Performance Analysis of PEM Fuel Cell with Six Pass Serpentine Flow Field under Various Operating Voltages

R.Girimurugan
Assistant Professor
Department of Mechanical Engineering
Nandha College of Technology,
Erode, Tamilnadu, India-638052.
giri2621988@gmail.com

R.Kishor kumar
UG Scholar- Final Year
Department of Mechanical Engineering
Nandha College of Technology
Erode, Tamilnadu, India-638052.

D.Gowsal
UG Scholar- Final Year
Department of Mechanical Engineering
Nandha College of Technology
Erode, Tamilnadu, India-638052.

E.Manoj
UG Scholar- Final Year
Department of Mechanical Engineering
Nandha College of Technology
Erode, Tamilnadu, India-638052.

P.Jayaprakash
UG Scholar- Final Year
Department of Mechanical Engineering
Nandha College of Technology
Erode, Tamilnadu, India-638052.

Abstract— **Performance of a Polymer Electrolyte Membrane (PEM) Fuel Cell is purely depends upon the design and various operating parameters. The reactants are uniformly distributed throughout the active area of the PEM fuel cell through the flow channels. Serpentine flow field gives better performance to the PEM fuel cell. In this research numerically investigates the effects of PEM fuel with six pass serpentine flow field under different operating voltages (0.35V- 0.95V). The six pass serpentine flow field design is modelled and analyzed using COMSOL 4.2 Multiphysics software. The numerical analysis shows that the PEM fuel cell with an operating voltage of 0.35V gives better performance parameters such as membrane current density, power density, cathode oxygen concentration, and gas diffusion layer's velocity, pressure distribution.`**

Keywords— PEMFC, six pass serpentine flow field, membrane current density, power density.

I. Introduction

Because of the expanding scene worry about the natural contamination and the consumption of fossil fuel holds, the arrangements for the era of clean vitality are an earnest interest. In the most recent decade, energy units give off an impression of being a standout amongst the most suitable choices for era of clean vitality and, among then, PEM energy units appear to be a standout amongst the most solid ones. A portion of the PEMFC favorable circumstances as to other sorts of power devices are their simple usage and their longer lifetime. Besides, their low operation temperature, high power thickness, quick new companies, soundness of the framework and low outflow have energized the enthusiasm of different industry areas to open up new fields of use for these power devices, including the engine business, the stationary force era, convenient applications, and so on [1].

Atul Kumar et al. [2] optimized the flow channel dimensions and shape in the flow field of end plates in a single pass serpentine flow field design. The triangular and hemispherical shaped cross section resulted in 9% excess hydrogen consumption in anode side, thus it can influence the enhanced performance of the PEM fuel cell.

In Aiyejina and Sastry [3] work, the authors present a thorough review on the mathematical modelling of PEMFC flow channel geometry, in order to improve of PEMFC performance. Also, some recommendations that can be implemented in optimizing the design of PEMFC flow fields for maximum performance are mentioned. Thus conclusions show that a 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.

Hwang [4] analysed 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 type flow fields, in which the channel to rib width ratio remained constant. Water management in the polymeric 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.

Li et al. [5] proposed a serpentine flow field design 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.

Owejan et al. [6] studied multiple serpentine PEMFC performance with flow fields of 50 cm^2 active areas, cross flow configuration 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.

Yan Wei-Mon et al. [7] 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.

In two similar works [8, 9] 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.

Choi et al. [10] studied the influence of different channel heights and widths on the performance of a PEMFC with multiple serpentine flow fields. 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.

A.P. Manso et al. [11] stated that 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. Generally, in this type of geometries, flow fields with rectangular shapes operate better than the squared ones. In addition, flow fields designs with shorter path lengths or larger number of parallel channels have better reactants distribution than flow fields with longer path channels or shorter number of parallel channels. 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. Variations in the channel height only show appreciable effect when operating at low potentials, increasing the current densities. The main disadvantage is that the pressure drop increases, which reduces the overall system efficiency. 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.

