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Research Paper

Numerical analysis of 16 cm^2 effective area of PEMFC for performance study.

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ABSTRACT: *The paramètres like operating pressure, temperature, stoichiometric ratio of hydrogen and oxygen, relative humidity and channel width to channel width (L:C), the shape of the flow channel and the number of passes on the flow channel are the deciding factors for the fuel cell performance. In this work, The Proton Exchange Membrane Fuel Cell (PEMFC) with interdigitated flow channel of 16 cm^2 effective area model has been analysed using CFD fluent software. The power density has been calculated for L:C 1:2 with the effect of various operating temperature, constant pressure 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 - 1:2 were found to be 0. 336 W/cm^2 at temperature of 313 K.*

KEYWORDS: *CFD, PEMFC, operating paramètres, landing to channel width ratio, interdigitated flow channel.*

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I. INTRODUCTION

The PEMFC comprises of polymer solid electrolyte membrane sandwiched between an anode and cathode. Fuel cells are converting chemical energy of hydrogen in the anode side and oxygen in the cathode side directly into electricity without any intermediate stage like classical combustion of two and four stroke engine. It has become an integral part of alternative energy sources with high energy efficiency without affecting the environment. Among all types of fuel cells, the PEMFC has reached important stage, particularly for mobile and portable applications. Besides their high-power producing capability, PEMFC's work at low temperatures, produce only water and heat as byproduct, and can be compactly assembled, making it as one of the leading candidates for the next generation power generator [1]. The performance of PEMFC with the active area of 5 cm2 under various operating conditions (temperatures, pressures, and humidity of reactant gases) was investigated experimentally by Amirinejad et al [2]. The results showed that the performance of PEMFC increased with the increase of the cell temperature and operating pressure. Santarelli & Torchio [3] discussed the characterization of the behavior of a PEMFC effective area of 25 cm2 with various operating parameters like cell temperature, the anode and the cathode flow temperature in saturation and dry conditions, and reactant pressure. The results showed that the increase of temperature, reactants pressure and humidification at high cell temperature improved the performance of PEMFC. Also the performance has been improved with increased pressure along with humidification at both anode and cathode but, the increase of the operating pressure of dry reactants did not show any performance improvement. Manso et al. [4] reviewed the performance of PEMFC by various geometric parameters of the flow fields such as pin type channels, integrated and interdigitated channels, straight and serpentine channels. Grujicic and Chittajallu [5] have studied the performance of PEMFC by using a single-phase two-dimensional electrochemical model. The model was coupled with a nonlinear constrained optimization algorithm to define an optimum design of the fuel cell with respect to the operation and the geometrical parameters of the cathode. The results of the optimization analysis showed that higher current densities at a constant cell voltage were obtained as the inlet air pressure. On the other hand, the statistical sensitivity analysis results showed that the equilibrium cathode/membrane potential difference has the largest effect on the predicted polarization curve of the PEMFC. 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 cm2 effective area was analyzed numerically by Lakshminarayanan et al [6]. The result concluded that the maximum power densities were obtained in the landing to channel width ratio of (L: C)- 1:1, 1:2 and 2:2, 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 cm2 active area of PEMFC by khazaee et al [7]. The results showed that an increase in the inlet temperature of reactants, cell temperature and inlet pressure can enhance cell performance of the PEMFC. Optimization of operating and design parameters with various landing to channel width on serpentine flow channel of 16 cm2 active area of the PEMFC was studied by Lakshminarayanan et al [8]. From the optimization study, the L: C- 1:2 has maximum influence on PEMFC performance and square of response factor (R2) was achieved by Taguchi method as 97.90 %. Numerical analysis with six different cross-sections of the channel, namely square, triangle, parallelogram 14o, parallelogram 26o, trapezium and inverted trapezium of 1.25 cm2 active area with a constant cross sectional area of 0.01 cm2 of single pass PEM fuel cell was carried out by Lakshminarayanan et al [9]. It was concluded that, square flow channel of single pass PEM fuel cell having a peak power density of 1.133 W/cm2.

