Performance Improvement of PEM Fuel Cell with in Serpentine Flow Channel Used in COMSOL

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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 serpentine flow channel is modelled & analyzed for various operating parameters to enhance the performance of the fuel cell. This project presents a comprehensive, consistent and systematic mathematical modelling for PEM fuel cells that can be used as the general formulation for the simulation and analysis of PEM fuel cells. As an illustration, the model is applied to an isothermal, steady state, three-dimensional, serpentine flow channel PEM fuel cell at different operation voltages to investigate the fuel cells performance parameters such as the oxygen concentration, the velocity distribution of reactant, GDL velocity distribution, pressure distribution, cathode current density distribution, and polarization curve. All of the model equations are solved with finite element method using commercial software package COMSOL Multi physics 4.2. The results from PEM fuel cell modeling for serpentine flow channel at different operation voltages are then compared with each other. Best PEMFC model will be validated experimentally.**

Keywords: **Pemfc, performance improvement, CFD, COMSOL.**

I. INTRODUCTION

A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent.Hydrogen is the most common fuel, but hydrocarbons such as natural gas and alcohols like methanol are sometimes used.

stroke method by using the solid work software. It is to use in the suction and compression purpose. So use to convert engine into air compressor by overcome in the overlapping problem. It is to allowing the exhaust air so there is no compress in the engine. Fuel cells are different from batteries in that they require a constant source of fuel and oxygen to run, but they can produce electricity continually for as long as these inputs are supplied.

Fuel cells come in many varieties; however, they all work in the same general manner. They are made up of three adjacent segments: the anode, the electrolyte, and the cathode.

Two chemical reactions occur at the interfaces of the three different segments. The net result of the two reactions is that fuel is consumed, water or carbon dioxide is created, and an electric current is created, which can be used to power electrical devices, normally referred to as the load.

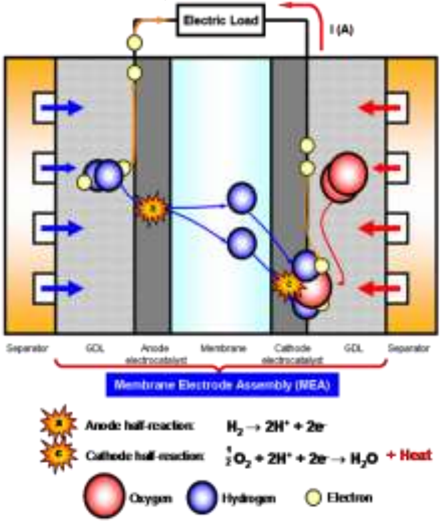

Figure 1.1 Fuel cell working process

1.1 Types of fuel cell: Fuel cells are classified primarily by the kind of electrolyte they employ. This classification determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors. These characteristics, in turn, affect the applications for which these cells are most suitable. There are several types of fuel cells currently under development, each with its own advantages, limitations, and potential applications.

- Polymer Electrolyte Membrane (PEM) Fuel Cells
- Direct Methanol Fuel Cells
- Alkaline Fuel Cells
- Phosphoric Acid Fuel Cells
- Molten Carbonate Fuel Cells
- Solid Oxide Fuel Cells
- Regenerative Fuel Cells

1.2 Info PEM fuel cell:

Polymer electrolyte membrane (PEM) fuel cells—also called proton exchange membrane fuel cells—deliver high-power density and offer the advantages of low weight and volume, compared with other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or on-board reformers.

