Optimization of serpentine flow channel of 81 cm2 of PEMFC

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Abstract

Operating parameters like pressure, temperature, stoichiometric ratio of reactants, relative humidity and design parameters like rib width to channel width (R:C) on flow channel design, shape of the flow channel and the number of passes on the flow channel are influenced the performance of the Proton Exchange Membrane Fuel Cell (PEMFC). In this paper, optimization of operating parameters such as, pressure, temperature, inlet reactant mass flow rate with rib width to channel width (R:C) - 1:1 on serpentine flow channel of 81 cm2 active area of the PEMFC was studied. Creo Parametric 2.0 and CFD Fluent 14.0 software packages were used to create the 3 Dimensional (3-D) model and simulation of PEMFC. The optimization was carried out on the various operating parameters of Taguchi method using Minitab 17 software. Based on the optimization the R: C- 1:1 has maximum influence on PEMFC performance and square of response factor (R2) was achieved as 98.71 %.

Keywords: CFD, Optimization, Operating parameters, Square of response factor, Taguchi method.

1. Introduction

The Proton Exchange Membrane Fuel Cell PEMFCs are being developed for commercial applications in the areas of transportation and back-up power. One of the main advantages is the negligible emission of pollutants, such as SOx, NOx, particulates [1].It is Eco-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 [2].The PEMFC consists of polymer solid electrolyte membrane placed between an anode and cathode. However, water is a by-product of electrochemical reaction on cathode flow channel and partial pressure of water vapour causes condensation of water on anode flow channel. 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 non-uniform concentration, current density distributions, high ionic resistance due to dry membrane and high diffusive resistance due to the flooding on the cathode which was addressed by Nattawut Jaruwasupanta & Yottana Khunatorna [3] and Owejan et al. [4]. So the critical issue for PEMFCs can be resolved through appropriate design of flow channels for effective removal of water built on the flow field (bipolar) plates.

However, operating parameters like pressure, temperature and reactants influenced the performance of PEMFC significantly. 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. [5].Equal current distribution must be ensured through uniform velocity distribution of the reactants at the flow channel. Otherwise, parasitic current may be occurred due to potential differences. The cell temperature must be kept uniform so that the heat produced by electrical resistance and electrochemical reactions must be removed from the cell addressed by Atilla Bıyıkoglu[6].A single channel PEMFC with ten operating and design parameters were optimized using Taguchi method for enhancing PEMFC performance by Karthikeyan et al. [7]. The maximum power density corresponding to Taguchi calculations were in good agreement with analysis software results indicating the compatibility of Taguchi method for PEMFC applications [8]. The various operating parameters with Multipass serpentine flow channel PEMFC with 36 cm2 effective area was analyzed numerically by Lakshminarayanan et al [9].The result was concluded that the maximum power densities was obtained in the L: C of 1:1. Nicholas S. Siefert [10] concluded in his study that the serpentine channels are very effective to remove the liquid because of its high gas velocity. However, Water accumulation leads the fuel cell performance unpredictable and unreliable under the nominal operating conditions. So the critical issue for PEMFC can be resolved through appropriate design of flow channels for effective removal of water built in the flow field plates.The performance of serpentine and interdigitated flow channel of PEM fuel cell with many parameters has been optimized by Taguchi method numerically. The result revealed that the interdigitated flow channel showed better performance than serpentine flow channel by Lakshminarayanan et al [11]. So identifying the proper channel and flow field design are also affecting the performance of fuel cell significantly [12]. 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) [13].It is clearly evident that there is a need for immediate attention towards analyzing and optimizing the simultaneous influence of operating parameters for the performance of the PEMFC using CFD Fluent 14.0 and MINITAB 17software packages. Hence this paper has a detailed study about the optimization of pressure, temperature and inlet reactant mass flow rate with rib to channel width (R:C)-1:1 on serpentine flow channel of 81 cm2 active area of PEMFC are studied and influence their performance were compared.

2. Model development

Three dimensional (3-D) PEMFC model with serpentine flow channel of R:C-1:1 configuration were created by Creo Parametric 2.0 as shown in Fig.1. 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.

Table 1. Dimensions and Zone type, assigning of 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

