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Performance Analysis of PEM Fuel Cell by Varying Flow Channel Design and Operating Parameters

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Abstract-

The Proton Exchange Membrane (PEM) fuel cell performance is depending on many parameters like material properties, design parameters, operating parameters. The PEM fuel cell with serpentine flow field has been modeled using Solidworks software and analyzed using ANSYS 15.0 software. This PEM fuel cell is numerically analyzed for three different temperatures to study its effects on the performance. From the analysis, the optimum operating temperature of the PEM fuel cell has been found.

PEM fuel cells are promising power generation sources for mobile and stationary applications. However, there are several technical problems to be solved in order to achieve practicability and popularization. Especially, water management inside a PEM fuel cell is essential for high performance operation. "Water flooding" and "Dry out" is a critical barrier for high efficiency and high power density.

To alleviate these issues, it is necessary to analysis the Proton Exchange Membrane Fuel Cell for different gas flow parameters and serpentine, spiral model is chosen with the area of 25 cm^2 by varying the temperature, pressure and various bend angles are analyses and the optimum temperature and pressure are chosen and compared with experimental validation and their performance are evaluated.

Keywords: Water management, Water flood & dry out, Flow parameter.

I. Introduction

The Proton Exchange Membrane (PEM) fuel cell is a device which is used to convert chemical energy into electrical energy. It is operated at low temperature below 100^{o}C, offer quick start up times. It requires only hydrogen and oxygen to operate. In fuel cell, there is less chance of pollution as compared to other source of energy. It is eco-friendly energy source. It is suitable for both portable and stationary application due to high energy density and low temperature range.

Ibrahim Dincer [1] studied the fuel cell technologies for sustainable development. Renewable energy utilization in hydrogen production can provide a potential solution to current environmental problems. Hong Liu et al. [2] compared various flow field designs and concluded that the serpentine is the best design. P. Karthikeyan et al. [3] optimized operating condition and design parameters by using Taguchi method and they improved the performance of PEM fuel cell. A.P. Manso et al. [4] present a thorough review on the influence of geometric parameters of the flow field on the performance of a PEM fuel cell. Tanmay Bsasak et al. [5] numerically analyzed the natural convection within porous trapezoidal enclosures for various inclination angles. M.Muthukumar et al. [6] numerically analyzed the PEM Fuel Cell with Different Landing to Channel and Width of Flow Channel; with the smaller width of landing, the performance of PEM fuel cell has increased. M.Muthukumar et al. [7] numerically studied PEM fuel cell with 2, 3 and 4 pass serpentine flow field designs. The result showed that three pass serpentine flow field has performance. V. Lakshminarayanan et al. [8] analyzed numerically with the single pass PEM fuel cell with various flow channel design and found that the square channel have high performance. Andrzejsobiesisk & Wenbohuang [9] developed a steady state 2D mathematical model with phase change and pressure effects and illustrated the inlet humidification and pressure effects on PEM fuel cell performance.

II. Modelling of PEM fuel cell

The layout or configuration of the flow channels is first and foremost important in the channel design. Due to the balanced water removal and limited pressure drop, the serpentine flow channel layout can give good cell performance compared to other designs. So the serpentine flow field design with U-bend was considered in this study. Solidworks 2008 and ANSYS 15.0 software package focused in this project is to create and simulate the different input and output parameters of "PEM fuel cell domains". Model creation starts with the "PEM fuel cell adding domains" then it goes to the 3D, steady state, serpentine U-bend flow field model. By using "advanced description domains", the required geometries were generated with respect to the relevant geometry parameters (Length, height, thickness, etc.). The Cartesian coordinates were used to describe the entire geometry in the required coordinate position. Finally model had been created by retrieving the data from design parameters table. The models consist of multiple channel domains and the under most GDL "adding's domain". The flow and the mass transport properties were modeled using a reacting flow, concentrated species adding's domain. The simulation has been solved by simultaneous equations like conservation of mass, momentum, energy, species, Butler–volmer equation, Joule heating reaction and Nernst equation to obtain reaction kinetics of PEM fuel cell namely mass fraction of O_2, and H_2O, pressure and current flux density distribution on flow channel. The model used to consider the system as three-dimensional and steady, the inlet gases as ideal gases, the system as an isothermal, the flow as laminar, the fluid as incompressible, the thermo physical properties as constant and the porous GDL, the two catalyst layers and the membrane as anisotropic.

