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EFFECTS OF FLOW CHANNEL GEOMETRY ON THE PERFORMANCE OF PEM FUEL CELL

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ABSTRACT: To generate greener environment, the alternative sources are necessary. In alternative sources, less emission energy sources are needed to control the emission and fossil fuel depletions. Proton exchange membrane fuel cells have the benefit of zero emission, quick start up, easy implementation, long lifetime and low operating temperature. Performance of PEM fuel cell is depending upon the various operating parameters and geometrical parameters. The performance is mainly caused by the geometrical parameters such as flow field, flow channel, catalyst layers. In this paper, the different flow channel cross sectional shape and the effects of the flow channel designs on the performance of proton exchange membrane fuel cell are reviewed. The major performance increment is depending upon the flow channel cross section. Because of the varying cross sectional areas, the fuel is forced on the gas diffusion layer and enhances the chemical reaction that increase the performance of proton exchange membrane fuel cell.

KEYWORDS: Alternative source, Flow channel, Fuel cell, PEM fuel cell, Zero emission.

1 INTRODUCTION

Now a days the world is concerned about the alternative sources to produce a cleaner environment by overcoming the emissions due to pollution and depletion of fossil fuels. One of the best alternative sources is a fuel cell. Due to the advantages and reliability of the fuel cell, it considered as the best alternative source. Depending upon the electrolyte used in the fuel cell, it has to be classified as follows, 1. Proton exchange membrane fuel cell, 2.Solid oxide fuel cell, 3.Phosphoric acid fuel cell, 4.Molten carbonate fuel cell. Due to the benefit of zero emission the PEM fuel cell has to be chased as best alternative instead of energy sources.

Fuel cells are the one which converts the chemical reaction in the fuel cell into electrical energy. PEM fuel cell consists of three segments; anode, membrane, cathode. Anode is made up of platinum powder and cathode is made up of Nickel and nano material based catalyst membrane that is used to separate the anode an cathode side. Bipolar plates, catalyst, membrane and the hardware are the secondary components of PEM fuel cell. Hydrogen diffuses to the anode catalyst that changed the protons and electrons. The protons are conducted from side to side the membrane and arrive at the cathode side. Due to the electrical insulating on the membrane, the electrons are forced to travel in external circuits on the cathode catalyst, oxygen reacts with electrons and produce water as a byproduct.

2 FUEL CELL DEVELOPMENTS

The fuel cell has invited at 1858 by the welsh physicist Willaim Groove. In 1955, the electrolyte had been interchanged as membrane by W. Thomas Grubb. The 15KW fuel cell was built by Hasey Ihrig in the year of 1959. Fuel cells were introduced in automotive applications in 1991. UTC power is the first company to create the fuel cell. By the development of fuel cell, the best fuel cell vehicles are demonstrated. So it is needed to improve the fuel cell performance.

3 VARIOUS FLOW CHANNEL DESIGNS

In many research papers, the performance improved by changing the parameters of the PEM fuel cell. The performance of the fuel cell depending on the operating conditions, transport phenomena inside the cell, electrochemical reactions and the physical components such as membrane electrode assembling and bipolar plates [1].

Many of the research projects focused on the performance of PEM fuel cell, due to the applications such as power back up systems, automobiles, forklifts and motor industries, portable and stationary applications. Because of the advantage of emission control, transportation applications are concentrated on fuel cells. Fuel cells are having low operating temperature and high power density, so motor companies focused on fuel cell vehicles. Toyota FCHV, Honda FCX-V3, Hyundai SANTA Fe FCV, etc. [2].

Flow field and flow channel are also important parameters to improve the performance of PEM fuel cell. Performance improved by studies on the effect on a single channels, double channels, cyclic single channels and symmetric singles channel serpentine flow field configurations [3].

By varying flow channel dimension may improve the performance, modification of length or height in the outlet flow channel of the serpentine flow field was designed by the dimension of 23mm*23mm*2.645mm at different voltages [4].

The tapered straight flow channel has been numerically analyzed by changing the height or width of the channel with 1 ATM pressure and operating temperature of 50`C, in this cell performance improved by a reduction in outlet height and enlarged flow channel length [5].

