PERFORMANCE STUDIES ON 25×25 cm^2 REACTIVE AREA SERPENTINE FLOW FIELD PROTON EXCHANGE MEMBRANE FUEL CELL WITH DIFFERENT CELL POTENTIALS

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ABSTRACT

This numerical study focuses on the performance enhancement of the Polymer Electrolyte Membrane Fuel Cell (PEMFC) with serpentine flow fields through optimization of the various cell potentials. Multiple path serpentine flow-field design was used for studying the effect of cell potential on the performance of the 25×25 cm^2 reactive area Proton Exchange Membrane Fuel Cell. Numerical simulations were effectively carried out for different cell potentials likely from 0.4V to 0.9V respectively. Numerical analysis shows that the better current density as well as power density has achieved at a cell potential of 0.4V. Studies on the effect of various cell potentials showed that lower operating voltages increase in the current density of the cell.

Keyword: - *PEMFC; performance; Serpentine flow field; Cell potential; Current densities; Power densities.*

1. INTRODUCTION

The polymer electrolyte membrane fuel cell (PEMFC) is one of the most promising candidates as a clean power source for electric vehicles or combustion engines in automotive transport, because of its high energy conservation efficiency, the possibility of using regenerative fuels, low or zero levels of noxious emissions of environmental pollutants, a low operating temperature, and a relatively quick startup [1]. A polymer electrolyte membrane fuel cell (PEMFC) is regarded as an interesting technology, especially for portable electrical devices, e.g., automobile, laptop, and mobile phone, because it can be operated at low temperatures and offers low weight and volume and high power density [2]. Over the past few years, the importance of water management to the successful operation of polymer electrolyte membrane (PEM) fuel cells has stimulated an extensive research focus on liquid water transport and its effect on performance and durability [3]. An optimum flow rate was essential for shallow channel depth to maintain sufficient pressure to force reactant into channel and also to have proper water balance [4]. The Serpentine flow field with small channel and rib size would perform the best at low operating voltages. Besides, it has been concluded that additions such baffles improve the performance of different types of flow channel designs [5]. In the case of flow fields with serpentine gas flow channels and at high operating voltages, the performance of a PEM fuel cell can be improved as the height to width channel ratio increases [6]. In order to solve the misdistribution of the reactants, serpentine flow field geometry has been proposed. In this design the reactant gas is forced to flow through a single path which may consist of one or more flow channels that extent over the entire active surface area. This configuration increases both, the flow speed and the pressure drop enhancing water and heat management by transporting the two-phase water through the channels [7]. In serpentine flow fields, it was shown that increasing the number of channels, channel length and the number of turns, favours the electrochemical reaction, reducing unreacted fuel at the exit and, therefore, increasing the fuel cell performance [8-9]. A serpentine flow field design is proposed that would set the appropriate pressure drop along the channel flow so that any liquid water generated inside the cell will be eliminated or evaporated through gas streams, thus preventing PEMFC malfunction by flooding. At the same time, the gas flow in the flow channel was kept completely saturated in order to prevent the membrane dehydration [10]. So, it is clear that there is a necessary need of investigating the instantaneous effect of various operating and design parameters. In this numerical investigation, the serpentine flow fields PEMFC for six different cell potentials were analyzed to study the effect of different cell potentials on the performance of PEM fuel cell.

