Numerical analysis of Interdigitated flow channel of PEM Fuel Cell

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ABSTRACT

The performance is depending on the operating and design parameters of Proton Exchange Membrane Fuel Cell (PEMFC). In this work, interdigitated flow channel of 16 cm^2 active area model has been created using Creo software and the created model has been analyzed using CFD fluent software. The power density has been calculated for L:C 2:1 with the effect of various operating temperature as 303, 313,323 and 333K, constant pressure of 2 bar and constant inlet reactant mass flow rate of the PEMFC has been considered. The maximum numerical power density of interdigitated flow channel with L:C - 2:1 were found to be 0. 293 W/cm^2 at temperature of 303 and 313 K.

Keyword: *- Interdigitated flow channel: PEMFC; operating parameters; Landing to channel width ratio; CFD*

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1. INTRODUCTION

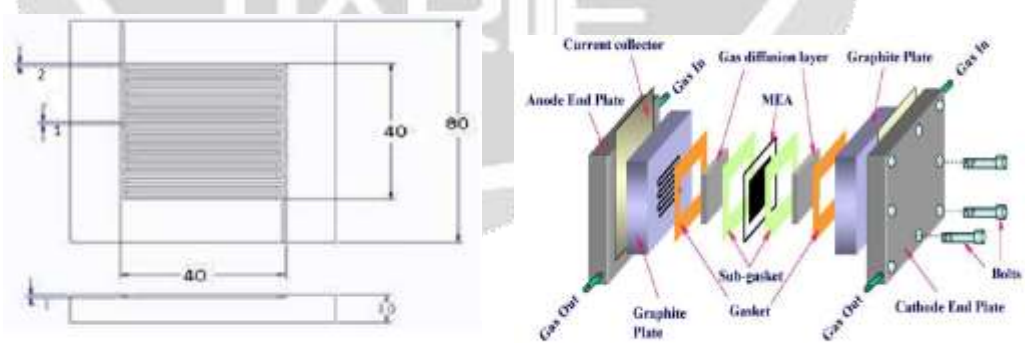
The PEMFCs are being established for commercial applications in the areas of transportation and back-up power due to the negligible emission of pollutants, such as sox, nox, particulates [1]. It is eco-friendly power source suitable for powering both portable devices and mobile application due to their high energy density and lower operating temperature range [2]. Hashemi et al. [3] investigated the performance of PEMFC with serpentine and straight flow fields. The results revealed that the serpentine flow field showed a better distribution of temperature and current density. Liu et al. [4] investigated the influences of positions of the ribs and channels like ‘rib to channel’ and ‘rib to rib’ in the anode and cathode flow fields on the performance of PEMFC. The result revealed that for pure hydrogen operation, it was better to arrange the anode and cathode channels and ribs to be ‘rib to channel’ to increase fuel cell performance; even though the GDLs conductivity is high. The effect of the various parameters and various landing to channel width of (L: C) 1:1, 1:2 and 2:2 multipass serpentine flow channel PEM fuel cell with 36 cm^2 effective area was analyzed numerically by Lakshminarayanan et al [5]. The result concluded that the maximum power densities of 0.658, was obtained in the landing to channel width ratio of 1:1.Yan et al. [6] experimentally investigated the effects of interdigitated flow channel with traditional flow channel on the performance of PEMFC. Besides, the effects of the flow area ratio and the baffle-blocked position of the interdigitated flow field were examined. The results concluded that, the cell performance can be enhanced with an increased inlet flow rate of reactant and cathode humidification temperature. The interdigitated flow fields have better performance than conventional flow field design. Also the results showed that the interdigitated flow field has larger limiting current density, and the power output was about 1.4 times than the conventional flow field.
The numerical investigation of 49 cm^2 active area of the PEMFC with various landing width to channel width of single pass serpentine flow channels with various pressure and various operating temperature was carried out by Lakshminarayanan et al [7]. Kanani et al.[8] investigated the effects of operating conditions (cathode and anode stoichiometry, gas inlet temperature and cathode relative humidity) for serpentine flow channel on the performance

