Performance study for 49 cm^2 multi pass flow channel of PEMFC

Dr.V.LAKSHMINARAYANAN[1] Dr.P.VELMURUGAN[2] JOBIN.C.VARGHESE[1]

[1]*Department of Mechanical Engineering, B V Raju Institute of Technology, Narsapur, Telangana, India – 502313,*
[2]*Department of Mechanical Engineering, Malla Reddy College of Engineering, Hyderabad, Telangana.*

ABSTRACT :- *The Polymer Electrolyte Membrane Fuel Cell (PEMFC) performance depends on the design and operatingparameters. In this paper, optimization of operating parameters such as pressure, temperature, stoichiometric ratio of inlet reactant mass flow rate and design parameters like various landing to channel width (L:C) 1:1, 1:2, 2:1 and 2:2 on 49 cm^{2}effective area multi pass serpentine flow channel of the PEMFC was studied. The analysis was carried out on the various parameters 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- 1:2havegiven 0.223 W/cm^{2}maximum power density on PEMFC performance and square of response factor (R^2) was achieved as 99.69 %.*

Keywords- *Optimization; Design parameters; PEMFC; CFD; Square of response factor; Multi pass serpentine flow channel.*

I. INTRODUCTION

Fuel cells are converting chemical energy of fuels (hydrogen and oxygen) 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 fuel cell has reached important stage, particularly for mobile and portable applications. Besides their high-power producing capability, PEMFCs 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 PEMFC consists of polymer solid electrolyte membrane sandwiched between an anode and cathode. However, water and heat is the by-product of electrochemical reaction. The water management of PEMFC has become an important task, whereas too much of water accumulation causes "flooding" or too little water causes dryness of membrane can adversely impact the performance and lifetime of PEMFCs. Water accumulation leads the fuel cell performance unpredictable and unreliable under the nominally identical operating conditions. In order to enhance the performance and reliability of PEMFC, it is important to know more about the mechanism which causes performance loss, such as current density distributions, high ionic resistance due to dry membrane and flooding on the cathode [2-4].Dehydration is drying the membrane due to deficiency of water in the anode side which indicates to higher ohmic and ionic losses, which leads to a significant drop of potential and power in the PEMFC [5-6].

The numerical analysis were carried out with six different cross-sections of the channel (square, triangle, parallelogram 14°, parallelogram 26°, trapezium and inverted trapezium) with a constant cross sectional area of single pass PEMFC [7]. It was concluded that, square flow channel of single pass PEMFC having a peak power density of 1.133 W/cm^2 @ 2.834 A/cm^2& 0.4 V. The performance enhancement of the combined effect of design and operating parameters of serpentine and interdigitated flow channel with 25 cm^2 active area of PEMFC with four different parameters using optimization technique and CFD [8]. The results revealed that the peak power density of interdigitated flow channel with landing to channel width (L:C) 1:2 showed better than the serpentine flow channel with L: C-1:2.optimization of operating and design parameters such as pressure, temperature, stoichiometricratio of inlet reactant mass flow rate and various landing to channel width on serpentine flow channel of 16 cm^2 active area of the PEMFC was studied by Lakshminarayanan et al [9]. The results were concluded that, the L: C- 1:2 has maximum power density of 0.422 W/cm^{2}and square of response factor (R^2) was achieved by Taguchi method as 97.90 %.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 PEMFC with 36 cm^2 (6cm x 6cm) effective area was analyzed numerically by Lakshminarayanan et al [10].He concluded that the maximum power density of 0.658W/cm^2 was obtained in the L: C of 1:1. However, operating parameters like pressure, temperature and inlet mass flow rate of reactants influenced the performance of PEMFC significantly. The critical issue for PEMFCs can be resolved through appropriate design of flow channels and finding the proper operating parameters for effective removal of water built on the flow field plates. Hence the immediate attention required towards optimizing the simultaneous influence of operating and design parameters for the performance of the PEMFC using CFD Fluent and MINITAB software packages. Hence this paper has a detailed study about the optimization of operating pressure, temperature, stoichiometric ratio of inlet reactant mass flow rate and various landing

International Journal of Advance Engineering and Research Development (IJAERD)
International Conference of Trends in Information, Management, Engineering and Sciences (ICTIMES)
Volume 5, Special Issue 02, Feb.-2018

to channel width (L:C)-1:1,1:2,2:1&2:2 of 49 cm^2 active area on multi pass serpentine flow channel of PEMFC are studied and influence their performance were compared.

