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REGULAR ARTICLE

A Computational Study on the Modelling of the Flow Field Plates of a Polymer Electrolyte Membrane Fuel Cell

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This study extensively investigates the modelling of the bipolar plates, flow field plates and fuel cell stacks of a Direct Alcohol Fuel cell. The crucial component of a fuel cell is the bipolar plates which supply fuel to anode and oxidant to cathode and also maintains electrical conduction between cells. Given that flow field plates plays an important role in distributing reactant gases to the reaction sites, modelling of flow field plates has thus proved to be quite challenging owing to the fact that the flow field plates has to be durable and conductive both thermally and electrically. Electrochemical losses are also observed in cases which occurs due to the diffusion of hydrogen ions and electrons and also sometimes due to the material's natural resistance. These loses can only be minimised using thinner electrolyte membrane and operating the fuel cell at low temperatures. This study therefore aims at the extensive examination of various parameters including electrochemical and thermal parameters by computational modelling using MATLAB and PYTHON which plays a pivotal role in influencing the flow of reactants and amount of current generated.

Keywords: Fuel Cell, Flow-field plates, Fuel cell stacks, Computational Modelling, Simulation.

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1. INTRODUCTION

In a PEM Fuel Cell, the catalyst layers and the gas diffusion layers are the crucial components. The catalyst layer is responsible for the transfer of electrons and protons and also aids for the transfer of non-charged species which includes oxygen, hydrogen and water. The Gas diffusion layer (GDL) on the other hand is responsible for maintaining the electrical conductivity between the bipolar plates and electrodes. Literatures suggest that computational modeling of GDL and catalyst layers has proved to be an effective tool for understanding and optimizing the conditions for effective performance [1-3]. The most crucial component of a fuel cell are the bipolar plates which supply fuel to anode and oxidant to cathode and is important for maintaining electrical conduction between cells. Several designs for the bipolar plates have been proposed which includes: straight, serpentine, parallel or pin type bipolar plates. [4-11]

Fig. 1 illustrates the schematic of a flow field plate of a PEM fuel cell.

In majority of PEM Fuel Cells, the bipolar plates are made of resin-impregnated graphite. Even though solid graphite is a very good conductor, corrosion resistant and chemically inert but it is quiet challenging to manufacture it probably because it is very expensive? The stacks are composed of repeating units of MEAs and bipolar plates. An increase in the number of cells in the stack and leads to an increase in the cell voltage. Also, with an increase in the surface area there is an increase in the current. [12]

Bipolar plate's accounts are responsible for the weight of the stack, volume; and so, it is necessary to prepare plates which have the least possible measurements (< 3 mm width). It is known that the geometry of the flow field plates has an impact on the flow of reactant and the mass transfer which in turn affects the cell performance. Therefore, modeling of the flow field channels has proved to be effective in deciding the optimal mass transfer, pressure drop, and also fuel cell water management.

The main problem of fuel cells as reported in literature is that flooding of the Gas Diffusion Layer (GDL) takes place due to the water generated by the cathodic reactions, which blocks the passage of oxygen. Computational Fluids Dynamics (CFD) model therefore allows one to study several physical phenomena such as mass transport, heat transport, fuel cell kinetics etc. Computational study on the modeling of flow field plates in PEMFCs is significant for advancing the understanding, optimization, and performance of fuel

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cell systems, ultimately contributing to the widespread adoption of clean and efficient energy technologies. Various modeling studies for PEM fuel cell was carried out by Springer et al. Bladimir et al proposed a 3D model for PEM fuel cell which allowed to study about heat transfer. Literatures suggest that bipolar configuration is the most commonly used stack configuration. Therefore, in order to design a fuel cell stack several challenges need to be considered, which includes: size, weight, cost, water management, distribution of fuel oxidant. This study aims to optimize the design and performance of PEMFCs by understanding and simulating the intricate flow patterns within the flow field plates.