Using the tapered flow channel design, reduction in channel depth in the BPs, forced the reactant gas on GDL to enhance the electrochemical reaction that leads to performance improvement by numerical predictions at the operating conditions such as low operating voltages or high current densities [6].

Shiang-Wu Perng and Horng-Wen Wu proposed that the finite element analysis of the tapered flow channel design with a baffle plate by the method of element-by-element preconditioned conjugate gradient. The results show that the model gives a good convection heat transfer performance and high fuel flow velocity. It depicts that the taper ratio and gap ratio of the cell give the performance improvement in the range of 12.86% and 15.48% respectively [7].

The method of simplified conjugate gradient is implemented to 3D, non-isothermal model.By varying the channel heights and widths. Due to that removing of liquid water and oxygen transport in the gas diffusion layer has increased. The performance improvement is 22.51% compared with basic design [8].

Water flooding in cathodes is the main cause to hinder the PEMFC commercialization to decrease flow field and flow channel optimization is needed and to design the BPs for maximum performance. Finally the small channel with varying heights, rib size and baffles could give the performance at low operating temperatures. By using the commercial software like FLUENT CFD, FEMLAB, COMSOL Multi-physics, CEDRC flow field and flow channel designs were analyzed at the operating voltages from 0.3 to 0.7V [9].

To optimize the designs by changing the dimensions of channel of flow field plate with the help of CED technique and the computational domain dimensions have 6, 7, 6 elements in x, y, z-directions respectively, totally 2556 elements are considered. The results predict the velocity distribution, pressure drop and the influence of length, curvature, depth of the channel, 4 and 6 channels is given that smooth and sharp curve in channel curvature and density respectively are 900 and 1200 mA/cm^2 at 0.6V. Finally, 6 channels are 25% better than 4 channels. So flow field provides better performance [10].

By the Richards equations, different liquid water mechanisms and two fluid methodhave been analyzed of PEM fuel cell. To investigate the effect of the flow channel aspect ratio on PEM fuel cell with single and triple serpentine flow field, the results concluded that the cell performance is independent of channel aspect ratio of operating voltage above 0.7V. Due to the electro-chemical reaction, lower operating voltage below 0.7V gives the slight improvement in performance due to the increment of oxygen transport [11].

In the stack of fuel cell, the flow field is depending on the inflow and outflow headers uniformity and non-uniformity. The non-uniformity headers have the some significant differences in stack performance by the confinement of outflow headers within two counter rotating vertical tubes with the separation of jets. The results concluded that stack configurations of U-stack (with the inflow and outflow headers opening in same directions) and Z-stack (with the inflow and outflow headers opening in opposite directions) used to share the flow in the fuel cells [12].

A PEM fuel cell with a 25 cm^2 active area and a Nafion 117 membrane with 4 mgpt cm^{-2} have been experimentally investigated and enhance the cell performance. A single cell with the size of 45*95*101 mm^2 and serpentine and triangular flow field channels with the weight of 1300g are the dimensions of the fuel cell. Due to the cell temperature increment, the exergy efficiency is varied from 58% to 42% at the temperature of 40°C, under the current density from 0.2 to 0.6 A/cm [13].

The gas flow (laminar, unsteady, isothermal and compressible) and straight channels for both anode and cathode are considered and simulated by a finite volume method. The inlet pressure is weaker because of oxygen and hydrogen concentration decrement from admission to exit with the Reynolds number considerations. When the height of the flow channel is decreased, the hydrogen and the oxygen concentrationisincreased in the high Reynolds number. So the influence of the channel height becomes important for a high Reynolds number, because the consumption of oxygen to the catalyst layer [14].

Cathode flow channel effect area ratio with parallel and interdigitated flow was numerically analyzed in the areas of 0.3, 0.4, 0.522, 0.6, 0.7. The parallel flow performance gets increased due to increase the contact area between GDL and catalyst layer. In interdigitated flow, flow channel ratio is not considered because of less effect baffle forced the fuel on porous layers to enhance the participation is helping to increase the performance [15].