The Proton Exchange Membrane (PEM) Fuel Cell performance not only depends on the operating parameters like temperature, pressure, the stoichiometric ratio of reactants, relative humidity and back pressure on anode and cathode flow channels, but it also depends on design parameters like channel width to rib width, channel depth and number of passes on the flow channel In this study, single pass interdigitated flow channel of 16 cm2 (4cm x 4cm) active area with landing to channel width ratio (L:C) - 1:2 has been created with the help of Creo software and the same modal was analyzed by Ansys CFD Fluent software. This performance of PEMFC has also been found out with various operating temperature of 313K, 323K,333 K and 343 K, constant operating pressure of 2 bar and three times to the theoretical inlet reactant mass flow rate at the anode and cathode side.

II. NUMERICAL ANALYSIS OF PEM FUEL CELL

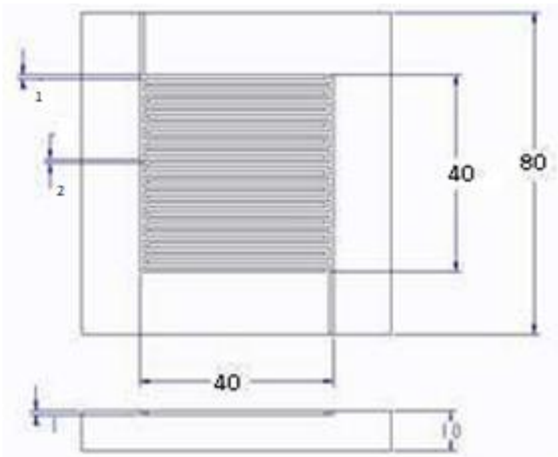

Figure 1. Interdigitated flow channel with Landing to channel width ratio -1:2 of PEM fuel cell

The modeling of landing to channel width ratio 1:2 with interdigitated flow channel of 16 cm2 active area of PEM fuel cell as shown in the Fig. 1 and the corresponding dimensions have been mentioned in Table 1.

Table 1. Dimensions of interdigitated fuel cell of 16 cm2 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 development of interdigitated flow channel of 16 cm2 of PEMFC 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. These parts were assembled using suitable constrains to form the complete PEMFC assembly. 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. 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.

Table 2. Continuum and boundary condition of interdigitated flow channel of 16 cm2 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.

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 H2, O2, and H2O, 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’.

Table 3. The current density and power density of L:C 1:2 for various temperature of PEMFC

VOLTAGE	313 K		323 K		333 K		343 K	
	A/cm^2	W/cm^2	A/cm^2	W/cm^2	A/cm^2	W/cm^2	A/cm^2	W/cm^2
0.875	0.136	0.119	0.084	0.074	0.055	0.048	0.043	0.038
0.85	0.171	0.145	0.109	0.093	0.079	0.067	0.079	0.067
0.825	0.207	0.171	0.145	0.120	0.116	0.096	0.114	0.094
0.8	0.247	0.198	0.185	0.148	0.166	0.133	0.145	0.116
0.775	0.285	0.221	0.223	0.173	0.214	0.166	0.172	0.133
0.75	0.312	0.234	0.25	0.188	0.231	0.173	0.22	0.165
0.725	0.359	0.260	0.297	0.215	0.276	0.200	0.255	0.185
0.7	0.395	0.277	0.333	0.233	0.314	0.220	0.313	0.219
0.675	0.418	0.282	0.356	0.240	0.357	0.241	0.335	0.226
0.65	0.453	0.294	0.391	0.254	0.382	0.248	0.371	0.241
0.625	0.488	0.305	0.426	0.266	0.416	0.260	0.405	0.253
0.6	0.538	0.323	0.476	0.286	0.467	0.280	0.456	0.274
0.575	0.572	0.329	0.51	0.293	0.501	0.288	0.49	0.282
0.55	0.606	0.333	0.544	0.299	0.535	0.294	0.524	0.288
0.525	0.64	0.336	0.568	0.298	0.552	0.290	0.558	0.293
0.5	0.672	0.336	0.6	0.300	0.591	0.296	0.589	0.295
0.475	0.701	0.333	0.632	0.300	0.623	0.296	0.622	0.295
0.45	0.735	0.331	0.653	0.294	0.644	0.290	0.653	0.294
0.425	0.757	0.322	0.685	0.291	0.676	0.287	0.675	0.287
0.4	0.788	0.315	0.716	0.286	0.707	0.283	0.706	0.282
0.375	0.809	0.303	0.747	0.280	0.738	0.277	0.727	0.273
0.35	0.839	0.294	0.777	0.272	0.768	0.269	0.757	0.265
0.325	0.87	0.283	0.808	0.263	0.799	0.260	0.788	0.256
0.3	0.9	0.270	0.838	0.251	0.829	0.249	0.818	0.245
0.275	0.93	0.256	0.868	0.239	0.859	0.236	0.848	0.233