II. PROBLEM FORMULATION

In serpentine type flow fields, longer straight channel segments between channel bends and narrower channels enhance convection. 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. 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. 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. So in this project we selected the serpentine flow channels to improve the performance of the PEM fuel cell.

III. MODELING

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 two, three &four serpentine channels and the underlying gas diffusion layer (GDL) of a polymer electrolyte fuel cell. The porous cathode is modeled 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.

A. Design parameters

The following modeling parameters which have been taken into the account to create the six pass serpentine flow field model.

Rib width	: 0.7 mm
Channel width	: 0.8 mm
Channel Length (A)	: 200 mm
Plate width (B)	: 50 mm
Channel height	: 0.8 mm
Gdl height	: 0.5 mm
Inner radius of channel corners	: 0.35 mm
Number of channels	: 6

B. Modeling procedure

COMSOL software focused in this project is to create and simulate the different input and output parameters of "PEMFC domains". Different adding's available to create the geometry for particular applications. Model creation starts with the "PEMFC adding domains" then it goes to the 3D, steady state, serpentine flow field model. After that by using an "advanced description domains" required geometry is generated with respect to the relevant geometry parameters (Length, height, width, etc...). Cartesian coordinates are used to describe the entire geometry in the required coordinate position. Finally model has been created by retrieving the data from the following design parameters table. The model geometry is shown in the figure. The model consists multiple channel domains and the under most GDL "adding's domain". The flow and the mass transport properties are modelled using a reacting flow, concentrated species adding's domain. The model geometry of six pass serpentine flow field is show in figure.1.

C. Operating parameters

Following operating parameters are used to carry out this numerical analysis in six pass serpentine flow field model.

Cell Voltage	: 0.35 V – 0.95 V
Lumped anode and membrane resistance	: 0.285 ohm/cm^2
Cell temperature	: 303.15 K
Oxygen reference concentration	: 40.88 mol/m^3
GDL permeability	: 1.88×10^{-11} m^2
Cathode Inlet Hydrogen mass fraction	: 0.023
Cathode Inlet Oxygen mass fraction	: 0.228
Inlet velocity	: 2 m/s
Fluid viscosity	: 2.46×10^{-5} Pa*s
Nitrogen molar mass	: 0.028
Water molar mass	: 0.018
Oxygen molar mass	: 0.032
Reference pressure	: 1×10^5 Pa

IV. MESHING

The mesh model of six pass serpentine flow field is shown in figure.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.

A. Meshing parameters

The following meshing parameters are considered into the account to carry out the numerical analysis in six pass serpentine flow field model.

