

performance decreased. Alizadeh et al. [4] in their study introduced a new cascade type serpentine flow field to determine their effects on important parameters such as current density, temperature distribution and water saturation. The results suggested that the flow field with channel, rib and depth of 1.2, 0.8 and 0.8 mm, respectively, showed the best performance. Furthermore, the single phase model was compared with the two-phase one and experimental results. Freire et al. [5] investigated the effect of operational parameters on the performance of PEMFCs by using serpentine flow field channels with different (rectangular and trapezoidal) cross-section shape. More than cell temperature and pressure, reactant humidification temperature had a significant influence on the effect of serpentine channels with trapezoidal cross-section on cell performance. Also it was found that the effect of on the performance of the cell with serpentine channels with rectangular cross-section was negligible. In addition to bipolar plate geometric parameters, operational parameters such as temperature and pressure, and GDL components such as PTFE had a strong influence on water management and fuel cell performance. Salva et al. [6] have used a one dimensional analytical model in order to optimize the operating conditions of a PEM fuel cell. The fuel cell used in experimental study was a 50 cm^2 active area with five-channel serpentine flow fields. The model was implemented in the commercial software EES (Engineering Equation Solver) which is a general equation-solving program that can numerically solve systems of coupled non-linear algebraic and differential equation. At the end of the study, the operating conditions obtained with the validated analytical model have been tested in the real cell in order to check the accuracy of the numerical results, obtaining a very good agreement between numerical and experimental results. [7] Experiments with different fuel cell operating temperatures, different cathode and anode humidification temperatures, different operating

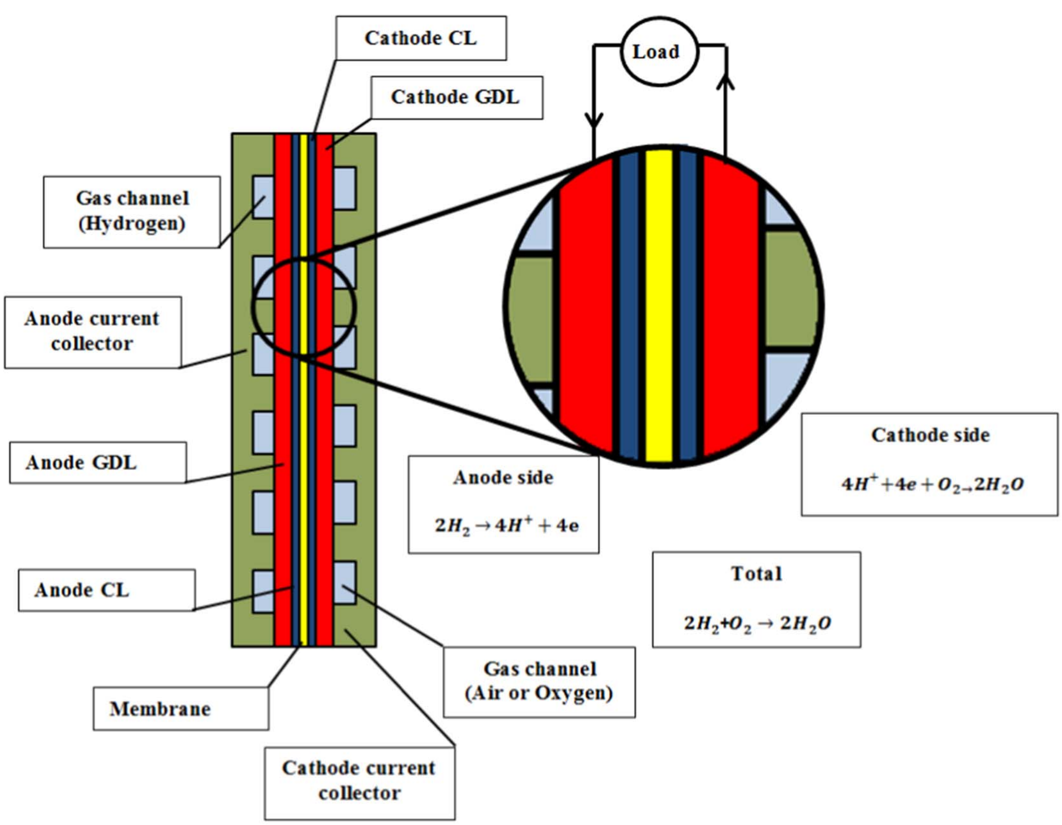

Fig. 1. A schematic view of single channel PEM fuel cell components.