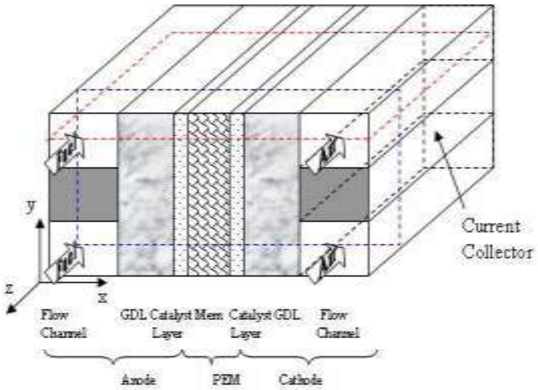

Figure 1.2 Polymer Electrolyte Membrane (PEM) Fuel Cell

2.Litrature survey:

Choi et al [1] studied the influence of different channel heights and widths on the performance of a PEMFC with multiple serpentine flow field. Seven 25 cm^2 flow field patterns of 5-passes and 4-turns with different channel widths and heights were numerically simulated. The obtained results showed that as the channel height increases, the pressure drop is decreased because of the increase in cross sectional area of the gas flow. This effect caused accumulation of liquid water at the outlet, slightly reducing the cell performance. On the other hand, as the channel width increases, the cell voltage decreases in large extend, compared to the cell voltage values observed when increasing the channel height. Membrane dehydration occurred with wider channel configurations, whereas the oxygen mass fraction in under-rib regions increased as convection was enhanced. Electrochemical reaction increased water content, however the actual channel configurations showed poor water removal affected by the lack of back diffusion effect.

Feser et al [2] analyzed the channel length and the numbers of channels are two of the most influential geometric parameters on the fuel cell performance, especially in serpentine flow fields. Several studies analyzed the reactants convective flow under the rib. The former work concludes that, in single-serpentine flow field geometry, the percentage of flow travelling through the GDL is directly related to the material and geometric parameters of catalytic layers where the electrochemical reactions occur. On the other hand, part of the reactants flow away from the gas diffusion layers and do not participate in such reactions. As a consequence, concentration losses and the amount of unreacted gas at the outlet of the cell increase, which reduces the efficiency of the system.

Hsieh et al [3] compared the effects of different parameters on three flow fields of 5 cm2 with three different geometries (Serpentine, interdigitated and mesh or pin type. They reported similar behaviours for all the microcells regarding variations in temperature and back pressure and confirmed that such behaviours 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.

Hwang et al [4] analyzed the influence of the of operation temperature on the performance of the PEMFC using plates with 25 cm^2 of active area, with single serpentine electrolyte membrane is essential to obtain the maximum power of a PEM type fuel cell as a complete hydration is required to allow good proton conduction. However, for low temperatures PEMFC and under certain operating conditions high humidification of the reactants, and high current densities, the gases inside the cells become oversaturated with water vapour which may condense in the cathode side resulting in a lower power output. Hydration of the MEAs can be achieved by moisturizing the reactive flows.

Karthikeyan.P et al. [5] 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.

Kumar et al [6] workout the, serpentine, parallel, multi-parallel and discontinuous flow channels were analyzed at PEMFC voltage values of 0.66, 0.64, 0.68 and 0.71 V, respectively, and a fixed current density of 5000 Am^2 , to study the steady and transient (by changing the load level current from 5000 to 8000 Am^2) behaviour of the PEM fuel cell. This work shows that in a steady state PEMFC performance the discontinuous design will perform better than the other three designs. The reason is that the discontinuity of the channels forced the gas into the GDL, thus converting the transfer of reactant through the GDL from diffusion to diffusion and convective, and thereby, increasing the local effective pressure of reactant at the reaction interface. However, it was found that the best PEMFC performance in transient response was for the parallel flow field design, showing the lower performance in a steady-state conduct. Thus this study determined that the use of the design is closely related to the type of PEMFC application.

Maharudrayya et al [7] analyzed 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 non-uniformity behaviour. 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.

Owejan et al [8] studied multiple serpentine PEMFC performance with flow fields of 50 cm active area, cross flow configurations and 0.52 mm^2 rectangular and triangular cross section channels. Variations were also made on the diffusion media properties (Toray and SGL gas diffusion layers) to evaluate the effects on the overall volume and spatial distribution of accumulated water. The study showed different in-plane permeability of the diffusion layers is responsible for the convective flow. Thus, Toray layers which showed the highest in-plane permeability enhanced gas water slugs, at low current densities. However SGL materials showed higher in-plane pressure drop, thus enhancing the convective removal of liquid water. Concerning the flow channels geometry, they concluded that triangular shape retains less water than rectangular channels of the same cross-sectional area, and water is accumulated in the corners adjacent to the GDL.