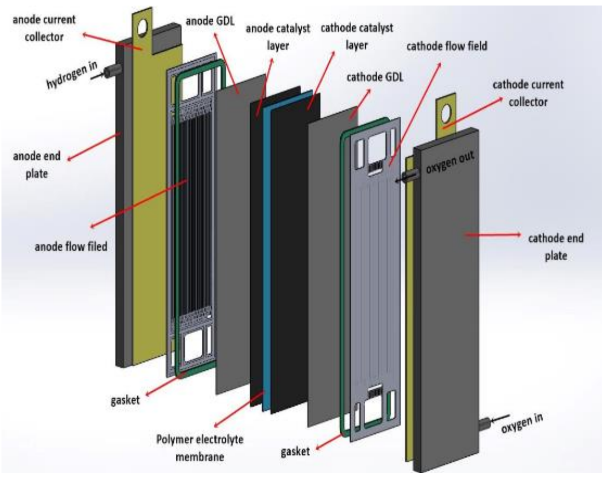

Fig. 1 – Schematic of flow field plate of fuel cell for PEMFC

2. METHOD FOR COMPUTATIONAL MODELLING

For the modelling of the flow field plates and fuel cell stacks, MATLAB (Software 22), PYTHON Windows 10 has been used.

3. RESULTS AND DISCUSSION

Assuming the fact that the electrolyte is electrically non - conductive and also not permeable to gases, it is noted that diffusion of little hydrogen and electron may occur through the electrolyte and may result in the actual decrease in the number of electrons. Although these loses are not very significant during the fuel cell operations but eventually becomes significant if the fuel cell operations are carried out at low current densities and this fact has been illustrated by (Fig. 2) given below.

It is seen that it is material's natural resistance to the charge flow which leads to ohmic loss. This results in cell voltage loss. The ohmic loss generated can be minimized by using a better ionic conductor or a thinner electrolyte layer which is illustrated by (Fig. 3)

In the bipolar plates the "area" can change. It depends on the area of flow channel. With the decrease in area, there is an increase in the resistance (Fig. 4) because the area term is in the denominator of contact resistance

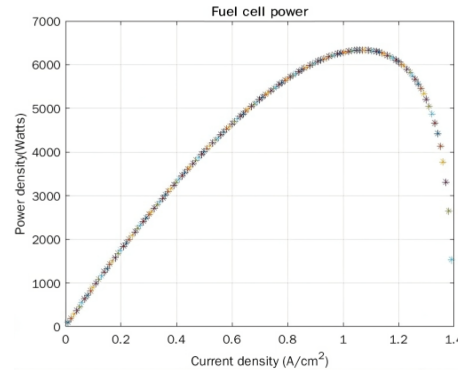

Fig. 2 – Power density Vs Current density Plot

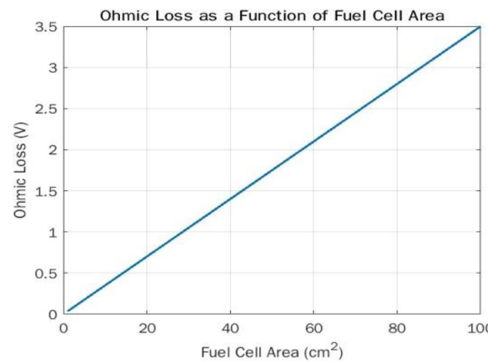

Fig. 3 – Ohmic Loss Vs Fuel Cell Area

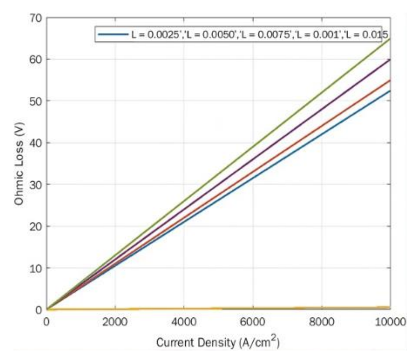

Fig. 4 – Ohmic Loss Vs Current Density

$$R_{contact} = R_{contact}/A_{contact}$$

and

$$A_{contact} = Land\ Area$$

Literature reports suggest that an adequate contact pressure needs to be maintained within the components of a fuel cell stacks so as to prevent the leakage of the reactants, thereby minimizing the contact resistance between the layers. It is observed that pressure impedes the flow through the GDL, causes damage to the MEA, thus resulting in a broken porous structure which causes a blockage in the passage of gas diffusion. In either case, the clamping pressure decreases the cell performance. (Fig. 5)

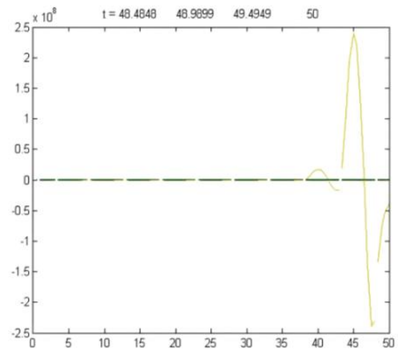

Fig. 5 – Pressure Vs Temperature

Fig. 6, 7, 8 represents a parametric model that can be used to predict the performance of a PEM fuel cell over a range of operating currents and temperatures.