of the PEMFC by using Design of Experiments. Response surface methodology was used to model the relationship between cell potential and power with various operating input parameters. The results revealed that the low and high stoichiometries of reactant on anode and cathode cause the minimum cell power.The performance of PEMFC has been analyzed from the numerical study also the better landing width to channel width of the flow channel, pressure and temperature was identified. The performance improvement of the serpentine flow channel with 64 cm^2 (8cm x 8cm) active area of the proton exchange membrane (PEM) fuel cell has been studied with the effect of design parameter like various landing to channel width ratio (L:C) 1:1, 1:2, 2:1 and 2:2 and the operating parameters like various operating temperature (313, 323 and 333), constant pressure of 2 bar and inlet reactant mass flow rate by Lakshminarayanan et al [9]. The results showed that the maximum numerical power densities of serpentine flow channel with R:C -1:2 was found to be 0.139 W/cm^2 for temperature 323 K respectively. The various operating parameters like cell temperature, pressure, reactants on anode and cathode flow rate has been investigated experimentally for triangular channel geometry on 25 cm^2 active area of PEMFC by khazaee et al. [10]. The results showed that an increase in the inlet temperature of reactants, cell temperature and inlet pressure can enhance cell performance of the PEMFC. Oosthuizen et al. [11] studied the air flow in a simplified model of the serpentine flow channels with a square cross-section and adjacent diffusion layer on the performance of the PEMFC. The results indicated that the flow crossover does have a significant influence on the pressure variation through the channel, tending to decrease the pressure drop across the channel. There can be crossover of air through the porous diffusion layer from one part of the channel to another due to the pressure drop along the flow channel.

In this study, single pass interdigitated flow channel of 16 cm^2 (4cm x 4cm) active area with landing width to channel width ratio (L:C) - 2:1 has been created with the help of Creo software and the created modal was analyzed by Ansys CFD Fluent software. This performance of PEM fuel cell has also been found out with various operating temperature of 303, 313,323 and 333K constant operating pressure of 2 bar and three times to the theoretical inlet reactant mass flow rate at the anode and cathode side.

2. NUMERICAL ANALYSIS OF PEM FUEL CELL

The modeling of landing to channel width ratio 2:1 with interdigitated flow channel of 16 cm^2 active area of PEM fuel cell as shown in the Fig. 1(a) and the corresponding dimensions have been mentioned in Table 1. The development of interdigitated flow channel of 16 cm^2 of PEM fuel cell model has been involved three major steps. Modeling the geometry of the fuel cell using Creo Parametric 2.0 was the first step. The modeling was done by creating individual parts such as anode, cathode, catalyst, gas diffusion layer and membrane as shown in the Fig. 1 (b). These parts were assembled using suitable constrains to form the complete PEMFC assembly.



(a) **(b)**

Fig. 1. Interdigitated flow channel of (a) Landing to channel width ratio -2:1 and (b)Various parts associated with PEM fuel cell

Table 1. Dimensions of interdigitated fuel cell of 16 cm^2 active area

Elements	Length(cm)	Width(cm)	Thickness(cm)
MEA Assembly	4	4	0. 0127
Gas Diffusion Layer	4	4	0.03
Flow Channel	4	4	0. 1
Anode Plate	4	4	1
Cathode Plate	4	4	1

The various single pass geometrical models form the basis for creating a computational mesh. The second step involved, creating the mesh from the geometry using ICEM CFD 14.5. Creating a good mesh has been one of the most difficult steps involved in modeling. It requires a careful balance of creating enough computational cells to capture the geometry without creating much of its care should be taken such that it would not exceed the available memory of the meshing computer.

Table 2. Continuum and boundary condition of interdigitated flow channel of 16 cm^2 active area

Continuum Zone	Boundary Conditions
Flow Channels for anode and cathode sides	Inlet and outlet zones for the anode gas channel
Anode and cathode current collectors	Inlet and outlet zones for the cathode gas channel
Anode and cathode gas diffusion layers	Surfaces representing anode and cathode terminals
Anode and cathode catalyst layers	Optional boundary zones that could be defined include any voltage jump surfaces, interior flow surfaces or non-conformal interfaces that are required.