Owejan et al. [16] proposed a study on multiple serpentine flow field design on the performance of PEM fuel cell with the active area of 50cm^{2}and also developed 0.52 mm^{2}triangular and rectangular geometry flow channel designs. Toray and SGL gas diffusion layers are to develop the special effects on the overall volume and distribution of accumulated water. By considering these channel geometries, results revealed that the triangular shaped geometry recollects minimum water than the rectangular cross sectional area.

By using the different manufacturing process, the effect of channel tolerances on the cell performance had been analyzed by Shimpalee et al. [17] in this article, the bipolar plates are fabricated with the aid of chemical and electroetching processes. Evaluation of the result was the influence of draft angle or etch factor exaggerated the cell performance over the changes in heat transfer, gas distribution uniformity and pressure drop.

Scholta et al. [18] investigated the parallel and counter flow fields with a model of 100 mm^2 active area and the effect of channel dimensions on the performance of PEM fuel cell with the aid of simple flow field designs. The channel geometry has been taken between the values of 0.7 and 1 mm. At low current densities, broader geometries are suitable to increase the performance, at high operating current densities and tapered design channels are preferred.

Shimpalee et al. [19] numerically analyzed the effect of the channel and rib width on the performance of the cell. The active area of 25 cm^2 was analyzed with the serpentine flow fields and several fluid flow arrangements. The tapered channel had more performance increment than the wider channel geometries because of the heat transfer enhancement and increased pressure drop. The further investigation showed that the design of the wider channel with tapered rib incites the reactants of local distribution kept non-uniformly to the entire channel and the reactants of global distribution kept uniform. The counter flow design of the PEM fuel cell exhibits more power increment than the co-flow design of the cell.

Seong-Ho Han et al. [20] designed the wave form cathode flow channel and analyzed in terms of numerical and experimental. Due to the design modifications, the velocity gradient of the flow increased, that enhance the performance of the cell. In numerical analysis, the active area of the cell taken as 84 cm^2, the performance increment of the cell was 5.17%. An experimental analysis, the active area taken as 25 cm^2, the performance increment was 5.76%.

Wang et al. [21] evaluated the effect of the cathode channel at different cross sectional areas of the flow channel designs with the parallel and interdigitated flow fields. The five flow channel area ratios were 0.3, 0.4, 0.522, 0.6 and 0.7. The result concluded that both of the parallel and interdigitated flow fields increased the performance of PEM fuel cell by the way of forcing the fuel into the porous layer increasing the fuel participation in the chemical reaction. An increment in the fuel transport rate and liquid water removal also enhanced.

Yan et al. [22] investigated the tapered flow channel designs with the active area of 198.87 cm^{2}and tapered channels was reduced either height or width of the channel. The results revealed that the novel tapered flow channel design increased the cell performance by the way of increases the fuel rate, fuel transport rate and liquid water removal.

Abhishek Raj et al. [23] analyzed the influence of multidimensional effect is investigated by creating the 2D and 3D models with the aid of COMSOL at parallel geometry under same operating conditions. With the aid of species concentration the multidimensionality is analyzed at several inlet stoichiometries, membrane conductivities and relative humidity values. The maximum effect is appeared due to the water concentration at the cathode, the slope of the large water concentration is more on the 3D model then 2D model.

An effective area of 25 cm^2 with 1mm and 1.5mm depth of the anode and cathode of flow channels were analyzed experimentally and compared with the numerical solutions by Hong Liu et al. [24]. The experimental result has been taken from the different values of the total width and rib ratio. By decreasing the total width of flow channels, there was slight improvement in the performance of the cell when compared to the normal flow channel. The results concluded that the optimized design of the PEM fuel cell has more advantage than the without optimized flow channel design.

The effect of the flow channel reduction in the PEM fuel cell was numerically investigated by Liu et al. [25] depending upon the operating voltages the cell performance varied. For low operating voltages, the fluid was forced to the gas diffusion layer in order to increase the electrochemical reaction. Due to the increased chemical reaction, the PEM fuel cell performance enhanced.

Yang et al. [26] analyzed the influence of outlet flow channel area reduction on the cell performance and compared the reduction flow field design with the conventional serpentine flow field design. Due to that the electrochemical reaction was improved by forcing the fuel on the GDL. The results concluded that the performance increased with the increment of reactant transport and liquid water removal, but the pressure loss enhancement reduced the performance. By concerning the pressure losses, at the height ratio and width ratio of 0.4 and 0.4 was optimum design to increase the PEM fuel cell performance. Fig.14 shows a height and width ratio of the channel outlet.