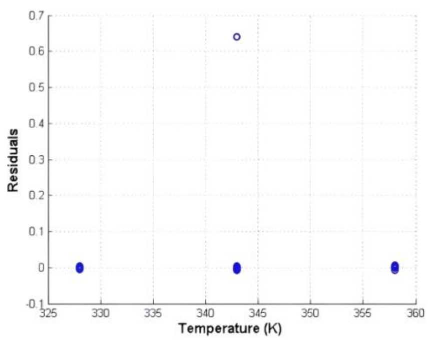

Fig. 6 – Residuals Vs Temperature

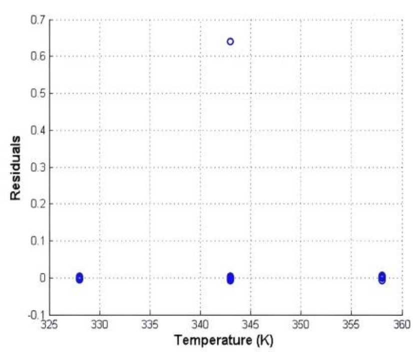

Fig. 7 – Residuals Vs Current Density

Various other parameters of the flow field plates of fuel cell like the air compressor, fan power, ideal work done, power density has been modeled and the results are tabulated in the following Tables 1-5.

4. CONCLUSION

Computational modeling has proved to be a very effective tool for the modeling of the flow field plates. Influence of physical parameters such as area, temperature, and pump diameter on the flow of fuel has been extensively studied.

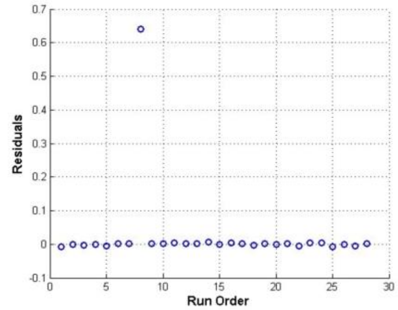

Fig. 8 – Residuals Vs Run order

Table 1 – Modelling of the Air compressor

Parameters	Values
Power_input	1 W
Power_output	50 W
Temperature_input	298.15 K
Temperature Output	129.85 K
Rise in temperature	107.85 K

Table 2 – Modelling of fuel cell stacks

Parameters	Values
Current	122.91 A
Current density	1.535 A/cm^2
Area required	3.0729 cm^2

Table 3 – Flow field plate

Parameters	Values
Stack current	29.395 A
Pressure drop in flow channels	19944 atm
Channel length	0.102 m
Friction factor	50
Parameters	**Values**
Flow rate at channel entrance	2.93*10^{-5} m/s

Table 4 – Fuel cell system

Parameters	Values
Fan power	0.05 W
Fan efficiency	0.5793
Mass flow rate	2*10^{-4} m/s
Outlet velocity	1 m/s

Table 5 – The Pump System

Parameters	Values
Ideal Work	1.02 J
Temperature change	1.492 K
Specific heat	4.18 calories
Pump diameter	100 cm

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Дослідження моделювання пластин поля потоку паливного елемента з мембраною полімерного електроліту

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У цьому дослідженні детально досліджується моделювання біполярних пластин, пластин поля потоку та пакетів паливних елементів прямого спиртового паливного елемента. Вирішальним компонентом паливного елемента є біполярні пластини, які подають паливо до анода та окислювач до катода, а також підтримують електричну провідність між елементами. З огляду на те, що пластини поля потоку відіграють важливу роль у розподілі газів-реагентів до реакційних центрів, моделювання пластин поля потоку виявилося досить складним через той факт, що пластини поля потоку мають бути міцними та провідними як термічно, так і електрично. Електрохімічні втрати також спостерігаються у випадках, які виникають через дифузію іонів водню та електронів, а також іноді через природний опір матеріалу. Ці втрати можна мінімізувати лише за допомогою тоншої електролітної мембрани та роботи паливного елемента при низьких температурах. Таким чином, це дослідження спрямоване на широке вивчення різних параметрів, включаючи електрохімічні та термічні параметри, шляхом обчислювального моделювання з використанням MATLAB і PYTHON, що відіграє ключову роль у впливі на потік реагентів і величину генерованого струму.

Ключові слова: Паливний елемент, Пластини потокового поля, Пакети паливних елементів, Обчислювальне моделювання, Моделювання.