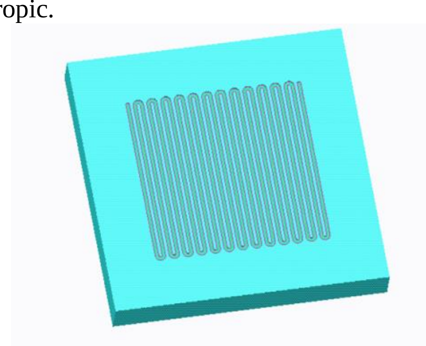

Fig.1 Model of serpentine channel with U-bend

III. Channel dimensions and operating parameters

The rib length, breadth, thickness of 2x2x2mm, the channel length, breadth, thickness of 50x50mm, plate length, breadth, thickness of 80x80x10mm, GDL length, breadth, thickness of 50x50x0.3mm, catalyst length, breadth, thickness of 50x50x0.08mm, membrane length, breadth, thickness of 50 x 50 x 0.127mm,U-bend radius of 2mm, GDL porosity of 0.4, GDL permeability of 1.18x1011m^2, inlet mass fraction of H_2 and H_2O of 0.8 and 0.2, outlet mass fraction of O_2 and H_2O of 0.2 and 0.1,mass flow rate anode of 5.6x10-7kg/s, mass flow rate cathode of 1.5x10-6kg/s and reference pressure of 2 bar were taken for all the designs. The four different operating temperatures for analyzing are 313K, 323K, 333K and 353K and seven different cathode voltage used for analyzed are 0.15V, 0.25V, 0.35V, 0.45V, 0.55V, 0.65V, 0.75V, 0.85V.

IV. Analysis of PEM models

Analysis of the serpentine model starts with well-defined boundary conditions using the "explicit command" and this command execute the three dimensional geometry at different geometrical parameters domains. The selection of different channels was done by execute the "selection domains" (inlet, outlet, GDL, boundary conditions, no of channels, etc.). After that material properties were assigned to "PEM fuel cell adding domains" to execute and initialize the fluid transportation, mass transportation phenomena, and porous media. These all material properties domains were used to execute the porous media of the "PEM fuel cell 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 was meshed by using "mesh creation domain" with tedra-hectral meshing. After that "study commands" were initialized to assign the required output parameters like (Fluid flow, cathode current density, Oxygen & Hydrogen mass fraction). Finally different output parameter results were obtained by using "compute adding domain" in terms of contour plot. Open circuit voltage was set as 0.95 V. The anode voltage was grounded and the cathode voltage had been varied from 0.15 V – 0.85 V as a cell potential for solving of reaction kinetics in order to get current flux density and oxygen concentration along the flow field design.

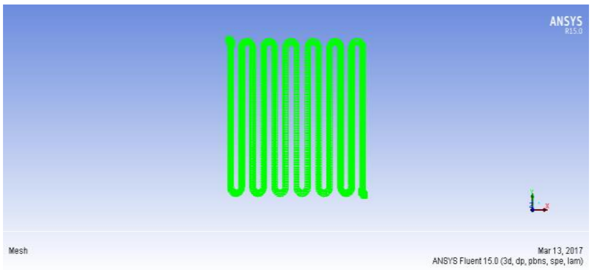

Fig. 2 Meshing

V. Result& Discussion

Results are obtained using ANSYS 15.0 for the following set of operating conditions: temperature of 313K or 40°C and pressure of 2 bar. FLUENT results are obtained for voltage as a function of current density and are tabulated in Table 1.

