PARAMETRIC ANALYSIS ON INTERDIGITATED FLOW CHANNEL OF PEMFC PERFORMED BY TAGUCHI METHOD

Dr. V.LAKSHMINARAYANAN
Department of Mechanical Engineering,
B V Raju Institute of Technology, Narsapur,
Telangana- 502313, India.
lux32engineer@yahoo.co.in

ABSTRACT

The Proton Exchange Membrane (PEM) fuel cell is an electrochemical device and its performance depend on the flow channel design, number of flow path, channel depth and width, cross section of the flow channel, operating pressure ,temperature, relative humidity ,mass flow rate of the reactant gases and stoichiometric ratio of the reactants. In this study, optimization of operating and design parameters on interdigitated flow channel of 36 cm^2 *effective area of the PEM fuel cell was considered. The 3-D modeling and analysis of PEM fuel cell was done by Creo Parametric 2.0 and Computational Fluid Dynamics (CFD) Fluent 14.5 software packages respectively. The optimization was done by Taguchi method. Based on the optimization study, the rib to channel width ratio (R: C) - 1:2 have achieved maximum power density of 0.289 W/cm*^{2}.

Keyword : -*Interdigitated flow channel; PEM fuel cell; CFD; Design parameters; Taguchi method.*

---

1. INTRODUCTION

Fuel cells are used to generate the electricity by directly converting chemical energy of fuels (hydrogen and oxygen) without any intermediate stage like classical combustion of two and four stroke engine. Among all types of fuel cells, the proton exchange membrane (PEMFC) has attained important stage, particularly for mobile and portable applications. Besides their high-power producing capability, PEMFCs work at low temperatures, produce only water as byproduct, and can be compactly assembled, making it as one of the leading candidates for the next generation power generator [1]. The PEMFC comprises of polymer solid electrolyte membrane sandwiched between an anode and cathode. However, water is the by-product of electrochemical reaction and water accumulation on cathode side. The removal of water from PEMFC has become an important task, because more water accumulation causes “flooding” and less water causes dryness of membrane can adversely affect the performance of PEMFC. Water accumulation leads the fuel cell performance unpredictable and unreliable under the nominally identical operating conditions. In order to improve the performance of PEMFC, it is important to know more about the mechanism which causes performance loss of PEMFC addressed by Owejan et al. [2] and Nattawut Jaruwasupanta & Yottana Khunatorna [3]. The numerical analysis on six different cross-sections of the flow channel like square, triangle, parallelogram 14o, parallelogram 26o, trapezium and inverted trapezium having 1.25 cm2 effective area of single pass PEMFC were carried out by lakshminarayanan et al [4]. It was concluded that, square flow channel had a peak power density of 1.133 W/cm2. The effect of the various parameters with various landing to channel width (L: C) 1:1, 1:2 and 2:2 of multi pass serpentine flow channel PEMFC with 36 cm2 (6cm x 6cm) active area was analyzed numerically by lakshminarayanan et al [5]. The results revealed that the maximum power density was obtained as 0.658 W/cm2 for the L: C of 1:1. However operating pressure, temperature and inlet mass flow rate of reactant gases influenced the performance of PEMFC considerably. 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 [6]. The results revealed that the maximum power density of interdigitated flow channel with landing to channel width 1:2 showed better performance than the serpentine flow channel with same design parameter. The various operating parameters like cell temperature, pressure, reactants on anode and cathode flow rate has been investigated with 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. The effects of interdigitated flow channel with traditional flow channel, the effects of the flow area ratio and the baffle-blocked position of the interdigitated flow field on the performance of PEMFC were examined experimentally by Yan et al [8]. The results concluded that, the cell performance can be enhanced with an increased inlet flow rate of reactant and cathode humidification temperature. The increasing of inlet pressure improved the consumption of reactants and more homogeneous distribution. The effect of channel design also changed the consumption of reactants and consequently increases water production by Zeroual et al. [9]. So identifying the proper channel and flow field design is a very important task while designing the fuel cell which also affects the performance of fuel cell significantly [10]. It is clearly indicated that immediate attention is required for optimizing the simultaneous influence of operating and design parameters for the performance of the PEM fuel cell. Hence this paper has a detailed study about the optimization of operating pressure, temperature, stoichiometric ratio of inlet reactant mass flow rate and various rib to channel width (L:C)-1:1,1:2, 2:1& 2:2 on interdigitated flow channel of 36 cm2 active area of PEM fuel cell are to be studied and influence their performance are compared.

