International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Articles available online http://www.ijoer.in

Vol.2., Issue.6, 2014

REVIEW ARTICLE

ISSN: 2321-7758

PERFORMANCE ENHANCEMENT STUDIES ON PEM FUEL CELL WITH DIFFERENT FLOW CHANNEL AND GAS DISTRIBUTION LAYER DESIGN -A REVIEW

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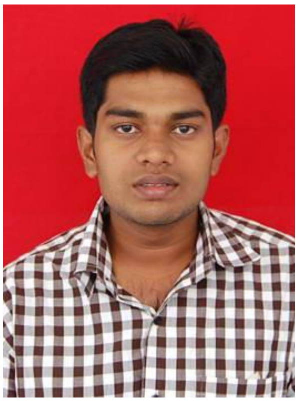
Article Received: 22/10/2014 Article Revised on: 13/11/2014 Article Accepted on:15/11/2014



ABSTRACT

The automobile vehicles emitting the greenhouse gases such as carbon dioxide are affecting the environment in several ways and they contribute to global warming. As the automobiles are using fossil fuels in internal combustion engines, the environmental pollution problems are unavoidable. The fuel cells are one of the alternate sources that can produce the power with zero emissions. The Proton Exchange Membrane (PEM) fuel cell is an electrochemical device that produces electricity, water and heat through electrochemical reactions as long as the hydrogen and oxygen are supplied. The PEM fuel cells are used in many areas, especially for transportation, stationary, portable and automobile applications. The PEM fuel cells are having high efficiency, working at atmospheric temperature and pressure. The performance of PEM fuel cell is highly influenced by the water management in the PEM stack. The accumulation of liquid water in polymer electrolyte membrane (PEM) fuel cells currently limits the performance of these devices. So by changing theGDL properties and design of flow channel, the flooding in PEM fuel cell can be minimized and the performance is enhanced. Improved water management is needed to achieve the increase in power densities required for commercial acceptance of PEM fuel cells in transportation and other demanding applications.

Keywords: Environmental pollution;Gas distribution layer; PEM fuel cells.

ELECROCHEMICAL REACTIONS IN PEM FUEL CELL:

The Hydrogen Oxidation Reaction (HOR) is carried out in the anode side and Oxygen Reduction Reaction (ORR) is carried out in cathode side as follows in the proton exchange membrane fuel cell.

Anode side : $H_2 \rightarrow 2H^+ + 2e^-$, Cathode side : $2H^+ + 2e^- + ½O_2 \rightarrow H_2O$, Overall reaction : $H_2 + ½O_2 \rightarrow H_2O$ + Electricity + Heat

INTRODUCTION

Due to the increase in number of fossil fuel based power generation systems, that leads to affect the environment, causes pollution and depletion of fossil fuel resource, later the automakers and industrial developers were investigating many possible solutions to bring out new methods of improving engine efficiency and to reduce environmental polluting pollutants that comes from the engine exhaust from both stationary and transportation application. In the last decade fuel cells appear to be one of the most suitablealternatives for the generation of clean energy. And PEM fuel cell seems to be one of the most reliable ones. Compared with other type of fuel cell, PEMFC has easy implementation and longer lifetime and works in low operating condition, high power density, fast start-ups, soundness of the system and low emission. PEM fuel cell work by direct conversion of chemical energy of reaction between hydrogen and oxygen into electricity. In addition with that there are several coupled fluid flow and mass transport process that occur in a fuel cell. Hydrogen-fuelled proton exchange membrane (PEM) fuel cells are considered to the most promising candidates for automotive applications. Heat and water management in PEMFC was the great challenge yet to be resolved by the PEMFC experts over the past several years.

The conventional PEMFC type has a straight gas flow channels where the reactant gases (H_2 and O_2) diffuse into the catalyst layer through the gas diffusion layer and gives the end product (H_2O). The performance of the PEMFCdepends on the different flow field design. There are different types of flow fields they are 1.Straight, 2.Parallel, 3.Serpentine, 4.Interdigitated and 5.Z-type.

LITERATURE REVIEW

The performance of PEMFC can be improved by changing the geomentric parameters of the flow fields. Thus the problems in mass transport, water management, mal-distribution of reactants can be solved by efficiently design of the flow flied. The homogeneous gas distribution in the flow channel can provide a uniform current density throughout the active area and addition with uniform temperature distribution causing less mechanical stresses and improving the PEMFC lifetime. In PEMFC with serpentine gas flow channels, the longer the straight channel sections provides larger gas pressure between adjacent channels that increases the under rib width convection and the fuel cell performance[1].

