International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017),e-ISSN:2455-2585
International Conference on
Recent Explorations in Science, Engineering And Technology (ICRESET'19)
Volume-5, Special Issue-March, 2019.

Performance enhancement of PEMFC by CFD

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Abstract- The various parameters affect the performance of the Proton Exchange Membrane Fuel Cell (PEMFC). In this work, the performance of 81 cm^2 active area with Rib to Channel width ratio of (R: C)-2:2 interdigitated flow channel of PEMFC with various operating temperatures ranges (313, 3123, 333 and 343 K), pressure (1, 1.5, 2 and 2.5 bar) and various mass flow rate of hydrogen and oxygen (2.5, 3, 3.5 and 4) was analysed. The model was developed and analysed using PRO-E software and the ANYSYS 14.0 software respectively. The L: C-2:2 has produced the maximum power density was obtained as 0.199 W/cm^2 at 2 bar pressure and 323 K on interdigitated flow channel of PEMFC. Based on the optimization study by MINITAB 17 software, the square of response factor (R^2) was achieved as 99.01%.

Keywords—CFD, Pro E, Power density, Rib to Channel width ratio.

I. Introduction

The environmental impacts of non-renewable power sources and energy scarcity in many countries, focuses on renewable energy development. The Polymer Electrolyte Membrane fuel cells are environment friendly power source which is suitable for powering both portable devices and mobile application due to their high energy density and lower operating temperature range viz, 30^{o}C - 70^{o}C [1]. The performance enhancement of the combined effect of operating and design parameters of single pass serpentine and interdigitated flow channel with 25 cm^2 active area of PEMFC carried out by Lakshminarayanan and Karthikeyan [2]. The results shown that the maximum power density of interdigitated flow channel with R:C- 1:2 exhibited better performance than the serpentine flow channel. To increase the polarization of fuel cell, the flow channel design of the fuel cell was properly designed that the uniform distribution of reactant was achieved to reach the membrane through the gas diffusion layer so that the improving current and proper temperature dissipation was achieved. So the performance was affected by the design parameters like flow field and channel design of PEMFC analyzed by Oosthuizen et al [3].It was an important task in identifying the flow field design and flow channel which affects the performance of fuel cell significantly while designing [4]. Generally the trend is going to do the analysis of PEM fuel cell with various flow field designs and their influence using Computational Fluid Dynamics (CFD) [5]. In this study, the performance of PEMFC with Rib to Channel width of (R: C-2:2) on interdigitated flow channel with various pressure (1, 1.5, 2 and 2.5 bar), operating temperature (313, 323, 333 and 343 K) and various mass flow rate of hydrogen and oxygen (2.5, 3, 3.5 and 4) was analysed numerically.

II. METHODOLOGY

The modelling of 81 cm^{2}effective area with interdigitated flow channel with the rib to channel width ratio of R: C-2:2 of PEM fuel cell involved three major steps. The first step was creating individual parts of the multi pass single channelled interdigitated PEM fuel cell which was done in Pro E software. Creating the mesh from the geometry using ICEM CFD 16.0 was the second step. The simulation has been solved by all the simultaneous equations to obtain reaction kinetics of PEM fuel cell, namely mass fraction of H_2, O_2, H_2O, temperature, static pressure and current flux density distribution. Creating a good mesh has been one of the most difficult steps involved in modelling. It requires a careful balance of creating enough computational cells to capture the geometry without creating much of its mesh 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 sample results when simulated. The last step was the adoption of boundary condition with physical and operating parameters of PEM fuel cell for solving the reaction kinetics. The analysis was done by the Pro E software and the Fluent CFD 16.0 software and the Fig.1 shows the 2D model of interdigitated flow channel of 81 cm^2 effective area with rib to channel ratio of R: C-2:2.

The Table1 shows the interdigitated flow channel of 81 cm^2 effective area of PEM fuel cell. 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 and the cathode terminal is at a fixed potential which is less than the open circuit potential. Both the terminals should be assigned as 'wall' boundary type. Voltage jump zones can optionally be placed between the gas diffusion layer and current collector. Faces which represent solid interfaces must be of the type 'wall'.