II. 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 assignments of zones for various parts were done by Workbench 14.5. The various geometrical models (L: C-1:1, 1:2, 2:1 and 2:2) of serpentine multi pass flow channel were meshed by using ICEM 14.5 (a module of Ansys 14.5). Three dimensional (3-D) PEMFC model with serpentine flow channel of various landing to channel width configurations were created by Creo Parametric 2.0 as shown in Fig.1.

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

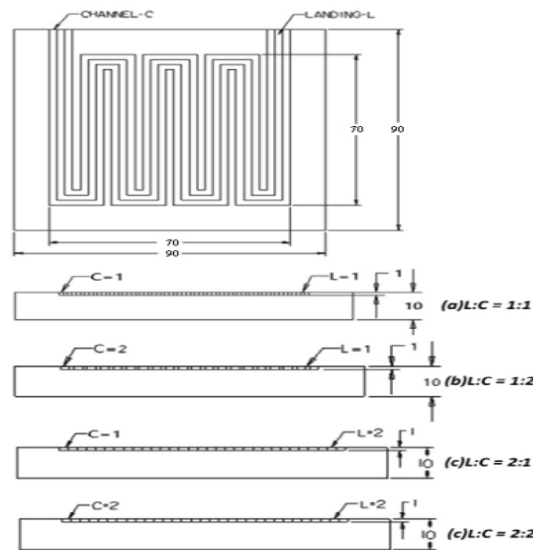| S.No	Part Name	Width (mm)	Length (mm)	Thickness (mm)	Zone type
1	Anode & Cathode Flow channel			10	Solid
2	Anode & Cathode catalyst			0.08	Fluid
3	Membrane	40	40	0.127	Fluid
4	GDL anode & cathode			0.3	Fluid

Fig.1.Various landing to channel width (L: C) (a)1:1 (b)1:2 (c)2:1 and (d)2:2 of multi pass serpentine flow channel of 49 cm^2 active area of PEMFC.

a. Boundary conditions

Anode gas channel and Cathode gas channel is set as inlet (mass flow inlet) and outlet zones(pressure outlet)

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

International Journal of Advance Engineering and Research Development (IJAERD)
International Conference of Trends in Information, Management, Engineering and Sciences (ICTIMES)
Volume 5, Special Issue 02, Feb.-2018

Anode and cathode catalyst layers

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 14.5 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

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 H_2, O_2, and H_2O 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, H_2, O_2, and H_2O 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 H_2, O_2, H_2O and water saturation. The electric and proton potential values were set at 0.0001. Stabilization method BCGSTAB was selected for H_2, O_2, H_2O, water saturation, electric and proton potential. The Anode and Cathode reference current density was set to be10000A/cm^{2}and 20 A/cm^2 respectively 0.1 kmol/m^3 was set to anode and cathode reference concentration,Anode and cathode exchange coefficient was set to be 2.The Reference diffusivity of H_2,O_2 and H_2O was set to as 3E-5.

III. TAGUCHI METHOD

Taguchi method can be used to find out the most optimum combination among the input parameters (Design and Operating) 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 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 landing to channel ratios on serpentine multi pass flow field design (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. The theoretical value of hydrogen in the anode side was 4.33E-07 kg/s and cathode side was 3.33E-06 kg/s.