2. MODELING &ANALYSIS

The commercial existing COMSOL Multiphysics software is used to generate and analyze the complete model of serpentine floe field PEM fuel cell. The whole three dimensional model is shown in figure.1. A fuel cell with 25×25 cm^2 reactive area serpentine flow field model square cross-section was considered. In general the PEM fuel cell was consisting of seven layers like membrane, anode and cathode catalyst layers, anode and cathode Gas Diffusion Layers (GDL), anode and cathode flow channels. The entire three dimensional model generation is taking place with the "PEMFC adding domains" in the COMSOL software. By using "forward-looking description domains", the required modeling terms were produced with respect to the relevant geometry parameters (Thickness, Length, height, width, etc.). The Cartesian coordinates were used to refer to the whole geometry in the necessary coordinate location. Finally the complete three dimensional model of serpentine flow field PEMFC had been created by reclaiming the data from modeling terms table in the software. Next the different operating parameters like Lumped anode resistance, membrane resistance, Cell temperature, Oxygen reference concentration, GDL Porosity, GDL permeability, membrane conductivity, GDL electric conductivity, Hydrogen molar mass, water molar mass, Oxygen molar mass, inlet mass fraction of H_2, inlet mass fraction of O_2 and inlet mass fraction of H_2O, inlet velocity, fluid viscosity, Nitrogen molar mass, water molar mass, Oxygen molar mass, N_2-H_2O binary diffusion coefficient, O_2-N_2 binary diffusion coefficient, O_2-H_2O binary diffusion coefficient, reference pressure and cathodic transfer coefficient were taken into account for the complete numerical analysis on serpentine flow field PEMFC under six cell potentials. The PEMFCs were functioned at a temperature of 50°C and an operating pressure of 1.5 bar respectively.

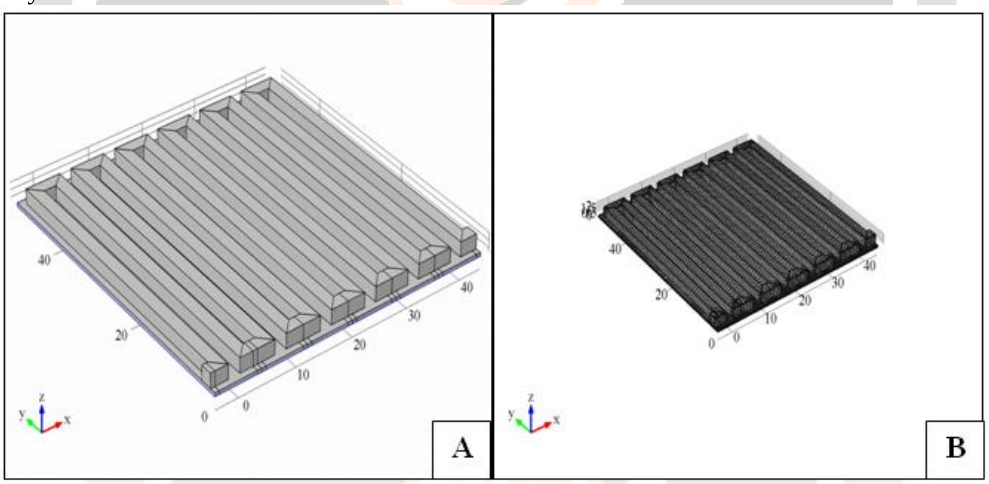

Fig-1: Serpentine flow field PEMFC (A) 3D model (B) Mesh model

3. RESULTS AND DISCUSSIONS

The serpentine flow field PEM fuel cell with seven layers namely membrane, anode and cathode catalyst layers, anode and cathode GDL, anode and cathode flow channels were functioned at the same operating conditions of 60°C temperature and 2.0 bar pressure. The current density (I) is the current engendered per unit active area, i.e. the ratio between the current that can be drawn from the cell equivalent to the particular voltage and the unit active area of the fuel cell. The power density (P) is the ratio between the power generated from the cell corresponding to the certain voltage and the unit active area of fuel cell. The polarization curve is the curve drawn between the current density and the voltage, whereas the power density curve is the curve drawn between current density and the power density. These polarization curves and power density curves are used to find the efficiency of the fuel cell system. The whole three dimensional serpentine flow field PEM fuel cell with various components like membrane, anode and cathode catalyst layers, anode and cathode GDL, anode and cathode flow channels was operated at the similar operating conditions of 60°C temperature and 2.0 bar pressure. In the beginning the serpentine flow field PEMFC with a cell voltage of 0.4V was involved and analyzed at the above mentioned operating parameters to evaluate the maximum current and power density.