III. RESULTS AND DISCUSSION:

The performance of the PEMFC with L:C 1:2 interdigitated flow channel and operating parameters has been shown by performance curve (P-I curve) and polarization curve (V-I curve). The obtained power density of interdigitated flow channel with constant pressure and various operating temperature for landing to channel width ratio 1:2 was to be 0. 336 W/cm2 and the corresponding current density was 0.672A/cm2 respectively at 313 K. similarly for 323K,333K and 343 K the power density was found to be 0.30 W/cm2, 0.296 W/cm2 and 0.295 W/cm2 and the corresponding current density of 1:2 was 0.632 A/cm2, 0.623 A/cm2 and 0.622 A/cm2 respectively. The performance (P-I) and polarization (V-I) curve of L: C-1:2, constant pressure and various temperatures have been shown in the Fig. 2. The current density and power density of L:C 1:2 for various temperature with constant stoichiometric ratio and constant pressure of 2 bar has been mentioned in table.3.

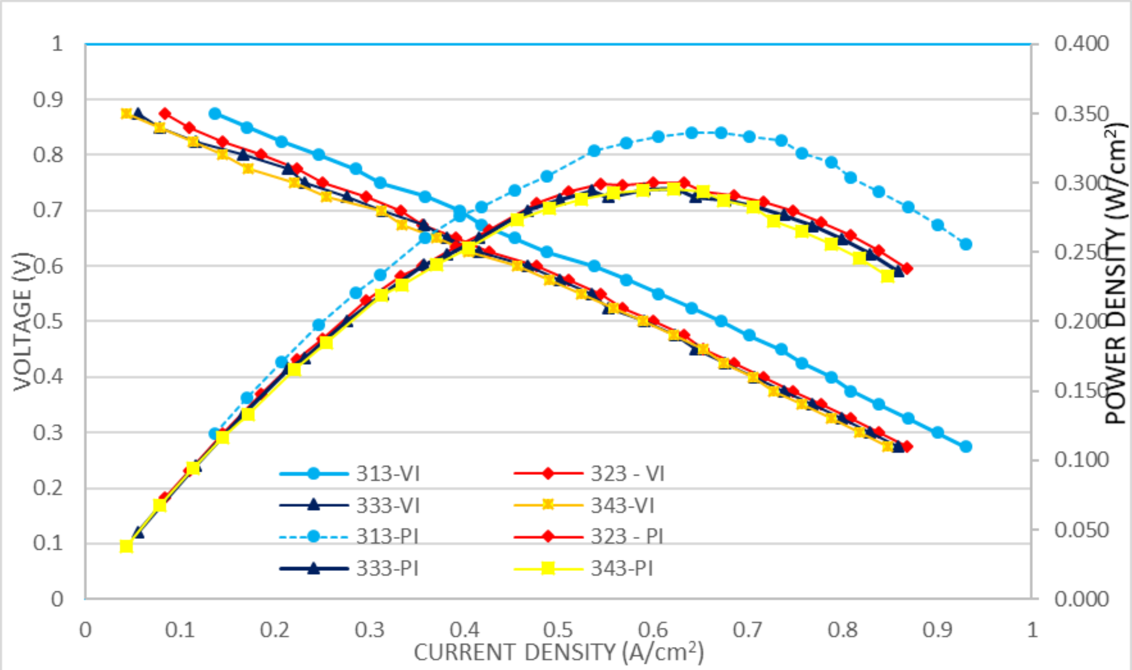

Figure 2. P-I and V-I curve of L:C – 1:2 of interdigitated flow channel with 16 cm2 active area

IV. CONCLUSION:

The maximum power density 0.336 W/cm2 and current density of 0.672 A/cm2 at 0.5 V was achieved in landing to channel width ratio of 1:2 with 16 cm2 active area of interdigitated flow channel at constant operating pressure of 2 bar and 313 K temperature. The maximum power density of a PEMFC is achieved between 0.4 - 0.5 cell potential for various operating temperatures and constant 2 bar pressure.

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