Evaluation of PEM Fuel Cell Performance with Single Flow Channel Configuration

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***Abstract*—Proton exchange membrane (PEM) fuel cell engines can potentially replace the internal combustion engine for transportation because they are clean, quiet, energy efficient, modular, and capable of quick start-up. Water generation on cathode side is affecting performance of the Fuel Cell, the water generation is influenced by design & operating parameters. In this project PEM Fuel Cell with single flow channel is modeled & analyzed for various operating parameters to enhance the performance of the fuel cell. As an illustration, the model is applied to an isothermal, steady state, three-dimensional PEM fuel cell at different operation voltages to investigate the fuel cells performance parameters such as the polarization curve, Ionic current density distribution in the polymer membrane, hydrogen concentration at the anode side, oxygen concentration at the cathode side, water concentration at anode side & cathode side. All of the model equations are solved using commercial software package COMSOL Multi physics 4.2.**

Keywords— PEMFC, single flow channel, performance, COMSOL.

I. INTRODUCTION

J. Larminie et al. [1] reported that the Proton Exchange Membrane (PEM) fuel cell has been regarded as an ideal power source for a variety of applications due to its significant advantages, i.e., high efficiency, low emission, silence and simplicity. Z.H. Wang et al. [2-5] reported that the water management is currently considered as one of the crucial issues to be fully understood and optimized before a successful commercialization of PEM fuel cells, since sufficient amount of water is necessary for maintaining the membrane ion conductivity whereas excess water, or water flooding, may block the porous electrodes and flow channels, reducing the reactant mass transfer to catalytic sites.

A.P. Manso et al. [6] reported that the flow field geometric configuration has little influence on the overall PEM fuel cell performance at high operation potentials. On the contrary, at low operation potentials, it significantly affected. The flow fields that offer a lower pressure drop generally shows lower performance. With serpentine and interdigitated flow fields, it can generally achieve more uniform reactants distribution. Although the elimination of condense water in the cathode is improved, the energy required to drive the gas increases, reducing the overall performance of the PEMFC. In serpentine type flow fields, longer straight channel segments between channel bends and narrower channels enhance convection. Also, contrary to what can be expected, an increase in the active area of the MEA results in a decrease of current density.

Hsieh et al. [7] compared the effects of different parameters on three flow fields of 5 cm^2 with three different geometries. Serpentine, interdigitated and mesh or pin type. They reported similar behaviors for all the microcells regarding variations in temperature and back pressure and confirmed that such behaviors were similar to those expected for a conventional PEMFC. They concluded that the flow field with interdigitated type channels yielded a better performance, although a lower pressure drop was found for mesh type flow channels at a fixed active area of the MEA.

Hu Guilin et al. [8] numerically analyzed a new type of flow field, called slotted-interdigitated channel, based on interdigitated channel. In order to reduce the pressure drop of interdigitated flow channel, small slots were designed at the reactant flow field side. However, CFD simulation results showed that an arbitrary design of the slots causes severe flow misdistribution. To resolve this problem, the number of slots was decreased to two and alternatively positioned every two neighboring channels. An analytical model was used to optimize the plate dimensions. Finally, even flow distribution was obtained according to optimum results and high fuel cell performance was achieved.

Karthikeyan.P et al. [9] numerically analyzed the both operating and design parameters of single flow channel of PEMFC namely cell temperature, back pressure, anode and cathode inlet velocities, Gas Diffusion Layer (GDL) porosity and thickness, cathode water mass fraction, flow channel dimensions, rib width and porous electrode thickness. The Numerical model of single channel PEM fuel cell was developed and analyzed by using COMSOL Multiphysics 4.2 software package. The optimization of design and operating parameters in software was carried out in two stages using standard orthogonal array of Taguchi method. From the first stage of analysis, it was inferred that back pressure had maximum effect and rib width had least effect on fuel cell performance. In the second stage of analysis, fine tuned optimization was performed on selected factors which caused for 3 % increase in power density and the results were also validated using COMSOL Multiphysics 4.2.

Maharudrayya.S et al. [10] A comparative study of simple serpentine, multiple serpentine, simple parallel, parallel types U, symmetrical in U, parallel in series and interdigitated flow fields, reflected that geometric configurations with smaller pressure drop present high a non-uniformity behavior. In other words, geometric configurations that showed large surface active areas (narrow rips) do not receive sufficient amounts of reactants because of their misdistribution. Therefore, although pressure drop in a fuel cell is one of the major determinants of its global efficiency, homogeneous distribution of reactants on the active area is essential to obtain an optimal cell performance.