Many other factors must also be considered into account in order to generate a computational mesh which provides representative results when simulated. The third and final step involves adoption of boundary condition with physical and operating parameters of PEM fuel cell for solving the above mentioned reaction kinetics. The Continuum and boundary condition of interdigitated flow channel as shown in the table 2.

In order to solve the myriad of equations associated with a fuel cell simulation, the entire cell was divided into a finite number of discrete volume elements or computational cells. The simulation has been solved simultaneous equations like conservation of mass, momentum, energy, species, Butler–Volmer equation, Joule heating reaction and the Nernst equation to obtain reaction kinetics of PEM fuel cell, namely mass fraction of H_2, O_2, and H_2O, temperature, static pressure and current flux density distribution. All the inlets should be assigned the boundary zone type as ‘mass flow inlet’ and outlets should be assigned as ‘pressure outlet’ type. The anode is grounded ($V = 0$) and the cathode terminal is at a fixed potential which is less than the open-circuit potential. Both the terminals should be assigned the ‘wall’ boundary type. Voltage jump zones can optionally be placed between the various components (such as between the gas diffusion layer and the current collector). Faces which represent solid interfaces must be of the type ‘wall’.

3. RESULTS AND DISCUSSION

The polarization and performance curves can be used to evaluate the performance of the PEMFC system. Current density is the current (electrons or ions) generated per unit active area of PEMFC, whereas the power density is the power generated per unit active area. A voltage-current (V-I) curve, also known as a polarization curve, is generally used to express the characteristics of a PEMFC. The Performance curve is the curve drawn between current density and the power density (P-I curve), which is useful for power demand characteristics on PEMFC. The total area of the catalyst layer influences the electrochemical reactions in the PEMFC. So, this area is called as an active area of PEMFC. The performance of PEMFC is measured from the power output of the cell with respect to current and cell potential. The various losses occur in the performance measurement on PEMFC.

The performance of the PEMFC with L:C 2:1 interdigitated flow channel and operating parameters has been shown by performance curve and polarization curve. The obtained power density of interdigitated flow channel with constant pressure and various operating temperature for landing to channel width ratio 2:1 was to be 0. 293 W/cm^2 and the corresponding current density was 0.617 A/cm^2 and 0.638 A/cm^2 for both 303K at voltage of 0.475 V and 313 K at the voltage of 0.45 V. similarly for 323K and 333 K the power density was found to be 0.286 W/cm^2 and 0.289 W/cm^2 and the corresponding current density of 2:1 was 0.602 A/cm^2 and 0.608 A/cm^2 respectively. The performance (P-I) and polarization (V-I) curve of L: C-2:1, constant pressure and various temperatures have been shown in the Fig. 2. The current density and power density of L:C 2:1 for various temperature with constant stoichiometric ratio and constant pressure of 2 bar has been mentioned in table.3.