2. MODEL DEVELOPMENT

Three dimensional (3-D) PEM fuel cell model with interdigitated flow channel of various rib to channel width configurations were created by Creo Parametric 2.0 as shown in Fig.1.

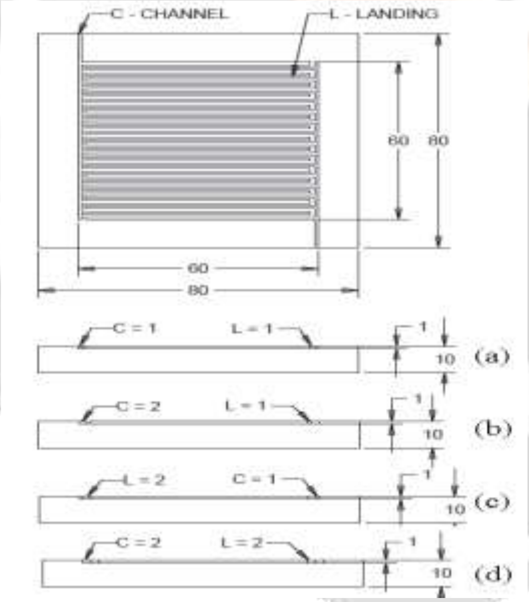

Fig.1.Various rib to channel width (L: C) (a) 1:1 (b) 1:2 (c) 2:1 and (d) 2:2 of interdigitated flow channel of 36 cm2 active area of PEM fuel cell

The modeling was done by creating all individual parts of the PEM fuel cell 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 (R: C-1:1, 1:2, 2:1 and 2:2) of interdigitated flow channel were meshed by using ICEM 14.5 (a module of Ansys 14.5).

Table 1.Dimensions and Zone type, assigning of fuel cell

S.No	Part Name	Width (mm)	Length (mm)	Thickness (mm)	Zone type
1	Anode & Cathode Flow channel	60	60	10	Solid
2	Anode & Cathode catalyst			0.08	Fluid
2 3	Membrane			0.127	Fluid
4	GDL anode & cathode			0.3	Fluid

After geometry modeling, the next step was discretization of PEM fuel cell done by ANSYS 14.5 ICEM software. The Cartesian grid meshing method was used, which is used in the formation of hexahedral mesh to attain accurate results. Split block method used for blocking. 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. The simulation of PEM fuel cell 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. 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.

A control volume approach based on commercial solver FLUENT 14.5 was used to solve the various governing equations. Three-dimensional, double precision and serial processing were used for this model. 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. Multigrid 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. Stabilization method BCGSTAB was selected for H2, O2, H2O, water saturation, electric and proton potential. The Anode and Cathode reference current density was set to be 10000 A/cm2 and 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 has been used to find out the most optimum combination among the input parameters which would result in getting the maximum possible output which cause the performance enhancement of PEM fuel cell. In Taguchi method L16 standard orthogonal array with 4-level and 4 factors was used and the parameters were considered as low, high and medium range values. 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 rib to channel ratios on interdigitated flow field design (R: 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. The theoretical value of hydrogen in the anode side was 4.33E-07 kg/s and oxygen in the cathode side was 3.33E-06 kg/s.

3. RESULTS AND DISCUSSION

As per L16 orthogonal array, the inputs were given to the Ansys CFD Fluent analysis software and having all other parameters constant. The power densities for all 16 runs, obtained from analysis software and the corresponding Signal/Noise (S/N) ratios were found from MINITAB 17 software as shown in the Table 2.

The rib to channel width ratio of 1:1 for interdigitated flow field has shown maximum power densities of 0.279 W/cm2 and minimum power densities of 0.202 W/cm2respectively. Similarly for R:C of 1:2 and 2:1 having maximum power density of 0.287 W/cm2 and 0.216 W/cm2 respectively. The minimum power densities for the same R:C ratios have 0.230 W/cm2 and 0.166 W/cm2 respectively. For the rib to channel width ratio of 2:2 has shown maximum power density of 0.236 W/cm2 and power density of 0.109 W/cm2. The optimization was performed for "Larger the Better" type of Taguchi method since power output of PEM fuel cell 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.3.