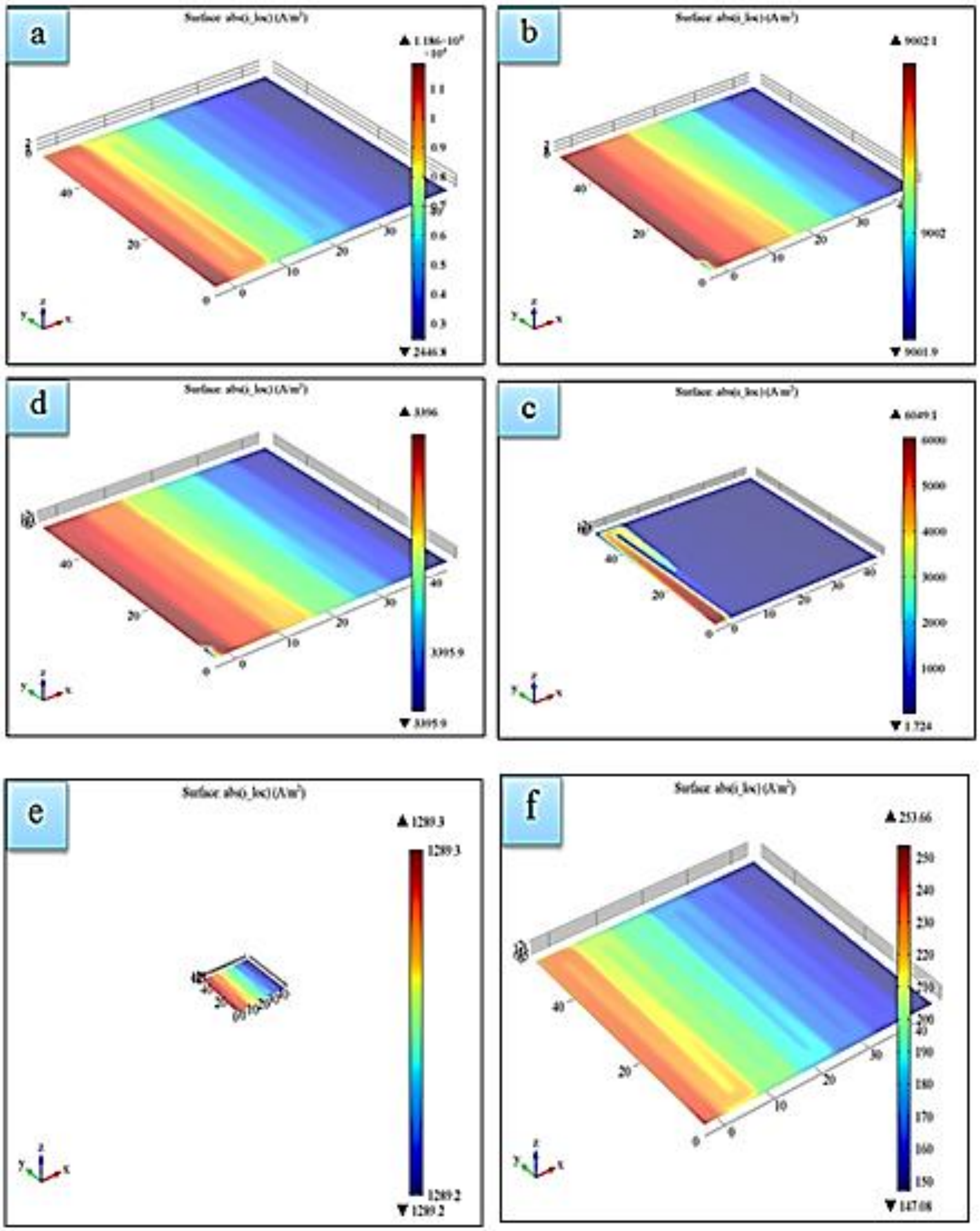

Fig-2: Current density of serpentine flow field PEMFC at cell potential (a) 0.4V (b) 0.5V (c) 0.6V (d) 0.7V (e) 0.8V (f) 0.9V