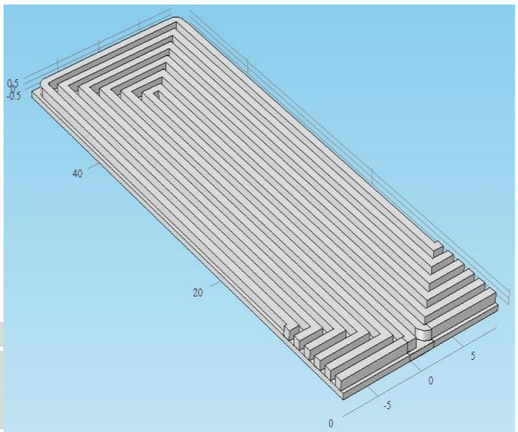

Fig.1. Isometric Model

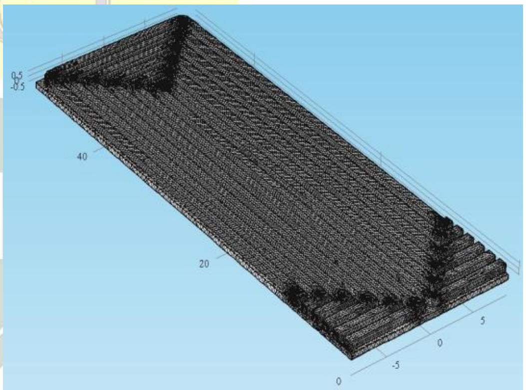

Fig.2. Mesh model

V. ANALYSIS

Analysis of the serpentine model starts with well defined boundary conditions using the "explicit command" and this command execute the modelled three dimensional geometry at different geometrical parameters domains. Selection of different channels is done by execute the "selection domains" (inlet, outlet, GDL, boundary conditions, no of channels, etc…). After that material properties were assigned to "PEMFC adding domains" to execute and initialize the fluid transportation, mass transportation phenomena, and porous media. These all material properties domains are used to execute the porous media of the "PEMFC domain" using the porous matrix method. Next level moves with meshing of the created geometry model. To enhance the results from the model (power density) entire model is meshed by using "mesh creation domain" with tedra-hectral meshing.
After that "study commands" are initialized to assign the required output parameters like (Fluid flow, cathode current density, Oxygen & Hydrogen mass fraction). Finally different

output parameter results are obtained by using "compute adding domain" in terms of contour plot or full page report.

VI. RESULTS & DISCUSSIONS

The following results have been obtained from COMSOL Multiphysics software under the different operating voltages.

A. Membrane current density

Figure.3 shows the membrane current density of six pass serpentine flow field model operating at 0.35 V. Among the other operating voltages PEM fuel cell with 0.35 V gives the maximum membrane current density of 1.3195 A/cm^2.

B. Power density

Compared with different operating voltages, PEM fuel cell with six pass serpentine flow field model gives the maximum power density of 0.482825 W/cm^2 at an operating voltage 0.35 V.

C. Gas diffusion layer pressure distribution

Figure.4 shows the gas diffusion layer pressure distribution of six pass serpentine flow field model operating at 0.35 V. There is a significant pressure difference between the up going and down going parts of the bottom channel. Among the other operating voltages PEM fuel cell with 0.35 V gives the maximum pressure distribution inside the cell (382.22 Pa).

D. Gas diffusion layer velocity distribution

Figure.5 shows the gas diffusion layer velocity distribution of six pass serpentine flow field model operating at 0.35 V. The velocity is highest in the middle of the channels; in the gas diffusion layer the velocities are generally low. The channel velocity is lowest around the upper end of the down most channels. Among the other operating voltages PEM fuel cell with 0.35 V gives the maximum velocity distribution inside the cell (0.2338m/s).

E. Cathode oxygen concentration

Figure.6 shows the cathode oxygen concentration of six pass serpentine flow field model operating at 0.35 V. The oxygen concentration towards the outlet in the down most channels is higher than in the other two channels. Among the other operating voltages PEM fuel cell with 0.35 V gives the maximum cathode oxygen concentration inside the cell (8.2054 mol/m^3).

F. Polarization curves

Figure.7 shows the effect of change of operating voltages inside the cell for current and power densities of six pass serpentine flow field model of PEM fuel cell. PEM fuel cells with six serpentine flow field model gives the maximum current and power densities (1.3195 A/cm^2 & 0.482825 W/cm^2) at 0.35 V respectively.

