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Optimization of PEMFC with three pass interdigitated flow channel for performance enhancement

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Abstract*— The *design and operating parameters influenced the performance of Polymer Electrolyte Membrane Fuel Cell (PEMFC). This research work shows, among the various operating parameters, the operating temperature ,pressure, stoichiometric ratio of hydrogen and oxygen (inlet) mass flow rate and design parameter like deferent landing to channel width ratio(L:C) on 49 cm^2 three pass interdigitated flow channel of the PEMFC is studied. The analysis was carried out by ansys fluent CFD (Computational Fluid Dynamics) and optimization was done by Taguchi method using Minitab 17 software. Based on the optimization study, the L: C- 1:2 have given 0.211 W/cm2maximum power density on PEMFC performance and square of response factor (R2) was achieved as 99.12 %.

Keywords*— Interdigitated, CFD, design parameter, PEMFC, optimization, performance

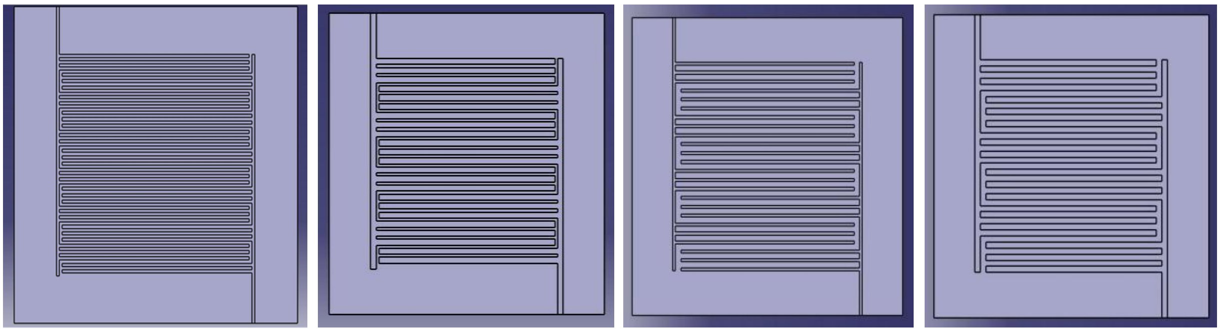
I. INTRODUCTION

The energy scarcity and environmental impacts of non-renewable power sources in many countries, focusing on renewable energy source development. The PEMFC are environment friendly power source and are suitable for powering both portable devices and mobile application [1]. The performance of PEMFC with design and various operating parameters analyzed by CFD and optimized by Taguchi technique was done by Lakshminarayanan et al.[2] Based on the optimization study, the L: C- 1:2 have given 0.223 W/cm2 maximum power density on PEMFC performance and square of response factor (R2) was achieved as 99.69 %. The numerical investigation of the performance of PEMFC with various flow field designs, namely, the single parallel, serpentine, interdigitated and the pin flow field have been considered by Lee et al. [3]. The results exposed that the single serpentine flow field exhibited the best performance characteristics to the interdigitated flow field design. The performance of PEMC on serpentine single pass flow channel of 64 cm2 (8cm x 8cm) active area with various landing to channel width ratio 1:1, 1:2, 2:1 and 2:2 , various operating temperature (313, 323 and 333), constant pressure of 2 bar and inlet reactant mass flow rate of the PEM fuel cell has been examined by Lakshminarayanan et al [4]. The results concluded that the power densities of serpentine flow channel with R:C -1:2 were found to be 0.134, 0.139 and 0.137 W / cm2 for temperature 313, 323 and 333 K respectively. Khazaee et al. [5] examined experimentally on 25 cm2 active area of PEMFC with various operating parameters like cell temperature, pressure, reactants on anode and cathode. He concluded that the performance of the PEMFC amended with the increase in operating pressure and increase in cell temperature. The effect of the design and operating parameters of multipass (two pass) interdigitated flow channel with 49 cm2 effective area affect the performance of the PEMFC was analyzed numerically by Lashminarayanan et al [6].The results revealed that the L:C-1:1 has produced maximum power of 12.58 watts with constant pressure and operating temperature of 333 K on multipass interdigitated flow channel of PEMFC. Vazifeshenas et al. [7] examined the compound flow field design along with serpentine and parallel designs were tested by using CFD software. The results revealed that the parallel flow field revealed weaker performance in comparison to the other two flow fields. The main reason is due to insufficient distribution of the reactants. Scholta et al. [8] considered the effect of landing to channel widths on 100 cm2 PEMFC with parallel and counter flow channel. They revealed the result that channel and landing width are influencing the performance enhancement of PEMFC. Hence, narrow and wider dimensions of flow channels have been better for high current density. The performance enhancement of the combined effect of operating and design parameters (operating pressure, temperature and inlet mass flow rate of reactant gases and rib to channel width ratio) of single pass serpentine and interdigitated flow channel with 25 cm2 active area of PEMFC carried out by Lakshminarayanan and Karthikeyan [9]. The results shown that the maximum power density of interdigitated flow channel with L:C- 1:2 exhibited better performance than the serpentine flow channel.