The performance of the PEMFC can be increased by inserting the wire coil in the oxygen supply channel. This results in increase of power density up to 41% in some layout when compared to the conventional straight flow channel. It has been found that there is a significant change in performance developed in PEMFC by inserting the wire coil in the oxygen flow channel. This type of flow movement can be more effective in moving the oxygen from main flow stream over the reaction zone or the gas distribution layer. The total effective area of the flow channel was $25cm^2$. Two machined graphite plates with the thickness of 5mm were used as flow field for anode and cathode sides. The flow channels of both cathode and anode were machined in straight shapes with a channel width of 1mm, a depth of 1mm and a length of 43mm. each plate consists of 28 parallel flow channels, arranged in equal space (ribs) with a width of 0.5mm [2].

Liquid water formation and transportation were investigated by direct experimental visualization of a single serpentine PEM fuel cell. where the different gas diffusion layer(GDL) material is used to remove water away from cathode and through the flow field with different operating conditions. By inserting cathode GDL with microporouslayer(MPL) there exists a pressure barrier for water produced at the catalyst layer. The higher amount of liquid water in the cathode channel can be removed efficiently from the catalyst layer. Thus the level of cathode flow field flooding at specified current density and operating condition can be used as a criterion to calculate the water management capability of the GDL materials. Untreated GDL were not able to push the water to the membrane side which results in low ionic conductivity of the membrane. Gas transport was inhibited by the pores saturated with the liquid water. So the wet-proofed GDLs are used to remove water from in the form of discrete droplets over the entire GDLs and channel interface, this results in leaving majority of pores available for gas transport. This improves the efficiency of the PEMFC [3].

A theoretical two dimensional along the channel has been developed to design the fuel channel for PEMFC. With the change in the design parameter and operating conditions such as inlet velocity, inlet pressure, height of the channel, catalyst activity and porosity of the gas diffusion layer gain a fuel cell with high performance. There often exists a compromise between the higher power density and higher efficiency of the fuel cell. To get a fuel cell with higher power density, we should increase the inlet velocity of fuel, increase the inlet pressure of the fuel, decrease the height of the fuel cell and to increase the porosity of the gas diffusion layer. To enhance the fuel efficiency of the cell it is necessary to apply a lower inlet velocity and a lower inlet pressure so that the fuel has a sufficiently long time to react with the catalyst in the gas diffusion layer. At the same time the channel with the larger height and gas diffusion layer with smaller porosity will also help in improving the fuel efficiency [4].

Air delivery is typically a largest parasitic loss in PEM fuel cell systems. There we develop a passive water management system that minimizes this loss by giving stable and flood free performance in parallel channel design at very low air stoichiometry with 19 parallel channels. By using both geometry and materials changes for the flow field design we compare the performance of the PEMFCs. By presenting the fabrication procedure where we in situ polymerize wicks on the flow field walls and manifold surface. This results in high quality, 150micrometer thick, monolithic wick structure, which produces a hydraulically connected pathway from reaction sites to the outside of fuel cell. Thus comparing the fuel cell performance using the water management flow field (WMFF) against the control cathode flow field (no integrated wicks) which had same open channel and manifold geometry. The WMFF significantly improved performance for stoichiometry air 1.15, 1.30 and 1.50 the WMFF extended operating range by 0.4, 0.3 and 0.2A cm^{-2}, respectively. Then the performance is improved was more significant for air stoichiometry of 1.15. at this very low air stoichiometry, the integrated wicks increases the power maximum up to 0.41 to 0.68W cm^{-2}. This results in increase in the peak power up to 62% [5].