4 Conclusions

The fuel cell is the alternative source to build the green environment. This review paper revealed the investigation of different flow channel cross section designs of Proton exchange membrane fuel cell and the influences of the different cross sectional shape of the fuel cell is also reviewed. When the flow channel areas are varied the performance is increased, because the fuel is forced on the gas diffusion layer with the enhancement of the performance.The serpentine gas flow channels of proton exchange membrane fuel cell have lengthier straightchannel sections thatharvest higher gas pressure increases on the adjacent channels and enhances the fuel cell performance with the convection of rib. The comparison of different flow channel cross section shaped such as rectangular, triangular and trapezoidal are considered. In that case, the rectangular cross section has, the more power generated than the triangular geometry. The reactant distribution can also make some part of performance increment at the concentration of shorter, longer path lengths and number of flow channels increased. Commonly, the narrower gas flow channels increased the cell performance with the better output power generation. Wider rib width displays a better power generation on the fuel cell performance.

References

[1]. A.P.Manso, F.F.Marzo, J.Barranco, X.Garikano, M.GarmendiaMujika, “Influence of geometric parameters of the flow fields on the performance of a PEM fuel cell: A review”, International journal of hydrogen energy. Vol:37, pp. 15256-15287, 2012.

[2]. Yun Wang, Ken Chen, Jeffrey Mishler, Sung Chan Cho, Xavier CordobesAdroher, “A review of polymer electrolyte membrane fuel cells: Technology, applications and needs on fundamental research”, Applied energy. Vol:88, pp. 981-1007, 2011.

[3]. D.H.Jeon, S.Greenway, S.Shimpalee, J.W.Van Zee, “The effect of serpentine flow-field designs on PEM fuel cell performance”, International journal of hydrogen energy. Vol:33, pp. 1052-1066, 2008.

[4]. Wei-Mon Yan, Hung-Yi Li, Po-Chiao Chiu, Xiao-Dong Wang, “Effects of serpentine flow field with outlet channel on cell performance of proton exchange membrane fuel cells”, journal of power sources.Vol: 178, pp. 174–180, 2008.

[5]. Wei-Mon Yan, Hui-Chung Lie, Chyi-Yeou Soong, Falin Chen, C.H.Cheng, Numerical study on cell performance and local transport phenomena of PEM fuel cells with novel flow field designs, journal of power sources. Vol:161, pp. 907–919, 2006.

[6]. H.C.Liu, W.M. Yan, C.Y.Soong, FalinChen,H.S. Chu,“Reactant gas transport and cell performance of proton exchange membrane fuel cells with tapered flow field design”, Journal of power sources. Vol:158, pp. 78-87, 2006.

[7]. Shiang-WuuPerng, Horng-Wen Wu., “Non- isothermal transport phenomenon and cell performance of a cathodic PEM fuel cell with a baffle plate in a taper channel”, Applied Energy.Vol:88,pp. 52-67, 2011.

[8]. Xiao-Dong Wang, Yu-Xian Huang, Chin-Hsiang Cheng, Jiin-Yuh Jang, Duu-Jong Lee, Wei-Mon Yan, Ay Su, “Flow field optimization for proton exchange membrane fuel cells with varying channel heights and widths”, ElectrochimicaActa, Vol:54,pp. 5522-5530, 2009.

[9]. ArarimehAiyejina, M. K. S. Sastry,“PEMFC Flow Channel Geometry Optimization: A Review”, ASME, Vol:9, pp. 011011-1 to 011011-24, 2012.

[10]. NattawutJaruwasupant, YottanaKhunatorn, “Effects of difference flow channel designs on proton exchange membrane fuel cell using 3D model, Energy Procedia”, Vol;9,pp. 326-337,2011.

[11]. Xiao-Dong Wang, Xin-Xin Zhang, Tao Liu, Yuan-Yuan Duan, Wei-Mon Yan, Duu-Jong Lee, “Channel Geometry Effect for Proton Exchange Membrane Fuel Cell With Serpentine Flow Field Using a Three-Dimensional Two-Phase Model”, ASME, Vol:7, pp. 051019-1 to 051019-9, 2010.