The various operating parameters like operating temperature, pressure, anode and cathode side reactants flow rate has been examined with triangular channel geometry on 25 cm2 effective area of PEMFC by Khazae 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. The effects of traditional flow channel was compared with interdigitated flow channel , the effects of the flow area ratio and the baffle-blocked position of the interdigitated flow channel on the performance of PEMFC were examined experimentally by Yan et al [11]. The results revealed that, the cell performance can be improved with an increased inlet reactant flow rate and cathode humidification temperature. The increasing of inlet pressure improved the consumption of reactants and more homogeneous distribution. Hence in this research, the factors considered for the analysis are landing to channel ratios (L: C-1:1, 1:2, 2:1 and 2:2), pressure (1, 1.5, 2 and 2.5 bar), temperature (313, 323, 333 and 343 K), anode and cathode reactants as stoichiometric ratios (S/F) of 3, 3.5, 4 and 4.5 on interdigitated three pass flow field design.

MODEL DEVELOPMENT

The modeling was done by creating individual parts of the PEMFC and the dimensions of individual parts such as the anode and cathode GDL, solid polymer electrolyte membrane, the anode and cathode catalyst layers as shown in the Table 1. The various geometrical models of interdigitated three pass flow channel were meshed by using ICEM 1. Three dimensional PEMFC model with three pass interdigitated flow channel were created by Creo Parametric 1.0 as shown in Fig.1.



(a) L:C-1:1 (b) L:C-1:2 (c) L:C-2:1 (d) L:C-2:2

Fig. 1. Three pass interdigitated flow channel with various L:C ratio of 49 cm2 effective area

A. Boundary conditions

Anode gas channel and Cathode gas channel is set as inlet and outlet zones. Surfaces that represent anode and cathode terminals optional boundary zones that could be defined include any voltage jump surfaces, interior flow surfaces or non-conformal interfaces that are required.

B .Continuum Zone

Flow Channels for anode and cathode-sides, Anode and cathode current collectors, Anode and cathode gas diffusion layers, Anode and cathode catalyst layers and Electrolyte membrane. 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.

a) Meshing on PEMFC

After geometry building, the next step was discretization done by ANSYS 14 ICEM software. The meshing method was used as Cartesian grid, which helps in the formation of hexahedral mesh to get accurate results. Hence the entire cell was divided into finite number of discrete volume elements or computational cells to solve the equations associated with the fuel cell simulation. Split block method used for blocking and meshing was done with Cartesian method. Body fitted mesh was used and projection factor was set to 1. The projection factor determines how closely the edges of the mesh match up with the grid.

b) Governing Equations

The simulation was solved by simultaneous equations like conservation of mass, momentum, energy, species concentration, butler–Volmer equation, Joule heating reaction and the Nernst equation to obtain reaction kinetics of the PEMFC. The model used to consider the system as 3-D, steady state and inlet gases as ideal condition, system as an isothermal and flow as laminar, fluid as incompressible, thermo physical properties as constant and the porous GDL, two catalyst layers and the membrane as an isotropic.