The characteristics of liquid water removal from GDL have been investigated experimentally by calculating the unsteady pressure drop in the cell which has the GDL initially wet with liquid water. GDL thickness is to be carefully examined.it is controlled by inserting various thicknesses of metal shims between the plates. Effective water removal can be achieved at high compression levels of GDL if the inlet air flow rate is high. At the lowest inlet Reynolds number (564), the water removal from the thinnest GDL (200µm) will be difficult because of small permeability, and the total time to reach a steady pressure drop for the thicker GDLs (250 and 300µm) is around 20mins. and at a higher inlet Reynolds number (1128), the GDLs starts similar water removal process, and the total time to reach to reach a steady pressure drop for the GDLs becomes longer (90-100mins), because more liquid water is removed. The thinner GDL retains less amount of water, and the effect of GDL permeability become weaker at the higher flow rates, this indicates that the air flow rate should be sufficiently high for effective water removal for highly compressed GDLs [6].

The transport of liquid water and gaseous reactants through a gas diffusion layer(GDL) is one of the most important water management problems in a PEMFC. In this work, where the liquid water break through along with the capillary pressure and water saturation passing through the GDLs with and without Micro porous layer is studied in an ex-situ setup which encourage a real fuel cell configuration and operating condition. In this process when the GDL is sampled without MPL, the dynamic change of breakthrough and recurrent water breakthroughs are highly observed, when for GDL samples with MPL there wont be any breakthrough is found. Besides, the water saturation levels for GDls with MPL is significantly lower than the samples without MPL. This provides the detail view that the MPL not only limits the number of water entries into the GDL, but also it neutralize the water paths. The GDL without MPL improves the flim flow and turns the slug-to-flim flow transition to the lower air flow rates, compared with the case of GDL with MPL [7].

Water management process is carried out in PEM fuel cell by introducing Air-breathing cathodes. Generally liquid water condensation and accumulation at the cathode surface is inevitable in a passive design operated over a wide range of ambient and load conditions. Basically the excessive flooding or the dry condition at the open cathode leads to reduction of fuel cell power. To reduce the severe effects of flooding, we introduce a thin electrically conductive water collector (a patterned wick) layer between the current collector and the cathode layer. The water collector initially absorbs and redistributes liquid water across the entire cathode and allows the water to escape outside of the cathode area without restricting the cathode oxygen supply. This shows that the water collector layer removes the effects of cathode flooding and provides the efficient cell operation [8].

The performance of the PEMFC can be improved by changing the way of placement of the cathode and anode, this deals with the gravity influence on discharge of water in PEM fuel cell cathode. The positions of the cathode upwards and the anode upwards at different humidification condition, the polarization curve are drawn using voltage and current density. Where the current density of PEM fuel cell is bigger at the anode-upwards than at the cathode-upwards. When other experimental condition do not change, the current density of anode humidification(cathode dehumidification) is bigger than the one of the cathode humidification(anode dehumidification). By comparing with the cathode-upwards, the excessive liquid water in the cathode is easily discharged out of the PEM fuelcell when placing the anode upwards [9].

The performance of the PEM fuel cell is greatly influenced by the optimization of both the operating and the design parameters like temperature, backpressure, anode and cathode inlet velocities, Gas diffusion layer, porosity, thickness, cathode water mass fraction, channel dimension, rib width and porous electrode thickness. The numerical model of single channel PEM fuel cell was developed and analysed by using COMSOL Multiphysics 4.2 software. The design and operating parameters in software to be carried out in two stages using Taguchi method. In first stage it was concluded that the back pressure had maximum effect and rib width had least effect on performance of fuel cell. By altering the optimized parameter the performance of the fuel cell is improved. In the second stage where by changing the parameters and selected factors the performance of the fuel cell is improved by 3% increase in power density [10].

Litster et al. experimentally concluded the gas or liquid water flow in the PEM fuel cell gas diffusion layers through a novel fluorescence microscopy technique for picturing the transport of liquid water in unsaturated hydrophobic fibrous media has been prepared and it is applied to the gas diffusion layer of a PEM fuel cell.in this experiment where the fluorescein dye solution is impelled through the fibrous hydrophobic gas diffusion layer (GDL) and pictured with fluorescence microscopy. This helps in resolving the dynamic transport of liquid water through distinct pathways. This helps to improve understanding about liquid water transport mechanism within these porous layers and analysis of the connectivity and interdependence of the liquid motion in several distinct flow paths.The experimental observations led to the account of the primary mechanism for liquid water transport in hydrophobic GDLs. This helps in developing the new model for predicting liquid water transport in operating fuel cells with better efficiency [11].