[12]. Boris Chernyavsky, Krishna Ravi, Pang-Chieh Sui, Ned Djilali and Pierre Benard,“Numerical investigation of flowfield in PEM fuel cell stack headers”,EnergyProcedia. Vol:29, pp. 102-111, 2012.

[13]. I.Khazaee, M.Ghazikhani, M. Mohammadiun, “Experimental and thermodynamic investigation of a triangular channel geometry PEM fuel cell at different operating conditions”, science Iranica, Vol:19, pp. 585-593, 2012.

[14]. M. Zeroual, S. Belkacem Bouzida, H. Benmoussa and H. Bouguettaaia,“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. Vol:18, pp. 205-214, 2012.

[15]. Xiao-Dong Wang, Yuan-Yuan Duan, Wei-Mon Yan,“Numerical study of cell performance and local transport phenomena of PEM fuel cells with various flow channel area ratios”, Journal of power sources, Vol:161, pp. 265-277, 2007.

[16] Owejan.J.P., Trabold.T.A.,Jacobson.D.L., Arif.M., Kandlikar.S.G. “Effects of Flow Field and Diffusion Layer Properties on Water Accumulation in a PEM Fuel Cell”.International Journal of Hydrogen Energy. Vol:32, pp.4489-4502, 2007.

[17] Shimpalee.S., Lilavivat.V., Van Zee.J.W., McCrabb.H., Lozano-Morales.A. “Understanding the Effect of Channel Tolerances on Performance of PEMFCs”. International Journal of Hydrogen Energy Vol:36 ,pp. 12512-12523 2011.

[18] Scholta.J., Escher.G.,Zhang.W., Ku¨ers.L., Jo¨rissen.L., Lehnert.W. “Investigation on the Influence of Channel Geometries on PEMFC Performance”. Journal of Power Sources Vol:155, pp. 66-71, 2006.

[19] Shimpalee.S., Van Zee.J.W. Numerical Studies on Rib & Channel Dimension of Flow-Field on PEMFC Performance. International Journal of Hydrogen Energy Vol:32,pp. 842-856, 2007.

[20] Seong-Ho Han, Nam-Hyeon Choi, Young-Don Choi. “Simulation and Experimental Analysis on the Performance of PEM fuel cell by the Wave like Surface Design at the Cathode Channel”. International Journal of Hydrogen Energy. Vol:39, pp. 2628-2638, 2014.

[21] Wang Xiao Dong, Duan Yuan Yuan, Yan Wei-Mon. “Numerical study of cell performance and local transport phenomena in PEM fuel cells with various flow channel area ratios”. Journal of Power Sources Vol:172, pp. 265-277, 2007.

[22] Yan Wei Mon, Liu Hui Chung, Soong ChyiYeou, Chen Falin, Cheng CH. “Numerical study on cell performance and local transport phenomena of PEM fuel cells with novel flow field designs”. Journal of Power Sources Vol:161, pp. 907-919, 2007.

[23] Abhishek Raj, Tariq Shamim. “Investigation of the effect of multidimensionality in PEM fuel cells”. Energy Conversion and Management Vol:86, pp. 443-452, 2014.

[24] Hong Liu, Peiwen Li, Kai Wang. “Optimization of PEM fuel cell flow channel dimensions and Mathematic Modeling Analysis and Experimental Verification”. International Journal of Hydrogen Energy Vol:38 , pp. 9835-9846 2013.

[25] Liu.H.C., Yan.W.M.,Soong.C.Y., Chen Falin, Chu.H.S.“Reactant gas transport and cell performance of proton exchange membrane fuel cells with tapered flow field design”. Journal of Power Sources Vol:158,pp. 78-87, 2006.

[26] Yan Wei-Mon, Li Hung-Yi, Chiu Po-Chiao, Wang Xiao-Dong. “Effects of serpentine flow field with outlet channel contraction on cell performance of proton exchange membrane fuel cells”. Journal of Power Sources Vol:178, pp. 174-180, 2008.