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/cm2)	S/N Ratio
1	1x1	1	323	3	0.202	-13.87
2		1.5	333	3.5	0.227	-12.88
3		2	343	4	0.253	-11.95
4		2.5	353	4.5	0.279	-11.08
5	1x2	1	333	4	0.230	-12.76
6		1.5	323	4.5	0.246	-12.19
7		2	353	3	0.283	-10.95
8		2.5	343	3.5	0.287	-10.84
9	2x1	1	343	4.5	0.194	-14.23
10		1.5	353	4	0.216	-13.30
11		2	323	3.5	0.166	-15.62
12		2.5	333	3	0.185	-14.67
13	2x2	1	353	3.5	0.109	-19.27
14		1.5	343	3	0.133	-17.52
15		2	333	4.5	0.236	-12.55
16		2.5	323	4	0.212	-13.49
Average S/N Ratio						-13.572

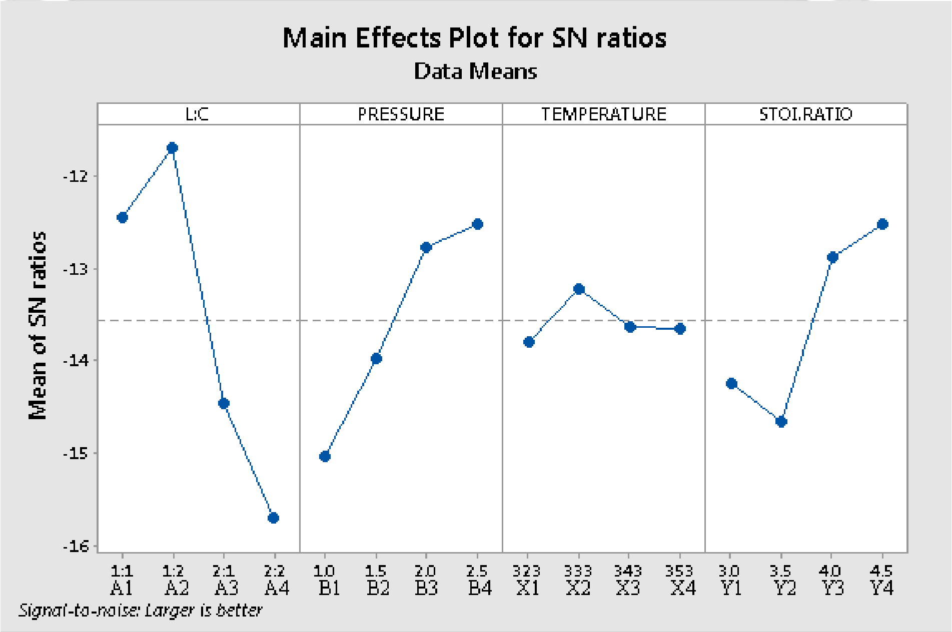

Fig .3. Mean S/N ratio plot for L:C (A1-A4),Pressure (B1-B4),Temperature (X1-X4), Stoi.Ratio (Y1-Y4)

It was concluded that the design parameter such as, rib to channel ratio of interdigitated flow channel having -1:2 as A2, and the operating parameters like pressure - 2.5 bar as B4, temperature - 333 K as X2, Stoichiometric ratio of inlet mass flow rate - 3.5 as Y2 were the optimum parameters to show the better PEM fuel cell 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 factor. It was found that pressure was the predominant factor affecting the performance of PEM fuel cell. The other parameters were also influencing the performance to a considerable extent such as, rib to channel width (R:C) of interdigitated flow channel, operating temperature, stoichiometric ratio of inlet mass flow rate respectively. The percentage contribution of individual parameters, P-test and F-test on the interdigitated flow fields for the performance of PEM fuel cell has been shown in the Table 5.