IV. 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 14.5 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 1:2 for serpentine multi pass flow field has shown maximum and minimum power density of 0.214 W/cm^2 and 0.151 W/cm^2 respectively. Similarly for L:C of 1:2 and 2:1 having maximum power density of 0.223 W/cm^2 and 0.133 W/cm^2 respectively. The minimum power densities for the same L:C ratios having 0.126 W/cm^2 and 0.104 W/cm^2 respectively. For the landing to channel width ratio of 2:2 has shown maximum power density of 0.178 W/cm^2 and minimum power density of 0.095 W/cm^2. 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.

International Journal of Advance Engineering and Research Development (IJAERD)
International Conference of Trends in Information, Management, Engineering and Sciences (ICTIMES)
Volume 5, Special Issue 02, Feb.-2018

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		1	313	3	0.151	-16.40
2	1x1	1.5	323	3.5	0.193	-14.28
3		2	333	4	0.214	-13.39
4		2.5	343	4.5	0.173	-15.24
5		1	323	4	0.126	-17.98
6	1x2	1.5	313	4.5	0.193	-14.27
7		2	343	3	0.219	-13.19
8		2.5	333	3.5	0.223	-13.04
9		1	333	4.5	0.125	-18.07
10		1.5	343	4	0.133	-17.53
11	2x1	2	313	3.5	0.114	-18.83
12		2.5	323	3	0.104	-19.62
13		1	343	3.5	0.095	-20.48
14	2x2	1.5	333	3	0.119	-18.49
15		2	323	4.5	0.163	-15.77
16		2.5	313	4	0.178	-15.00
					Average S/N Ratio	-16.35

It was concluded that the design parameter such as, landing to channel ratio of serpentine multi pass flow channel having -1:2 as A2, and the operating parameters like

pressure - 3 bar as B3, temperature - 333 K as C3, Stoichiometric ratio of inlet mass flow rate - 4.5 as D4 were the optimum parameters to show the better PEMFC performance.
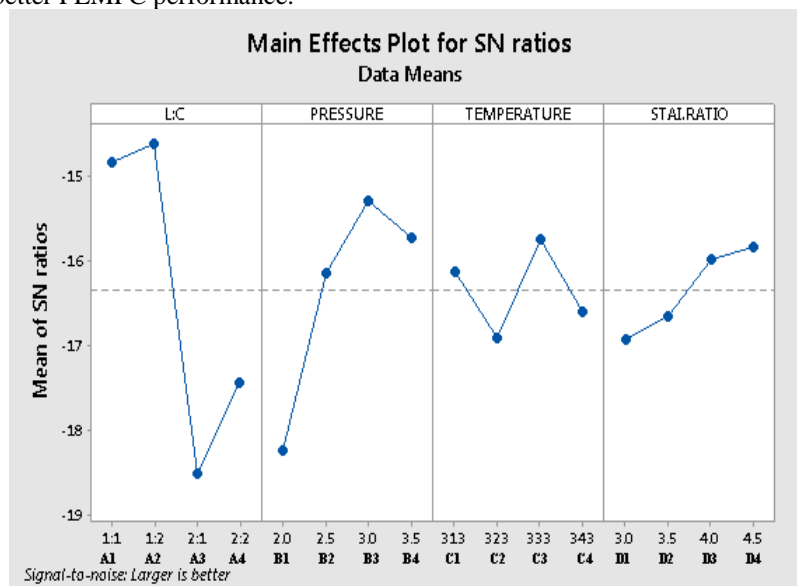

Fig .2. Mean S/N ratio plot for L:C (A1-A4),Pressure (B1-B4),Temperature (C1-C4), Stoi.Ratio (D1-D4).

International Journal of Advance Engineering and Research Development (IJAERD)
International Conference of Trends in Information, Management, Engineering and Sciences (ICTIMES)
Volume 5, Special Issue 02, Feb.-2018

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.