Roshandel et al. [9] carried out a comparative study was carried out between parallel, serpentine and a new bipolar plate design inspired from the existed biological fluid flow patterns. The results indicated that the bio inspired pattern showed more uniform fuel rates and pressure profiles on catalyst surface. With the new design, the obtained power density was higher than serpentine and parallel flow channels; up to 26% and 56% respectively.

Wang Xiao-Dong et al [10] carried out an optimization method for a single serpentine PEM fuel cell, with 5 channels of 81 mm^2 active area, was proposed by varying the height flow channel. This geometrical variable was only applied in the cathode, maintaining slightly similar the anode flow channel in order to keep a constant channel section. An optimized geometry allows an increase in the cell output power by 11.9 over that of a cell with straight channels. The optimal model is composed of three tapered channels (channels 2e4) and a final diverging channel (channel 5). According to the authors, the convergent channels improve the main channel flow and sub-rib convection, both increasing the local oxygen transport rate and, hence, local electrical current density.

Yang et al [11] carried out a study on a multiple serpentine type flow field with 5.29 cm^2 active area, investigated the influence of reduction of the outlet channel flow area reduction on PEM fuel cell performance and local transport phenomena. They concluded that, the reactant transport, reactant utilization and liquid water removal were enhanced in comparison with a conventional serpentine flow field as the reduction of the outlet channel flow area was greater. Nevertheless, the pressure drop also increased, reducing the global performance of the cell. Concerning the pressure losses, the optimal PEMFC performance was obtained at a height contraction ratio of 0.4 (defined as HC/H0) and a length contraction ratio of 0.4 (defined as LC/L0).

3. Problem Identification:

- In serpentine type flow fields, longer straight channel segments between channel bends and narrower channels enhance convection [1-3].
- In PEMFC with serpentine gas flow channels, longer straight channel sections produce higher increases in gas pressure between adjacent channels, which enhances under rib convection and fuel cell performance [5].
- In serpentine gas flow channels, reductions in flow channel height, especially at the cathode outlet, improves the mass transfer towards the diffusing layers, promotes water elimination, enhance the electrochemical reaction and increase the fuel efficiency, allowing better results in fuel cell performance[1-2].
- 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 [5-6].

4. Research methodology:

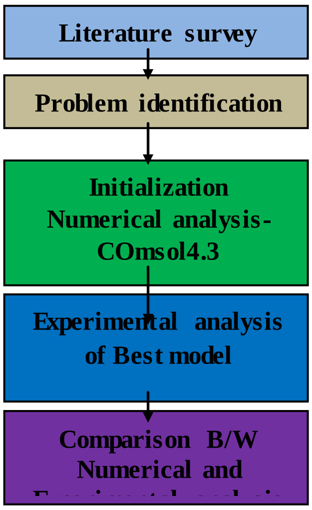

Figure1.3 Methodology process

5. About Model generation:

The design of the fuel cell flow pattern governs the fuel utilization, the current distribution, and the pressure drop in the cell. A common design approach is to use serpentine channels in order to evenly distribute the reacting fluid over the electrode area.

The serpentine design has the advantage of creating a set of parallel channels of equal length and similar flow resistances for a small inlet manifold. However, the design may induce unnecessarily high pressure drops. Also, for low temperature fuel cells, clogging due to water condensation may occur in the serpentine bends.

For the serpentine channel design to work properly, the channel-to-channel cross flow, due to in-plane convection in the underlying porous material layer, should be moderate, since large cross flow may lead to stagnant zones and uneven flow between the channels.

This model describes the cathode air flow and mass transport in three serpentine channels and the underlying gas diffusion layer (GDL) of a polymer electrolyte fuel cell.