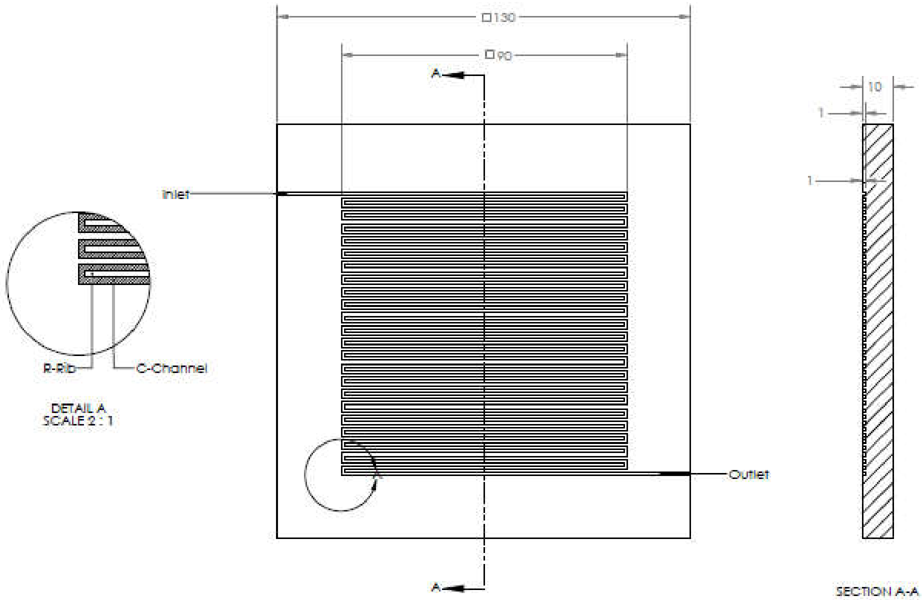

Figure 1. Rib to channel width (R: C)- 1:1 of serpentine flow channel of 81 cm2 active area of PEMFC

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, 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 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 L9 standard orthogonal array with 3-level and 3 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 9 runs itself. The factors considered for the first stage of analysis are pressure (1, 1.5 and 2 bar), temperature (303, 313, 323 and 333 K) on R:C- 1:1of serpentine flow channel of PEMFC.

3. Results and discussion

As per L9 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 9 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 9 runs of optimization

S. NO	PRESSURE(bar)	TEMPERATURE (K)	STOI.RATIO	POWER DENSITY(W/cm2)	S/N Ratio
1	1	303	3	0.1509	-16.4286
2	1	313	3.5	0.1584	-16.0049
3	1	323	4	0.1535	-16.2778
4	1.5	303	3.5	0.1408	-17.0279
5	1.5	313	4	0.1485	-16.5655
6	1.5	323	3	0.1511	-16.4147
7	2	303	4	0.1462	-16.7011
8	2	313	3	0.1503	-16.4608
9	2	323	3.5	0.1522	-16.3517
Average S/N Ratio					-16.4703

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.

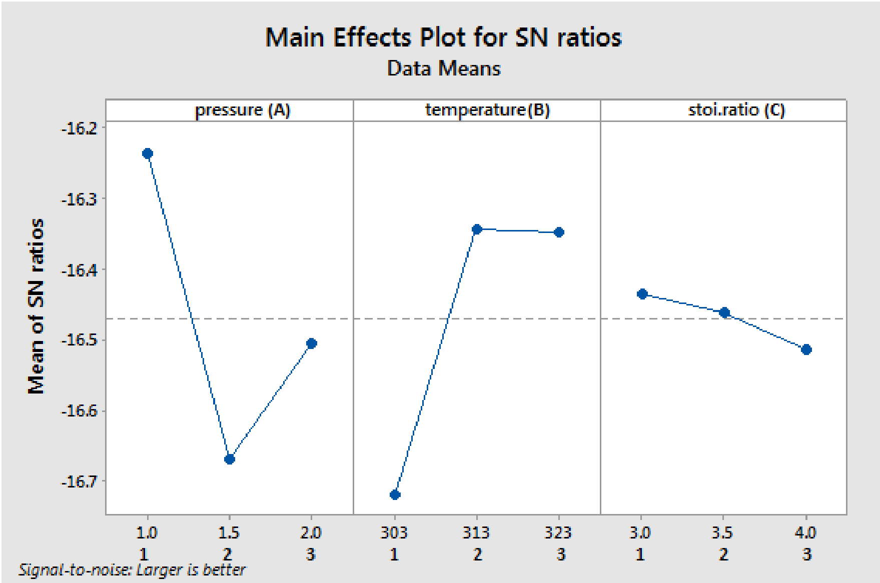

Figure 2. Mean S/N ratio plot for Pressure (A), Temperature (B) and Stoichiometric ratio (C)

It was concluded that the serpentine flow channel having R:C-1:1, operating parameter such as pressure having -1bar as A1, temperature - 313 K as B2 and the mass flow rate - 3 as C3 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	Delta	Rank
pressure	-16.24	-16.67	-16.5	0.43	1
Temperature	-16.72	-16.34	-16.35	0.38	2
Stoi.Ratio	-16.43	-16.46	-16.51	0.08	3

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 (R2) of 98.71% was achieved and was computed from the MINITAB 17 software.

4. 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 serpentine flow channel of 81 cm2 active area of PEMFC using Minitab 17 and R2 value was arrived 98.71. 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 and 2), operating temperature (303, 313, 323 and 333 K) and stoichiometric ratio (3, 3.5 and 4), the operating pressure of 1 bar, 313K temperature and 3 times the stoichiometric ratio shows highest significant values on 81 cm2 effective area with R:C- 1:1 of PEMFC.

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