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Numerical investigation of 16 cm^2 active area of PEMFC for performance analysis.

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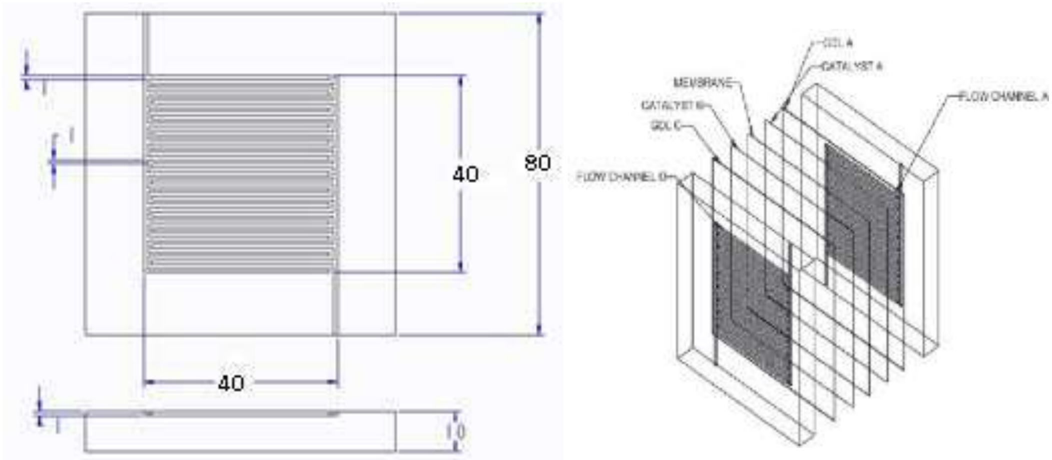
*Abstract:*The Proton Exchange Membrane Fuel Cell (PEMFC) performance depends on the operating and design parameters like operating pressure, temperature, stoichiometric ratio of hydrogen and oxygen, relative humidity and rib width to channel width (R:C), the shape of the flow channel and the number of passes on the flow channel. In this work, interdigitated flow channel of 16 cm^2 (4cm x 4cm) active area model has been created using Creo software and it has been analyzed using CFD fluent software. The power density has been calculated for R:C 1:1 with the effect of various operating temperature (313, 323,333 and 343K), 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 R:C -1:1 were found to be 0. 301 W/cm^2 at temperature of 313 K.

Keywords: PEMFC; operating parameters; rib to channel width ratio; CFD; interdigitated flow channel

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]. The PEMFC consists 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 proton exchange membrane (PEM) fuel cell has reached important stage, particularly for mobile and portable applications. Besides their high-power producing capability, PEM fuel cells 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 [3]. 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 (6cm x 6cm) effective area was analyzed numerically by Lakshminarayanan et al [4]. The result concluded that the maximum power densities of 0.658, 0.642 and 0596 W/cm^2 were obtained in the landing to channel width ratio of (L: C)- 1:1, 1:2 and 2:2, respectively. The numerical investigation on the performance of PEMFC with various flow field designs, namely, the single parallel, serpentine, interdigitated and the pin flow field have been studied by Lee et al. [5]. The results revealed that the single serpentine flow field showed the best performance characteristics to the interdigitated flow field design. However, the single parallel and the pin flow field design showed the worst mass transfer characteristics, because of the flooding and drying of the membrane caused by uneven flow circulation. The numerical investigation of 49 (7X7) cm^2 active area of the PEMFC with various Landing width to channel width (L: C-1:1, 1:2, 2:1 and 2:2) of single pass serpentine flow channels with various pressure (1, 1. 5, 2 and 2. 5 bar) and various operating temperature (323, 333, 343 and 353) was carried out by Lakshminarayanan et al [6]. 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 cm2 (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 [7]. The results showed that the maximum numerical power densities of serpentine flow channel with R:C -1:2 were found to be 0.134, 0.139 and 0.137 W/cm^2 for temperature 313, 323 and 333 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. [8]. 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. [9] 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.



(a) **b)**

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

In this study, single pass interdigitated flow channel of 16 cm^2 (4cm x 4cm) active area with rib width to channel width ratio (R:C) -1:1 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 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.

I. NUMERICAL ANALYSIS OF PEM FUEL CELL:

The modeling of various rib to channel width ratio 1:1 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.

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 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.

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'.

II. RESULTS AND DISCUSSION:

The performance of the PEMFC with R:C 1:1 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 rib to channel width ratio 1:1 was to be 0. 301 W/cm^2 and the corresponding current density was 0.635 A/cm^2 respectively at 313 K. similarly for 323K,333K and 343 K the power density was found to be 0.30 W/cm^2, 0.296 W/cm^2 and 0.30 W/cm^2 and the corresponding current density of 1:1 was 0.632 A/cm^2, 0.623 A/cm^2 and 0.632 A/cm^2 respectively. The performance (P-I) and polarization (V-I) curve of R: C-1:1, constant pressure and various temperatures have been shown in the Fig. 2.The current density and power density of R:C 1:1 for various temperature with constant stoichiometric ratio and constant pressure of 2 bar has been mentioned in table.3.