The porous cathode is modelled as a boundary condition at the bottom of the GDL domain. The anode, membrane and GDL voltage losses are described using a lumped resistance. The same model parameters are used as in the Mass Transport Analysis of a High Temperature PEM Fuel Cell example.

5.1Model Definition

The model geometry is show in Fig. 1. The model consists of three channel domains and the underlying GDL domain. The channel inlets are on the left and the outlets on the right. The bottom GDL boundary faces the cathode.

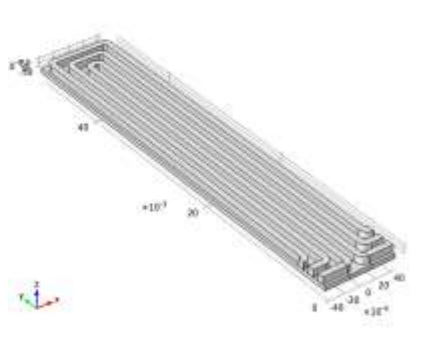

Figure 1.4 pass flow channel model

5.2 Reaction flow process:

The flow and the mass transport are modelled using a Reacting Flow, Concentrated Species interface. This physics interface solves for the fluid velocity and pressures, as well as the mass fractions of oxygen, water and Nitrogen in the air stream. The porous cathode reaction reduces oxygen according to formula reaction

This reaction is modelled as an Electrolyte-Electrode Interface Coupling boundary condition on the cathode boundary. The local current density, i_{loc} (A/cm^2) depends on the oxygen concentration and the local over potential according to the following kinetic expression:

$$i_{\text{loc}} = i_0\left(\exp\left(\frac{\alpha_a}{RT}F\eta_c\right) - \left(\frac{c_{O_2}}{c_{O_2,\text{ref}}}\right)\exp\left(-\frac{\alpha_c}{RT}F\eta_c\right)\right)$$

The Electrolyte-Electrode Interface Coupling boundary sets up the appropriate normal mass flux and flow boundary conditions according the stoichiometric coefficients of the electrode reaction. Inlet/Inflow and Outlet/Outflow are used on the inlet and outlet boundaries, respectively. No slip wall conditions are used for the channel walls, whereas slip conditions are used for the GDL walls. The cathode over potential, η (V), is calculated by relating the cell voltage to the sum of the potential contributions in the various parts of the cell according to

$$\eta_c = E_{\text{cell}} - E_{\text{OCV}} - Ri_{\text{loc}}$$

Where *E*cell (V) is the cell potential, *E*OCV (V) is the open circuit cell voltage and *R* (Ω·cm2) is a lumped effective resistance for the membrane, anode and the GDLs. The current density variable is solved for on the cathode boundary using a Boundary ODEs and DAEs interface.

The mesh is shown in Fig. 2. The bottom channel, and the GDL area between the serpentine bend of the bottom channel have a finer mesh in order to resolve the channel-to-channel cross flow.

Figure 1.5 mesh generation

6. RESULT AND DISCUSSION:

6.1Pressure Distribution:

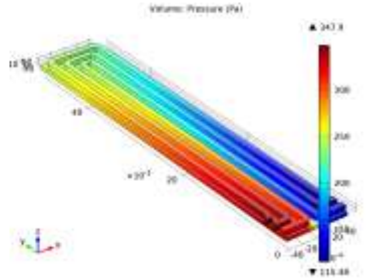

Figure 1.6 Pressure Distribution

Fig.5.1 shows the pressure in the cell. There is a significant pressure difference between the up going and down going parts of the bottom channel.

$$O_2 + 4H^+ + 4e^- \leftrightarrow 2H_2O$$

6.2Velocity:

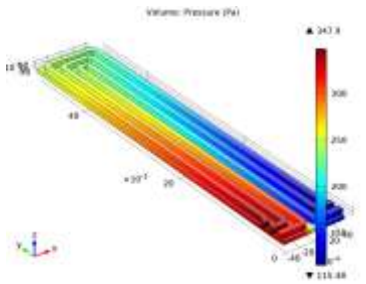

Figure 1.7 Pressure Distributions

Fig.5.2 shows the velocity in the cell. The velocity is highest in the middle of the channels; in the GDL the velocities are generally low. The channel velocity is lowest around the upper end of the down most channels.