Thitakamol et al. [11] the performance of a PEM fuel cell with a mid baffle interdigitated cathode flow field with 50.41 cm^2 active area was experimentally investigated. Results were compared to those of a conventional interdigitated flow field. In both cases, a conventional interdigitated flow field was placed in the anode. When the oxidant reactant gas was oxygen, both geometries presented a similar performance. On the other hand, when air was used and depending on the air flow rate, the maximum power output of the mid-baffle interdigitated flow field was nearly 1.2e1.3 times that of the conventional one. Polarization curves in the latter case showed large limiting current densities at every flow rate used. Finally, the experimental study also demonstrated that increasing the oxidant gas flow rate and operating pressure, the PEMFC performance can be enhanced.

Wang et al. [12] numerically analyzed the effect of the cathode flow channel area ratio on a PEMFC with parallel and interdigitated flow channel designs, for five different flow channel area ratios (flow channel to total reaction area ratios): 0.3, 0.4 0.522, 0.6 and 0.7. Results showed that, for parallel flow channel designs, fuel is driven into the GDL and CL mainly by diffusion. So that, the greater the flow channel area ratio was, the better the cell performance mainly due to the increase of the contact area between the fuel and the GDL. It was also found that for interdigitated flow channels the flow channel area ratio is not a critical value to be considered due to its less effect. The baffle configuration in the interdigitated flow fields forced the fuel into the porous layers enhancing fuel participation in the electrochemical reaction. This effect not only increased the fuel transport rates, but also enhanced the liquid water removal, increasing PEM fuel cell performance.

Wang and Liu et al. [13] used an interdigitated flow field of 50 cm^2 active areas to study the effect that the fuel cell temperature, the humidification of the reagents, the pressure of the gases and stoichiometry had over the PEMFC performance.

Yan Wei-Mon et al. [14] reported that the bipolar plates are one of the key components of a fuel cell, since they perform different functions that are essential for an effective performance of the system. Although some of these functions are better associated with physical-chemical and fluid-dynamic phenomenon, they are closely related with the BPs themselves, and with the flow channel geometry in particular. Thus, they provide the necessary mechanical support for the stack, keep the different reactants isolated from each other distributing them on the catalyst surface of the MEA through the gas diffusion layer, and help to manage the water and heat generated inside the cell. Therefore their design can reach a significant impact on the performance and power density obtained from a PEMFC. Increases up to 50% in produced power density have been described only with an optimal design of the flow field of reactants.

Yang Ching-Hung et al. [15] analyzed flow fields with an active area of 198 cm^2 with parallel, serpentine and interdigitated type channels were used. It was found that the former flow field design displayed better performance than the parallel flow field as it forces reactive gases to pass through gas diffusion layers (GDLs).In addition, it was shown that a fuel cell with interdigitated flow field can perform similarly to another cell with parallel channels geometry, but with a lower fuel consumption.

II. MODELING

Modeling of single flow channel PEM fuel cell is created in design domain which is available in COMSOL Multiphysics software. Different design parameters such as channel length, channel height, channel width, membrane thickness, etc are used to create the complete three dimensional model which is given in fig.1. Complete mesh model of single flow channel PEMFC is given in fig.2.