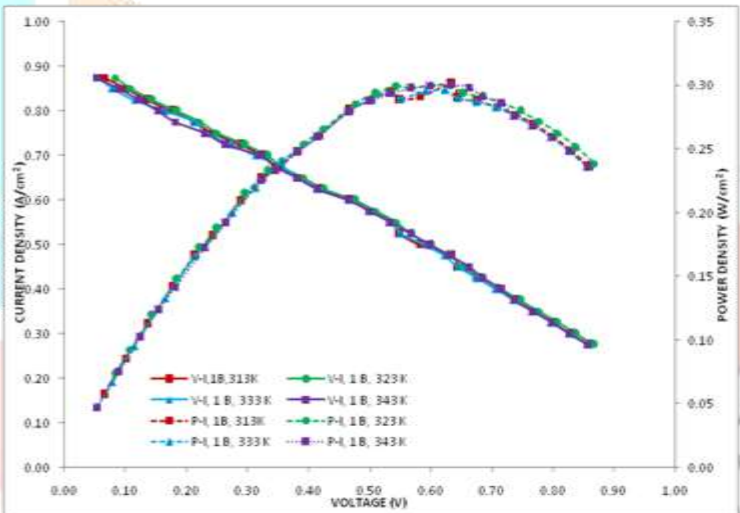


Fig. 5. P-I and V-I curve of R:C – 1:1 of interdigitated flow channel with 16 cm^2 active area

Table-3: Maximum Power densities of Rib to Channel width ratio 1:1 of interdigitated flow channel

VOLTAGE	313 K		323 K		333 K		343 K	
	A/cm2	W/cm2	A/cm2	W/cm2	A/cm2	W/cm2	A/cm2	W/cm2
0.875	0.066	0.057	0.084	0.073	0.055	0.048	0.053	0.047
0.850	0.101	0.086	0.109	0.093	0.079	0.067	0.089	0.076
0.825	0.137	0.113	0.145	0.119	0.116	0.095	0.124	0.103
0.800	0.177	0.142	0.185	0.148	0.166	0.133	0.155	0.124
0.775	0.215	0.166	0.223	0.173	0.214	0.165	0.182	0.141
0.750	0.242	0.182	0.250	0.188	0.231	0.173	0.230	0.173
0.725	0.289	0.209	0.297	0.215	0.276	0.200	0.265	0.192
0.700	0.325	0.227	0.333	0.233	0.314	0.220	0.323	0.226
0.675	0.348	0.235	0.356	0.240	0.357	0.241	0.345	0.233
0.650	0.383	0.249	0.391	0.254	0.382	0.248	0.381	0.248
0.625	0.418	0.261	0.426	0.266	0.416	0.260	0.415	0.260
0.600	0.468	0.281	0.476	0.286	0.467	0.280	0.466	0.280
0.575	0.502	0.289	0.510	0.294	0.501	0.288	0.500	0.288
0.550	0.536	0.295	0.544	0.299	0.535	0.294	0.534	0.294
0.525	0.550	0.289	0.568	0.298	0.552	0.290	0.568	0.298
0.500	0.582	0.291	0.600	0.300	0.591	0.296	0.599	0.299
0.475	0.635	0.301	0.632	0.300	0.623	0.296	0.632	0.300
0.450	0.645	0.290	0.653	0.294	0.644	0.290	0.663	0.298
0.425	0.677	0.288	0.685	0.291	0.676	0.287	0.685	0.291
0.400	0.708	0.283	0.716	0.286	0.707	0.283	0.716	0.286
0.375	0.739	0.277	0.747	0.280	0.738	0.277	0.737	0.276
0.350	0.769	0.269	0.777	0.272	0.768	0.269	0.767	0.268
0.325	0.800	0.260	0.808	0.263	0.799	0.260	0.798	0.259
0.300	0.830	0.249	0.838	0.251	0.829	0.249	0.828	0.248
0.275	0.860	0.236	0.868	0.239	0.859	0.236	0.858	0.236

This design has converted the transport of the gaseous reactant to/from the catalyst layers from a diffusion mechanism to a convection mechanism at the interface of catalyst and GDL. Convection having much faster than diffusion, the reaction rates at the catalyst sites could be significantly enhanced.

III. CONCLUSION:

The maximum power density 0.301 W/cm^2 and current density of 0.635 A/cm^2 at 0.475 V was achieved in rib to channel width ratio of 1:1 with 16 cm^2 active area of interdigitated flow channel at constant operating pressure of 2 bar and 313 K temperature. The maximum power density of a PEM fuel cell is achieved between 0.4 - 0.5 cell potential for various operating temperatures and constant 2 bar pressure.

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