Table 1. Results at a temperature of 313 K

S.No.	**Volt (V)**	**Current density**	**Power density**

		(A/cm^2)	(W/cm^2)
1	0.15	1.208203	0.18123045
2	0.25	1.209827	0.30245675
3	0.35	1.210069	0.42352415
4	0.45	1.209455	0.54425475
5	0.55	1.207775	0.66427625
6	0.65	1.207028	0.7845682
7	0.75	1.206057	0.90454275
8	0.85	0.760491	0.64641735

In numerical plan we have achieved maximum power density of 0.90454275 W/cm^{2}with corresponding current density of 1.206057 A/cm^2. We have achieved minimum power density of 0.18123045 W/cm^2 with corresponding current density 1.208203 A/cm^2.

Results are obtained using ANSYS 15.0 for the following set of operating conditions: temperature of 323K or 50°C and pressure of 2 bar. FLUENT results are obtained for voltage as a function of current density and are tabulated in Table 2.

TABLE 2.RESULTS AT A TEMPERATURE OF323 K

S. No.	Volt (V)	Current density (A/cm^2)	Power density (W/cm^2)
1	0.15	1.206892	0.1810338
2	0.25	1.208045	0.30201125
3	0.35	1.207777	0.42272195
4	0.45	1.207398	0.5433291
5	0.55	1.207064	0.6638852
6	0.65	1.206716	0.7843654
7	0.75	1.206254	0.9046905
8	0.85	0.755798	0.6424283

In numerical plan, we have achieved maximum power density of 0.9046905 W/cm^2 with corresponding current density of 1.206254 A/cm^2. We have achieved minimum power density of 0.1810338 W/cm^2 with corresponding current density 1.206892 A/cm^2

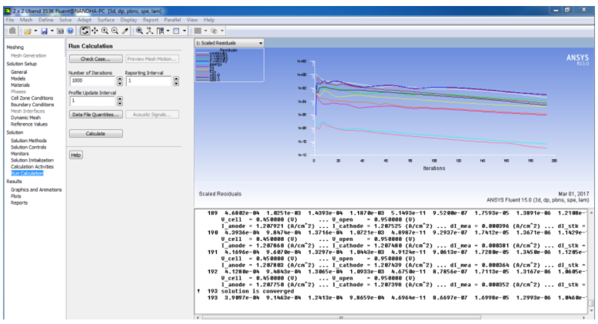

Fig. 3 Diagram of Iteration

Results are obtained using ANSYS 15.0 for the following set of operating conditions: temperature of 333K or 60°C, pressure of 2 bar, FLUENT results are obtained for voltage as a function of current density and are tabulated in Table 3.

TABLE 3. RESULTS AT A TEMPERATURE OF 333 K

S. No.	Volt (V)	Current density (A/cm^2)	Power density (W/cm^2)
1	0.15	1.206719	0.18100785
2	0.25	1.206741	0.30168525
3	0.35	1.206647	0.42232645
4	0.45	1.206541	0.54294345
5	0.55	1.206548	0.6636014
6	0.65	1.206639	0.78431535
7	0.75	1.207088	0.905316
8	0.85	0.49503	0.4207755

In numerical plan, we have achieved maximum power density of 0.905316 W/cm^2 with corresponding current density of 1.207088 A/cm^2. We have achieved minimum power density of 0.18100785 W/cm^2 with corresponding current density 1.206719 A/cm^2.

VI. CONCLUSION

The effect of temperature on the performance of PEM fuel cell is studied numerically. The PEM fuel cell with active area of 25 cm^2 and serpentine type flow field was modeled using Solidworks 2008 and meshing is done using ANSYS15.0. By analysis, the PEM fuel cell with three different temperatures 313K, 323K and 333K and with a constant pressure of 2bar has been considered. From the numerical analysis, it is found that 333 K at 2 bar giving the best performance of cell potential at 0.75V.

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