c) Solver

The species concentration on anode side of H2, O2, and H2O were 0.8, 0, and 0.2 respectively. Similarly, on the cathode side were 0, 0.2 and 0.1 respectively. The porosity at anode and cathode side was 0.5. Open circuit voltage was set at 0.95 V on the cathode and the anode was grounded. The cathode voltage has been varied from 0.05 V to 0.95 V used for solving kinetics reaction in order to get the current flux density, H2, O2, and H2O fractions along with the flow field design. Multi grid settings were modified as F-Cycle for all the equations and entered termination restriction value was set as 0.001 for H2, O2, H2O and water saturation. The electric and proton potential values were set at 0.0001. The Anode and Cathode reference current density was set to be10000A/cm2and 20 A/cm2 respectively 0.1 kmol/m3 was set to anode and cathode reference concentration, Anode and cathode exchange coefficient was set to be 2.The Reference diffusivity of H2,O2 and H2O was set to as 3E-5.

TAGUCHI METHOD

Taguchi method can be used to find out the most optimum combination among the input parameters which will result in getting the maximum possible output which cause the performance enhancement of PEMFC. In Taguchi method L16 standard orthogonal array with 4-level and 4 factors was used. When this orthogonal array was used, significance of factors and optimum combination can be found in 16 runs itself. The factors considered for the analysis were landing to channel ratios on interdigitated three pass flow channel (L: C-1:1, 1:2, 2:1 and 2:2), operating pressure (1, 1.5, 2 and 2.5 bar), operating temperature (313, 323, 333 and 343 K), stoichiometric ratio of reactants 3, 3.5, 4 and 4.5 times to the theoretical value of hydrogen and oxygen as 4.33E-07 kg/s and 3.33E-06 kg/s respectively.

RESULTS AND DISCUSSION

As per L16 orthogonal array, the inputs were given to the analysis software and having all other parameters constant. The power density from polarization curve was found by numerical study using CFD Fluent 14 software package for all 16 runs and the corresponding Signal/Noise (S/N) ratios were found from MINITAB 17 software and were shown in Table 2.

The landing to channel width ratio of 1:1 for interdigitated three pass flow field has shown maximum and minimum power density of 0.202 W/cm2 and 0.140 W/cm2 respectively. Similarly for L:C of 1:2 and 2:1 having maximum power density of 0.211 W/cm2 and 0.122 W/cm2 respectively. The minimum power densities for the same L:C ratios having 0.115 W/cm2 and 0.093 W/cm2 respectively. For the landing to channel width ratio of 2:2 has shown maximum power density of 0.166 W/cm2 and minimum power density of 0.084 W/cm2.

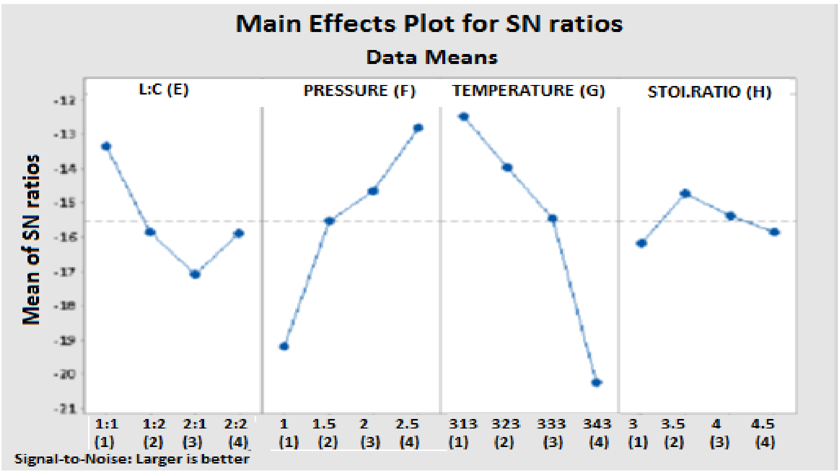


Fig .2. Mean S/N ratio plot for L:C -E(1-4),Pressure –F (1-4),Temperature –G (1-4), Stoi.Ratio –H (1-4).

The optimization was performed for "Larger the Better" type of Taguchi method since power output of PEMFC must be maximized. The S/N ratio plot for the same were obtained using MINITAB 17 software and the corresponding maximum S/N ratio gives better performance as analyzed based on larger the better as shown in the Fig.2.