The maximum power density of 0.4744 W/cm^2 was obtained corresponding to the cell potential of 0.4V at a temperature 60°C. The corresponding peak current density was 1.18600 A/cm^2. Next serpentine flow field PEMFC with a cell voltage of 0.5V was involved and analyzed for the above mentioned operating parameters to evaluate the maximum current and power density. The maximum power density of 0.450105 W/cm^2 was obtained corresponding to the cell potential of 0.5V at a temperature 60°C. The corresponding peak current density was 0.90021 A/cm^2. Next serpentine flow field PEMFC with a cell voltage of 0.6V was involved and analyzed for the above mentioned operating parameters to evaluate the maximum current and power density. The maximum power density of 0.60491 W/cm^2 was obtained corresponding to the cell potential of 0.6V at a temperature 60°C. The corresponding peak current density was 0.362946 A/cm^2. Next serpentine flow field PEMFC with a cell voltage of 0.7V was involved and analyzed for the above mentioned operating parameters to evaluate the maximum current and power density. The maximum power density of 0.23772 W/cm^2 was obtained corresponding to the cell potential of 0.7V at a temperature 60°C. The corresponding peak current density was 0.33960 A/cm^2. Next serpentine flow field PEMFC with a cell voltage of 0.8V was involved and analyzed for the above mentioned operating parameters to evaluate the maximum current and power density. The maximum power density of 0.103144 W/cm^2 was obtained corresponding to the cell potential of 0.8V at a temperature 60°C. The corresponding peak current density was 0.12893 A/cm^2. Next serpentine flow field PEMFC with a cell voltage of 0.9V was involved and analyzed for the above mentioned operating parameters to evaluate the maximum current and power density. The maximum power density of 0.022824 W/cm^2 was obtained corresponding to the cell potential of 0.8V at a temperature 60°C. The corresponding peak current density was 0.02536 A/cm$^{2.}$ The power density and polarization curves for all six cell potentials were showed in Fig.4 in which the current density values (I) were taken in x-axis and the cell potential (V), Power density (P) was taken in y-axis. From the polarization curves, it was found that the serpentine flow field PEMFC at a cell potential of 0.4 V has produced the maximum current density compared to other five cell potentials. From the power density curves, it was found that the serpentine flow field PEMFC with a cell potential of 0.4 V produced maximum power density compared to other five cell potentials.

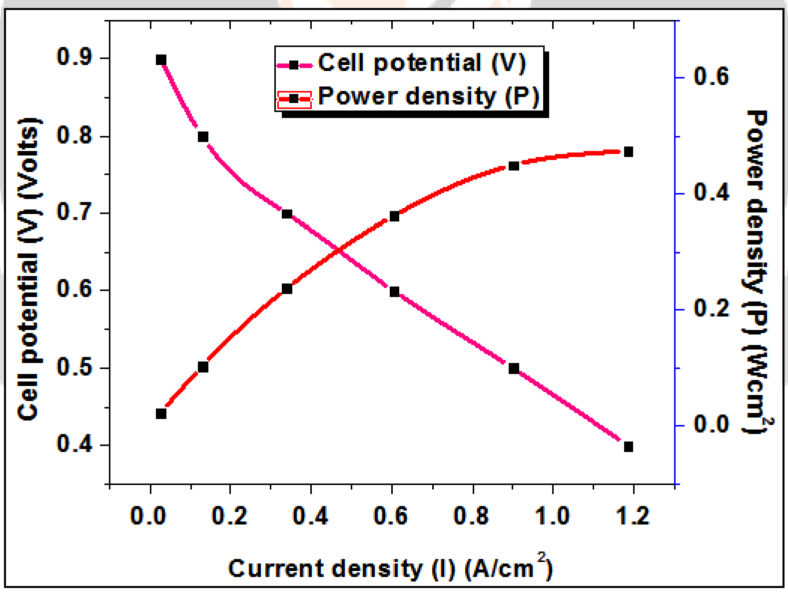

Fig-3: Power density and Polarization curves of all cell potentials

4. SUMMARY

The entire three dimensional 25×25 cm^2 reactive area serpentine flow field proton exchange membrane fuel cell is numerically analyzed using commercial existing software package to investigate its performance under six different cell potentials. The six dissimilar cell potentials and current densities were considered for this analysis. Apart from the cell potentials and current densities, all other modeling and operational parameters were retained same for all the analysis. From these numerical investigations it can be concluded that the serpentine flow field PEMFC with a cell potential of 0.4V has made the superior performance with peak power density of 0.4744 W/cm^2 and peak current density of 1.186 A/cm^2 paralleled to other five cell potentials. Due to the better water management at a cell potential of 0.4V the performance of the serpentine flow field PEMFC is better at 0.4V compared than five cell potentials.

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