6.3 Oxygen Concentration:

Fig.5.3 shows the oxygen distribution in the cell. The oxygen concentration towards the outlet in the down most channels is higher than in the other two channels.

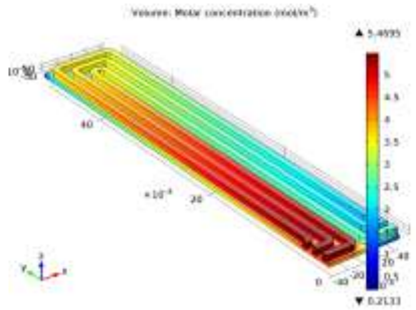

Figure 1.8 Molar concentration

6.4 Velocity In The Gdl:

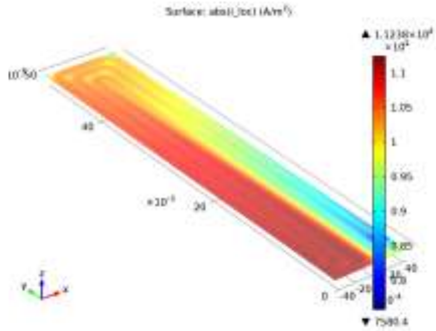

Figure 1.9 Velocity in the GDL

Fig.5.4 shows the velocity distribution in the GDL. The channel-to-channel cross flow velocities is highest between the up going and down going areas of the down most channels. This channel-to-channel cross flow explains the differences seen in oxygen concentration distribution and channel velocities.

6.5 Cathode Current Density:

Comparing the current densities to those found in the Mass Transport Analysis of a High Temperature PEM Fuel Cell example one can see that the current densities are slightly higher in this model. The main reason is that the lumped cell resistance does not account for the voltage losses due to mass transport limitations within the cathode gas diffusion electrode.

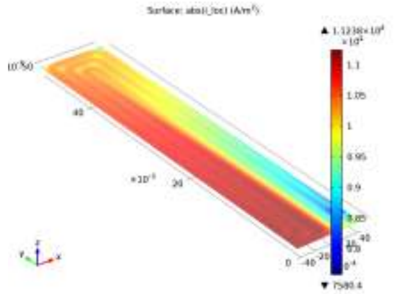

Figure 1.10 Cathode current Density

7. CONCLUSION

- ❖ The serpentine flow channel shape and size were considered for the analysis in PEM fuel cell. Various flow parameters, Oxygen concentration at the cathode in the cell, Velocity, Pressure distribution, velocity in GDL & Cathode current densities are analyzed.
- ❖ The results show maximum and minimum cathode current densities are 1.1238 A/Cm^2 & 0.75804 A/Cm^2.
- ❖ The oxygen concentration towards the outlet in the down most channels is higher than in the other two channels. (Maximum value of 5.4695 mole / m^3 & Minimum value of 0.21133 mole / m^3).
- ❖ These above results are given based on numerical analysis done in COMSOL Multiphysics 4.2 software. However, these results are to be verified by conducting experiments in the actual set ups.
- ❖ The results show maximum and minimum pressure distributions are 347.9 Pa & 115.48 Pa.
- ❖ Velocity is highest in the middle of the channels; in the GDL the velocities are generally low. The channel velocity is lowest around the upper end of the down most channels. Maximum and minimum velocity distributions are 1.407×10^{-4} m/s & 0.0711 m/s.
- ❖ Velocity distribution in the GDL the channel-to-channel cross flow velocities is highest between the up going and down going areas of the down most channels.

Maximum and minimum velocity distributions are 4.9183 m/s & 0 m/s.

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