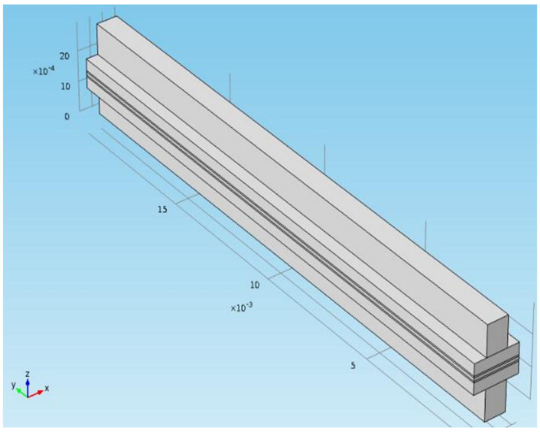

Fig. 1 Isometric model of single flow channel PEM Fuel Cell

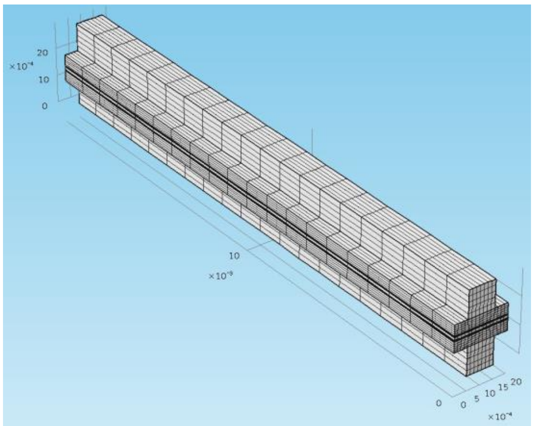

Fig.2. Mesh model of single flow channel PEM Fuel Cell

III. RESULTS & DISCUSSIONS

The following results have been obtained from COMSOL Multiphysics software under the operating voltage at 0.4 V.

A. Cell voltage vs cell average current density

Fig.3 shows the polarization plot of the cell. At the starting stage the fuel cell voltage is very high around (0.9 V) and it is gradually reduced with the increasing cell average current density. Maximum current density obtained in this analysis is around (0.9 A/cm^2).

B. Ionic current in the polymer membrane

Fig.4 shows the ionic current in the *z* direction at the center of the membrane for 0.4 V. In the *y* direction the current density is lower towards the outlet (due to lower reactant concentrations).In the *x* direction the currents density is highest in the region close to the channel, where the reactant concentrations are higher, but the current density is reduced towards the very center of the channel. This is due to Ohmic drops in the GDLs.

C. Hydrogen concentration at the anode

Fig.5 shows the hydrogen concentrations for the same voltage level. For the anode the trend is the same but the hydrogen concentration level is more uniform.

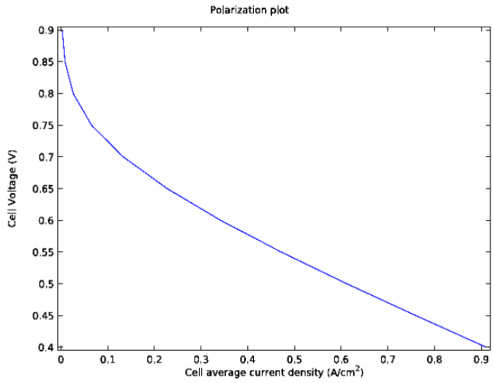

Fig.3. Polarization plot

D. Oxygen concentration at the cathode side

Fig.6 shows the oxygen concentrations for the same voltage level. The oxygen concentration is significantly lower in the porous electrode and towards the end of the flow channel compared to the inlet level.