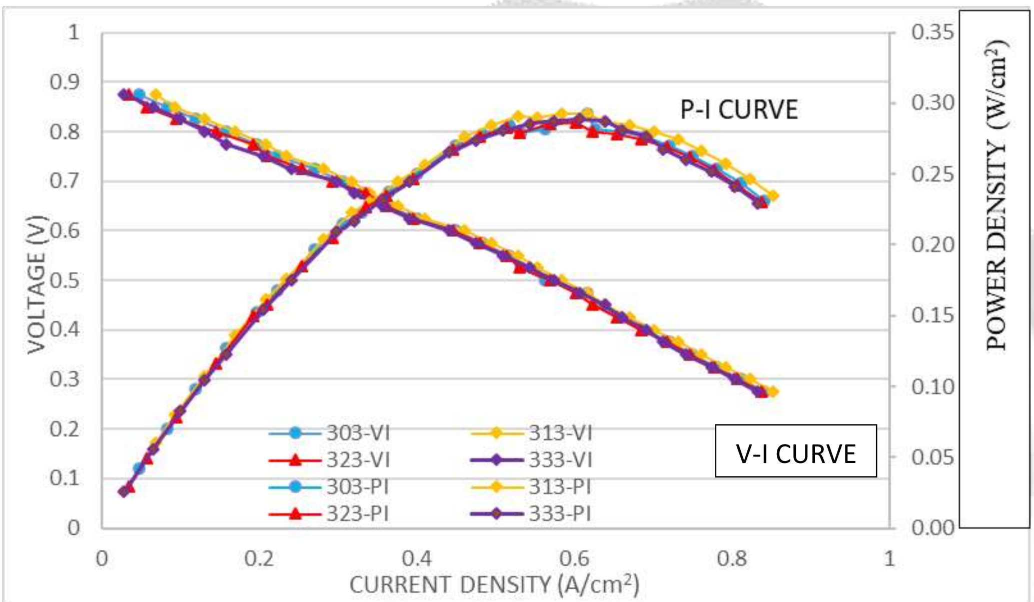


Fig. 2. P-I and V-I curve of L:C – 2:1 of interdigitated flow channel with 16 cm^2 active area

VOLTAGE	303 K		313 K		323 K		333 K	
	A/cm2	W/cm2	A/cm2	W/cm2	A/cm2	W/cm2	A/cm2	W/cm2
0.875	0.048	0.042	0.069	0.060	0.034	0.030	0.029	0.025
0.85	0.083	0.071	0.094	0.080	0.058	0.049	0.065	0.055
0.825	0.119	0.098	0.13	0.107	0.095	0.078	0.1	0.083
0.8	0.159	0.127	0.17	0.136	0.145	0.116	0.131	0.105
0.775	0.197	0.153	0.208	0.161	0.193	0.150	0.158	0.122
0.75	0.224	0.168	0.235	0.176	0.21	0.158	0.206	0.155
0.725	0.271	0.196	0.282	0.204	0.255	0.185	0.241	0.175
0.7	0.307	0.215	0.318	0.223	0.293	0.205	0.299	0.209
0.675	0.33	0.223	0.341	0.230	0.336	0.227	0.321	0.217
0.65	0.365	0.237	0.376	0.244	0.361	0.235	0.357	0.232
0.625	0.4	0.250	0.411	0.257	0.395	0.247	0.391	0.244
0.6	0.45	0.270	0.461	0.277	0.446	0.268	0.442	0.265

0.575	0.484	0.278	0.495	0.285	0.48	0.276	0.476	0.274
0.55	0.518	0.285	0.529	0.291	0.514	0.283	0.51	0.281
0.525	0.532	0.279	0.553	0.290	0.531	0.279	0.544	0.286
0.5	0.564	0.282	0.585	0.293	0.57	0.285	0.575	0.288
0.475	0.617	0.293	0.617	0.293	0.602	0.286	0.608	0.289
0.45	0.627	0.282	0.638	0.287	0.623	0.280	0.639	0.288
0.425	0.659	0.280	0.67	0.285	0.655	0.278	0.661	0.281
0.4	0.69	0.276	0.701	0.280	0.686	0.274	0.692	0.277
0.375	0.721	0.270	0.732	0.275	0.717	0.269	0.713	0.267
0.35	0.751	0.263	0.762	0.267	0.747	0.261	0.743	0.260
0.325	0.782	0.254	0.793	0.258	0.778	0.253	0.774	0.252
0.3	0.812	0.244	0.823	0.247	0.808	0.242	0.804	0.241
0.275	0.842	0.232	0.853	0.235	0.838	0.230	0.834	0.229

4.CONCLUSION

The maximum power density 0.293 W/cm2 and current density of 0.617 A/cm2 and 0.638 A/cm2 at 0.475 V and 0.45 V was achieved in landing to channel width ratio of 2:1 with 16 cm2 active area of interdigitated flow channel at constant operating pressure of 2 bar at 303 K and 313 K temperature. The maximum power density of a PEMFC is achieved between 0.4 - 0.5V of cell potential for various operating temperatures and constant 2 bar pressure.

5. REFERENCES

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