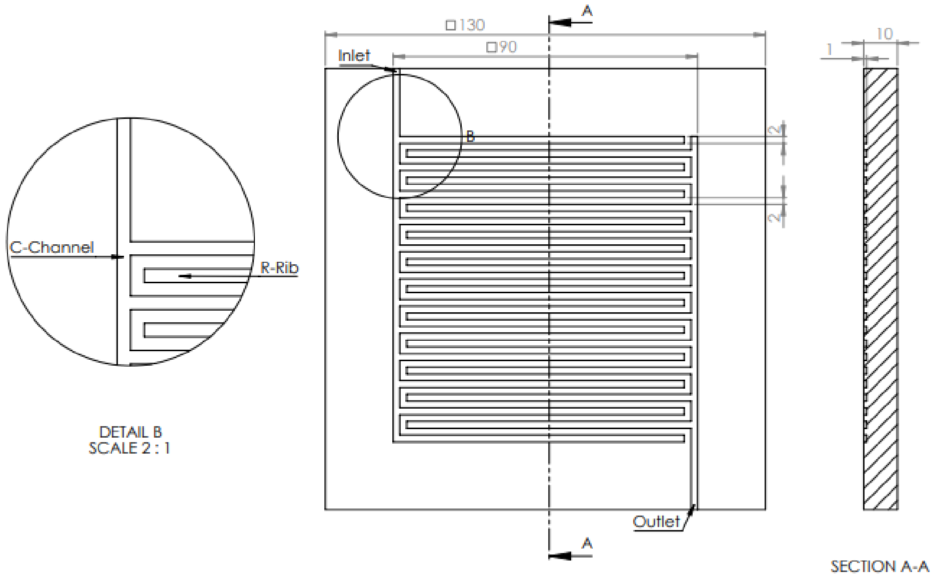

Fig. 1. 2D model of interdigitated flow channel of 81 cm^2 effective area with Rib to Channel ratio R: C-2:2

Table 1. DIMENSIONS OF ACTIVE AREA OF PEM FUEL CELL

S.No	Part Name	Width(mm)	Length(mm)	Thickness (mm)	Zone type
1	Catalyst - anode & cathode	90	90	0.08	Fluid
2	Current collector - anode & cathode	130	130	10	Solid
3	Membrane	90	90	0.127	Fluid
4	GDL - anode & cathode	90	90	0.3	Fluid

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. A control volume approach based on commercial solver FLUENT 14.0 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, H_2, O_2, and H_2O 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 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 specification of the PEMFC was listed in Table 1.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 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 are pressure (1, 1.5, 2 and 2.5 bar), temperature (313, 323, 333 and 343 K) and various stoichiometric ratio of hydrogen and oxygen on R:C- 2:2 of interdigitated flow channel of PEMFC.

III. 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 14.0 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.

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

S.NO	PRESSURE (bar)	TEMPERATURE (K)	STOI.RATIO		POWER DENSITY (W/cm2)	S/N Ratio
			HYDROGEN	OXYGEN		
1	1.0	313	2.5	2.5	0.1852	-14.6472
2	1.0	323	3.0	3.0	0.1913	-14.3657
3	1.0	333	3.5	3.5	0.1943	-14.231
4	1.0	343	4.0	4.0	0.1950	-14.199
5	1.5	313	3.0	3.5	0.1920	-14.334
6	1.5	323	2.5	4.0	0.1925	-14.311
7	1.5	333	4.0	2.5	0.1904	-14.407
8	1.5	343	3.5	3.0	0.1935	-14.266
9	2.0	313	3.5	4.0	0.1993	-14.009
10	2.0	323	4.0	3.5	0.1921	-14.329
11	2.0	333	2.5	3.0	0.1894	-14.452
12	2.0	343	3.0	2.5	0.1863	-14.596
13	2.5	313	4.0	3.0	0.1963	-14.142
14	2.5	323	3.5	2.5	0.1832	-14.742
15	2.5	333	3.0	4.0	0.1909	-14.384
16	2.5	343	2.5	3.5	0.1886	-14.489
Average S/N Ratio						

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.