It was concluded that the design parameter such as, landing to channel ratio of interdigitated three pass flow channel having -1:1 as E1, and the operating parameters like pressure – 2.5 bar as F4, temperature - 313 K as G1, Stoichiometric ratio of inlet mass flow rate – 3.5 as H2 were the optimum parameters to show the better PEMFC performance. The optimization results of various parameters were based on S/N ratios and the significance of each factor by ranking them according to their performance. Delta value of each factor available on the MINITAB 17 software itself was shown in Table 3. The factor with highest delta value indicates higher significance.

It was found that landing to channel width (L:C) of 49 cm2interdigitated three pass flow channel was the predominant factor affecting the performance of PEMFC. The percentage contribution of individual parameters for the performance of PEMFC has been shown in the Table 4.

Table 2. Factors, levels, power density and S/N ratio for 16 runs of optimization

Run	L:C	Pressure	Temperature	Stoi.Ratio	Power Density (W/cm^2)	S/N Ratio
1	1x1	1	313	3	0.140	-17.09
2		1.5	323	3.5	0.182	-14.97
3		2	333	4	0.202	-14.08
4		2.5	343	4.5	0.162	-15.93
5	1x2	1	323	4	0.115	-18.67
6		1.5	313	4.5	0.182	-14.96
7		2	343	3	0.200	-13.88
8		2.5	333	3.5	0.211	-13.73
9	2x1	1	333	4.5	0.113	-18.76
10		1.5	343	4	0.122	-18.22
11		2	313	3.5	0.101	-19.52
12		2.5	323	3	0.093	-20.31
13	2x2	1	343	3.5	0.084	-21.17
14		1.5	333	3	0.098	-19.18
15		2	323	4.5	0.142	-16.46
16		2.5	313	4	0.166	-15.69
Average S/N Ratio						-17.04

Table 3. Mean S/N ratios, Delta and Rank for each level of factors

Factors	Level 1	Level 2	Level 3	Level 4	Delta	Rank
Landing to Channel width (L:C)	-15.57	-15.69	-19.33	-18.83	4.2	1
Pressure (bar)	-19.83	-17.24	-16.71	-16.27	3.74	2
Temperature (K)	-17.13	-17.93	-16.78	-17.52	2.27	3
Stoichiometric Ratio	-17.74	-17.23	-16.99	-16.24	2.11	4

Table 4.The percentage contribution of individual parameters of interdigitated three pass flow channel

Factors	DOF	Sum of squares	Variance	F-test	P-Test	Contribution (%)
Pressure	2	0.0069455	0.00331	161.24	0.043	33.9
Temperature	2	0.002586	0.00064	2.55	1.254	6.11
Stoi.ratio	2	0.000549	0.00022	11.02	0.325	1.6
L:C	3	0.009396	0.00280	68.20	0.183	28.2
Pressure & Temperature	1	0.000875	0.00089	22.01	0.050	9.1
Pressure & L:C	3	0.004999	0.00163	39.48	0.031	15.9
Error	2	0.000091	0.00004			5.19
Total	15	0.025442	0.010255	304.50	1.886	100

It has been observed that the operating pressure has been shown to be 33.9 % contribution on peak power performance of the PEMFC for the interdigitated three pass flow field. Similarly for the L:C, operating temperature and stoichiometric ratio of the reactants has contributed 28.2 %, 6.11 % and 1.6 % respectively of the PEMFC performance. Also the combined effect of combination of pressure with temperature and pressure with L:C has shown 9.1 % and 15.9 % respectively contributing to peak power performance of the PEMFC.

II. CONCLUSION

The maximum power density of optimizing the four different parameters on interdigitated three pass flow channel of 49cm2 active area of PEMFC using Minitab 17 provides 0.211 W/cm2 and R2 value was arrived 99.12 %. The optimum power density 0.211 W/cm2 was obtained from L:C-1:2 with 2.5 bar operating pressure, 333 K temperature and 3.5 stoichiometric ratio of inlet reactant gases of 49 cm2 active area of the CFD PEMFC model. The effect of operating and design parameters was affecting the performance of PEMFC more significantly. The combined effect of all the parameters exhibited a different response compared to their individual effects.

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