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
Rib to Channel width (R:C)	-12.44	-11.68	-14.45	-15.71	4.02	1
Pressure (bar)	-15.03	-13.97	-12.77	-12.52	2.51	2
Temperature (K)	-13.79	-13.21	-13.63	-13.65	0.58	4
Stoi.Ratio	-14.25	-14.65	-12.87	-12.51	2.14	3

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

Factors	DOF	Sum of squares	Variance	F-test	P-Test	Contribution (%)
Pressure	2	0.008165	0.00408	88.71	0.283	45.24
Temperature	2	0.000064	0.00003	27.26	0.566	0.97
Stoichiometric ratio	2	0.002082	0.00104	19.39	0.825	10.54
R:C	3	0.005352	0.00178	5.4	0.036	19.02
Pressure & Temperature	1	0.000107	0.00011	0.22	0.428	0.11
Pressure & R:C	3	0.004808	0.00160	0.81	0.059	16.95
Error	2	0.000234	0.00012			7.17
Total	15	0.039138	0.008766167	141.79	2.197	100

It has been observed from the Table 4, operating pressure has been contributed to be 45.24 % , operating temperature was 0.97 %, the stoichiometric ratio of the reactants and R:C has contributed 10.54 % and 19.02 % respectively of the PEM fuel cell performance. Also the combined effect of combination of pressure with temperature and pressure with R:C has shown 0.11 % and 16.95 % respectively contributing to peak power performance of the PEM fuel cell.

4. CONCLUSIONS

The combined effect of all the parameters exhibited a different response compared to their individual effects. The maximum power density of optimizing the four different parameters on interdigitated flow channel of 36 cm2 active area of PEM fuel cell using Minitab 17 provides 0.287 W/cm2 from R:C-1:1 with 2.5 bar operating pressure, 343 K temperature and 3.5 stoichiometric ratio of inlet reactant gases and R2 value was arrived 95.2 %. The effect of operating and design parameters was affecting the performance of PEM fuel cell considerably.

5. REFERENCES

[1]. Yun Wang, Suman Basu, Chao-Yang Wang. Modeling two-phase flow in PEM fuel cell channels, Journal of Power Sources. , 2008, 179 ; 603–617.

[2]. Owejan JP, Trabold TA, Jacobson DL, Arif M, Kandlikar SG . Effects of flow field and diffusion layer properties on water accumulation in a PEM fuel cell, International Journal of Hydrogen Energy., 2007, 32; 4489 – 4502.

[3]. NattawutJaruwasupanta , YottanaKhunatorna.,Effects of difference flow channel designs on Proton Exchange Membrane Fuel Cell using 3-D Model, Energy Procedia, 2011, 9; 326 – 337.

[4]. Lakshminarayanan V, Karthikeyan P, Muthukumar M, Senthilkumar A P, Kavin B, Kavyaraj A, ‘Numerical investigation of performance studies on single pass PEM fuel cell with various flow channel design’, Applied Mechanics and Materials, Vols. 592-594 , pp 1672-1676, 2014.

[5].Lakshminarayanan V, Karthikeyan P, Kiran Kumar DS and Dhilip Kumar SM K. Numerical analysis on 36cm2 PEM fuel cell for performance enhancement, ARPN Journal of Engineering and Applied Sciences, 2016, 11, no. 2.

[6].Lakshminarayanan V & Karthikeyan P. Optimization of Flow Channel Design and Operating Parameters on Proton Exchange Membrane Fuel Cell Using Mat lab. Periodica Polytechnica Chemical Engineering. Budapest Univ Technology Economics. 2016, 60, 3; 173-180.

[7]. Khazaee, I, Ghazikhani, M &Mohammadiun, M , 'Experimental and thermodynamic investigation of a triangular channel geometry PEM fuel cell at different operating conditions', ScientiaIranica, vol. 19, no. 3, pp. 585-593, 2012.

[8].Yan WM, Chen CY, Mei SC, Soong CY & Chen F. 'Effects of operating conditions on cell performance of PEM fuel cells with conventional or interdigitated flow field, Journal of Power Sources,2006, 162, no. 2; 1157-1164.

[9]. Zeroual,M.; BelkacemBouzida,S.; Benmoussa,H.;Bouguettaiaa,H.(2012). Numerical study of the effect of the inlet pressure and the height of gas channel on the distribution and consumption of reagents in a fuel cell (PEMFC), Energy procedia, 18, 205-214.

[10]. AtillaBıyıkoglu. Review of proton exchange membrane fuel cell models, International Journal of Hydrogen Energy,2005, 30, 1181 – 1212.