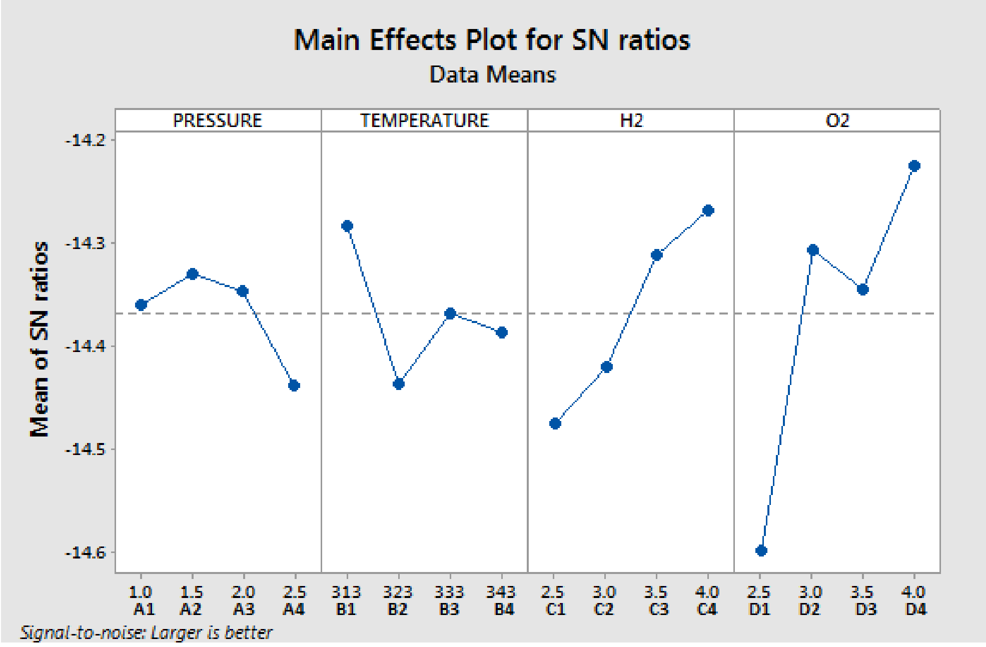

FIGURE 2. MEAN S/N RATIO PLOT FOR PRESSURE (A), TEMPERATURE (B) AND STOICHIOMETRIC RATIO (C)

It was concluded that the serpentine flow channel having R:C-2:2, operating parameter such as pressure having -1.5 bar as A2, temperature - 323 K as B2 and the mass flow rate of hydrogen as - 4 as C4 and oxygen 4 as D4 respectively 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.

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

Level	1	2	3	4	Delta	Rank
pressure	0.1915	0.1921	0.1918	0.1898	0.0023	4
Temperature	0.1932	0.1898	0.1912	0.1908	0.0034	3
Stoi.Ratio of Hydrogen	0.1889	0.1901	0.1926	0.1934	0.0045	2
Stoi.Ratio of Oxygen	0.1863	0.1926	0.1918	0.1944	0.0081	1

The factor with highest delta value indicates higher significance. In order to validate the power density obtained from the Taguchi method, the optimum combination of parameters was given as input to CFD Fluent 14.0 software package. The power density obtained from the CFD Fluent 14.0 was in close agreement with power density obtained from Taguchi calculation with square of response factor (R^2) of 99.01% was achieved and was computed from the MINITAB 17 software.

IV. CONCLUSION

The combined effect of all the parameters exhibited a different response compared to their individual effects. The maximum power density of optimizing the three different parameters on interdigitated flow channel of 81 cm2 active area of PEMFC using Minitab 17 and R^2 value was arrived 99.01. The effect of operating and design parameters was affecting the performance of PEMFC more significantly. Among the various operating parameters like pressure (1, 1.5, 2 and 2.5), operating temperature (313, 323, 333 and 343 K) and stoichiometric ratio (2.5, 3, 3.5 and 4), the operating pressure of 1.5 bar, 313K temperature , and stoichiometric ratio of hydrogen and oxygen 4 times to the theoretical values show highest significant values on 81 cm^2 effective area with R:C- 2:2 of PEMFC.

REFERENCES

1.Manso,A.P.Garikano, X.& Garmendia Mujika,M.(2012)„Influence of geometric parameters of the flow fields on the performance of a PEM fuel cell‟, A review International Journal of Hydrogen Energy, 37, pp15256-15287.

2. V. Lakshminarayanan & P. Karthikeyan, 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.

3. P.H. Oosthuizen, L. Sun, K.B. McAuley, "The effect of channel-to-channel gas crossover on the pressure and temperature distribution in PEM fuel cell flow plates," Appl. Thermal Eng. 25, 2005, pp. 1083–1096.

4. Andrew Higier, Hongtan Liu, "Effects of the difference in electrical resistance under the land and channel in a PEM fuel cell," Int. J. Hydrogen Energy, 36, 2011, pp. 1664-1670.

5. GalipH.Guvelioglu, Harvey G.Stenger, "Computational fluid dynamics modeling of polymer electrolyte membrane fuel cells," Journal of Power Sources.147, pp.95-106, 2005.