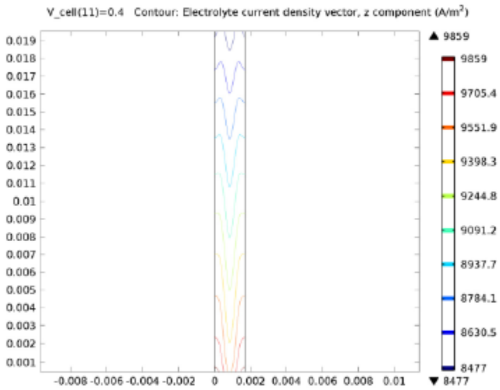

Fig. 4. Ionic current in the polymer membrane at 0.4 V

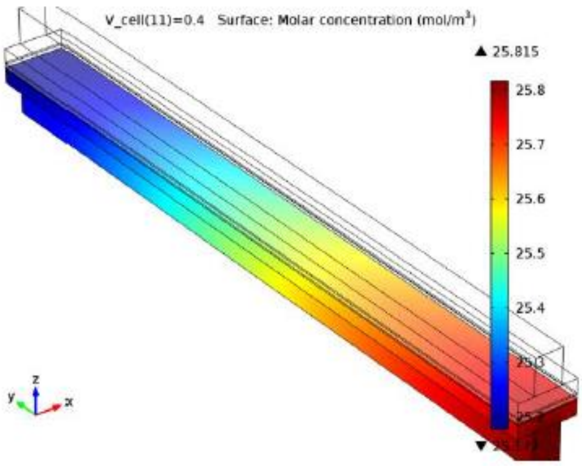

Fig.5. Hydrogen concentration at the anode in the cell at 0.4 V

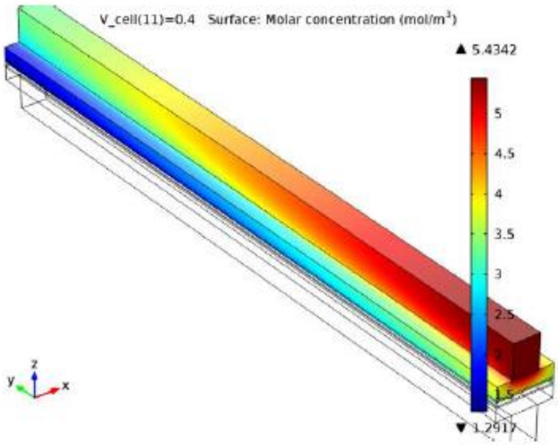

Fig.6. Oxygen concentration at the cathode in the cell at 0.4V

E. Water concentration at anode & cathode side

Fig.7 and Fig.8 shows the water concentration in the cell for the same voltage level. The concentration increase due to water production at the cathode is much larger than the effect of removing hydrogen from the gas stream at the anode for these flow and current levels.

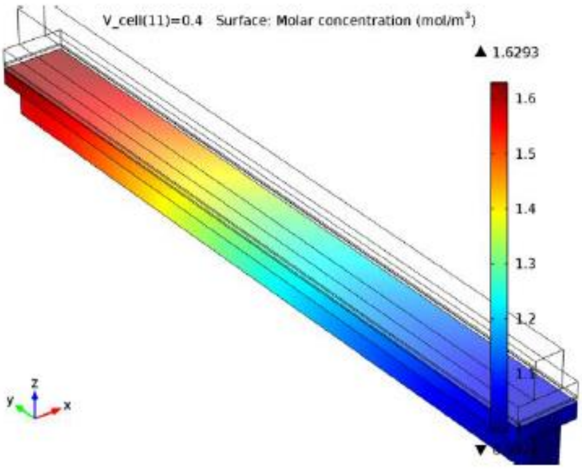

Fig.7. Water concentration on the anode in the cell at 0.4V

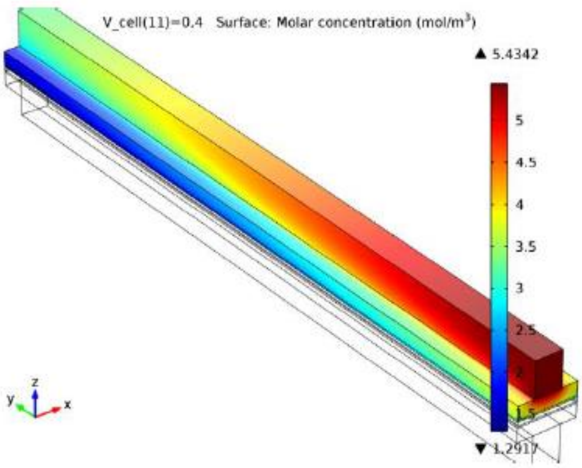

Fig.8. Water concentration at the cathode in the cell at 0.4 V

IV. SUMMARY

The single flow channel shape and size were considered for the analysis in PEM fuel cell. Various flow parameters, Cell average current, Hydrogen concentration at the anode in the cell, Oxygen concentration at the cathode in the cell, Water concentration on the anode in the cell, Water concentration at the cathode in the cell are analysed. Maximum and minimum ionic current densities in the polymer membrane are 0.9859 A/cm^2 & 0.8477 A/cm^2. Hydrogen concentration at the inlet of the cell in anode side is comparatively high with respect to the outlet of the cell. (Maximum value of 25.815 mole / m^3 & Minimum value of 25.17 mole / m^3). Oxygen concentration at the inlet of the cell in cathode side is comparatively high with respect to the outlet of the cell. (Maximum value of 5.4342 mole / m^3 & Minimum value of 1.2917 mole / m^3). Compare with cathode side water concentration on the anode in the cell is gradually increases with respect to its flow (Maximum value of 1.6293 mole / m^3 & Minimum value of 0.9921 mole / m^3). Compare with anode side water concentration on the cathode in the cell is gradually decreases with respect to its flow (Maximum value of 5.4342 mole / m^3 & Minimum value of 1.2917 mole / m^3). These above results are given based on numerical analysis done in COMSOL Multiphysics 4.2 software.

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