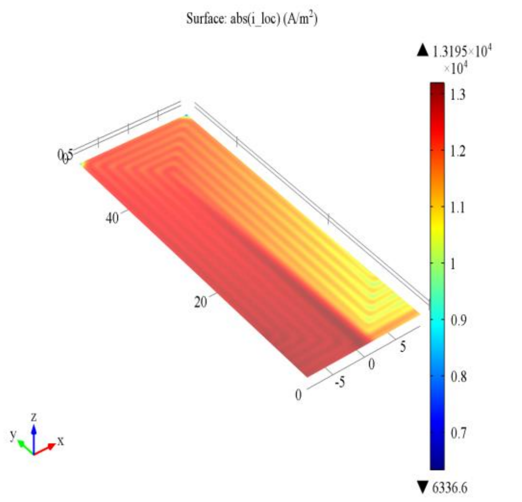

Fig.3. Membrane current density at 0.35 V

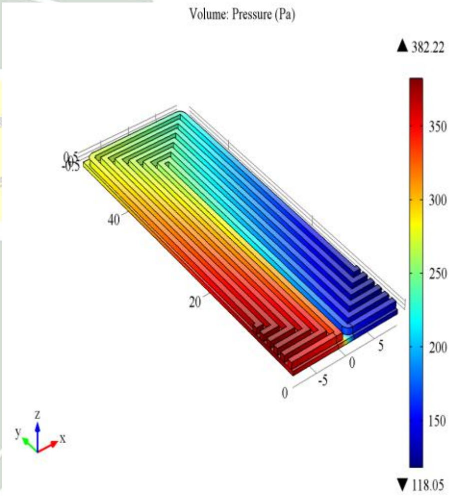

Fig.4. Gas diffusion layer pressure distribution at 0.35 V

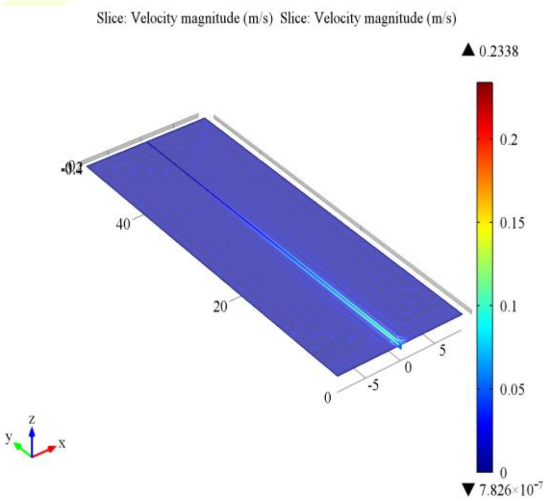

Fig.5. Gas diffusion layer velocity distribution at 0.35 V

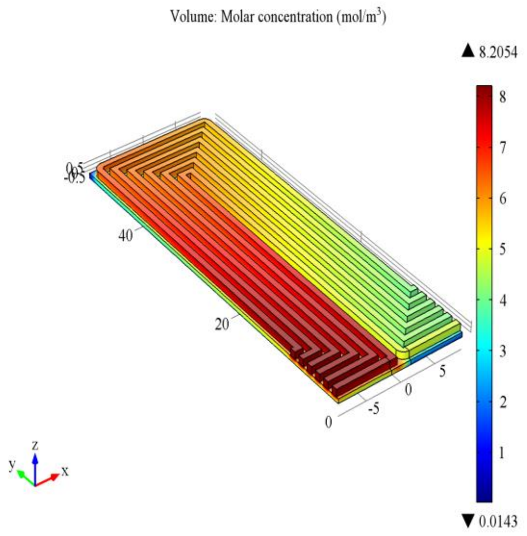

Fig.6. Cathode oxygen concentration at 0.35 V

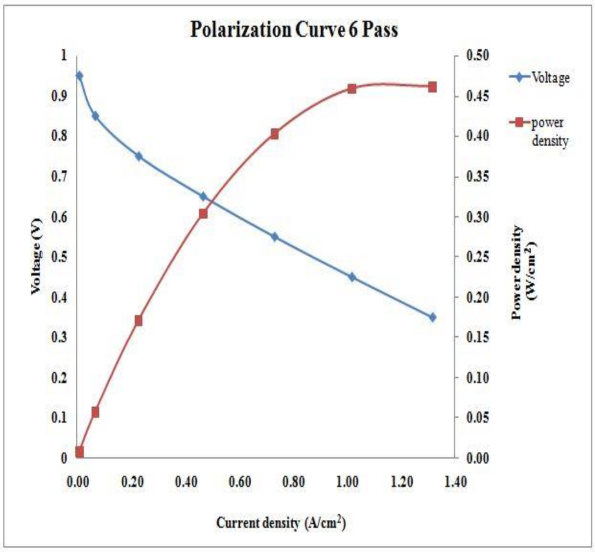

Fig.7. Polarization curve

VII. SUMMARY

The three dimensional model of PEM fuel cell with 6 pass serpentine flow field channels under different operating voltages (0.35 V - 0.90 V) were analysed using COMSOL 4.2 Multiphysics software. From this numerical analysis PEM fuel cell with six pass serpentine flow field yields the better performance parameters at an operating at 0.35 V. In future different flow channel cross section will be examined both numerically and experimentally.

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