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)	-14.83	-14.62	-18.52	-17.43	3.9	1
Pressure (bar)	-18.23	-16.14	-15.3	-15.73	2.94	2
Temperature (K)	-16.13	-16.91	-15.75	-16.61	1.17	3
Stoi.Ratio	-16.93	-16.66	-15.97	-15.84	1.09	4

It was found that landing to channel width (L:C) of 49 cm^2 serpentine multi pass flow channel was the predominant factor affecting the performance of PEMFC. The other parameters were also influencing the performance of PEMFC to a considerable extent such as, operating pressure, operating temperature, stoichiometric ratio of inlet mass flow rate respectively. The percentage contribution of individual parameters, P-test and F-test on the serpentine multi pass flow fields for the performance of PEMFC has been shown in the Table 4.It has been observed thatthe operating pressure has been shown to be 34.3 % contribution on peak power performance of the PEMFC for the serpentine multi pass flow field. Similarly for the L:C, operating temperature and stoichiometric ratio of the reactants has contributed 28.9 %, 6.3 % and 1.9 % respectively of the PEMFC performance. Also the combined effect of combination of pressure with temperature and pressure with L:Chas shown 9.8 % and 16.6 % respectively contributing to peak power performance of the PEMFC.

Table 4.The percentage contribution of individual parameters of serpentine multi pass flow channel

Factors	DOF	Sum of squares	Variance	F-test	P-Test	Contribution (%)
Pressure	2	0.006615	0.00331	157.44	0.031	34.3
Temperature	2	0.001287	0.00064	2.08	1.021	6.3
Stoi.ratio	2	0.000447	0.00022	10.65	0.299	1.9
L:C	3	0.008395	0.00280	66.61	0.015	28.9
Pressure & Temperature	1	0.000891	0.00089	21.2	0.044	9.8
Pressure & L:C	3	0.004882	0.00163	38.73	0.025	16.6
Error	2	0.000084	0.00004			2.2
Total	15	0.027311	0.009533	296.71	1.435	100.00

CONCLUSION

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 serpentine multi passmulti flow channel of 49cm^2 active area of PEMFC using Minitab 17 provides 0.223 W/cm^2 and R^2 value was arrived 99.69 %. The optimum power density 0.404 W/cm^2 was obtained from L:C-1:2 with 3bar operating pressure, 333 K temperature and 4.5 stoichiometric ratio of inlet reactant gases of 49 cm^2 active area of the CFD PEMFC model. Theeffect of operating and design parameters was affecting the performance of PEMFC more significantly.

International Journal of Advance Engineering and Research Development (IJAERD)
International Conference of Trends in Information, Management, Engineering and Sciences (ICTIMES)
Volume 5, Special Issue 02, Feb.-2018

REFERENCES

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

[2] Owejan, J.P.; Trabold, T.A.; Jacobson, D.L.; Arif, M.; Kandlikar, S.G. (2007). Effects of flow field and diffusion layer properties on water accumulation in a PEM fuel cell, International Journal of Hydrogen Energy, 32, 4489 – 4502.

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

[4] Xianguo Li, Imran Sabir, Jaewan Park, "A flow channel design procedure for PEM fuel cells with effective water removal," Journal of Power Sources, vol.163(2), pp.933-942, 2007.

[5] Y. Sone, P. Ekdunge, D. Simonsson, "Proton Conductivity of Nafion 117 as Measured by a Four-Electrode AC Impedance Method," J. Electrochem.Soc,vol. 143, pp. 1254-1259, 1996.

[6] T. V. Nguyen, R.E. White, "A Water and Heat management Model for Proton-Exchange-Membrane Fuel Cells," J. Electrochem. Soc. Vol.140, pp. 2178–2186,1993.

[7] 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.

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

[9]. Lakshminarayanan V, BalaKarthick KS. Optimisation of 16cm^2 Single Pass Serpentine Flow Channel of PEMFC Using Taguchi Method', International Journal of Theoretical and Applied Mechanics, 2017, 12, 523-532.

[10] Lakshminarayanan V, Karthikeyan P, Kiran Kumar D S and Dhilip Kumar S M K, 'Numerical analysis on 36cm^2 PEM fuel cell for performance enhancement', ARPN Journal of Engineering and Applied Sciences, Vol. 11, no. 2, 2016. ISSN 1819-6608.