Mathias et al. [12] and Ihonen et al. [13] have explained in detail about the categorizations of gas diffusion layer materials. The materials they compared are the carbon cloths and the carbon paper.Two structures, they both consistingof carbon fibers, dominate the forms of gas diffusion layers currently available. Carbon cloth is fabricated of woven tows consisting of individual carbon fibers. On the other hand, carbon paper is formed from randomly laced carbon fibers.The carbon cloth has the thickness between 350 and 1000 µm, though carbon paper is available in thicknesses as low as 90µm. where the thickness increases with increase in power loss due to Joule heating and increased resistance to mass transfer. In addition, the two gas diffusion layer structures fluctuate by spatial uniformity and degree of anisotropy. Because of the woven structure the carbon cloth is spatially dissimilar on a macroscopic scale. Whereas carbon paper is roughly spatially similar due to its random lacing. While comparing the porous structure of both the carbon cloth and carbon paper, the carbon paper electrode features a much more porous structure than their cloth counterparts.The mean pore diameter and porosity of carbon paper is approximately 35 µm and 85%, respectively and the Carbon cloth values are much lower and difficult to calculate.All three forms of porous media in PEM electrodes are potted in Table 1.

Table 1
Summary of porous media in PEM electrodes

Porous media	Spatial uniformity	Dimension of anisotropy	Porosity (%)	Mean pore diameter (μm)	Thickness (μm)
Catalyst layer	Homogeneous	Isotropic	5-55	~1	~15
Carbon cloth	Heterogeneous	3D	30-40	~10	350-1000
Carbon paper	Homogeneous	2D	70-90	~30-40	90-350

Woo-kum Lee et al [14] has experimentally investigated about the effects of compression and gas diffusion layers on the performance of a PEM fuel cell. the experiment were done by comparing three types of gas diffusion layers with operating condition of 202 kPa and 353ºk respectively. The gas diffusion medium used here are ELAT, CARBEL and TORAY. It is used in the gas diffusion layer. The effect of varying the gas diffusion layer and bolt torque on the performance of a PEM fuel cell have been studied at fixed stoichiometric flow rates for the fuel and reactant. For the three torques used here, a peak bolt torque was obtained for the ELAT and the combination of CARBEL and TORAY diffusion layers. This optimum was described
in terms of the changes in the porosity and the electrical contact resistance. TORAY medium is used in case for less compressible and brittle material. However the CARBEL media is used for softer material. The pressure inside the fuel cell was calculated for various bolt torques. The change in thickness between the gasket and the diffusion layer will affect the pressure inside the fuel cell.

JiabinGe et al [15] has designed and created unique fuel cell to study the effects of GDL compression on fuel cell performance. Uniform and accurate GDLCompression can be achieved and the compression can be altered and measured without disassembling the fuel cell. Using this fuel cell setup, the effect of GDL compression on PEM fuel cell performance for two types of GDL material under various anode and cathode flow rates was studied. From the experiment it is noted that depend upon the compression of GDL the performance of the PEM fuel cell is varied. This is common for both ELAT carbon cloth and TORAY carbon fiberPaper. The effect is greater when carbon fiber paper GDL is used. The effect of GDL compression is also greater in the high current density region.the experimental results shows that the fuel cell performance, as observed through the polarization curve, first increases with the increase of compression, then decreases with increase of compression after passing a certain point. From the polarization curve the peak compression ratio of the GDL can be obtained where the performance of the PEM fuel cell is maximized.

Jinhua Chen et al[16] has experimentally concluded that water management can be controlled significantly by inserting the water management layer(WML) between the traditional GDL and the catalyst layer of the PEMFC. A simulator were developed for the optimization of the GDL, where the water distribution in the electrode and the profile of the water transport in the polymer membrane could be expected. The WML coated on the carbon paper could make the water distributionin the MEA more uniform and could efficiently avoid any drying-out of polyelectrolyte and flooding of the cathode, this results in a high performance of the PEM fuel cell, and effective designing of WML also leads to develop a PEM fuel cell with low humidity or zero humiditywhich results in improving the performance of PEM fuel cell.

Yasser Ben Salah el al [17] has examinedthe optimum gas channel design for water drainage by applying a scheme for two-phase flow with large density differences using the lattice Boltzmann method. Where different channel geometries of rectangle trapezoidal and triangular were used and the channel geometries are taken with the cross section with width of 1 mm and a depth of 0.5 mm respectively. And the comparisons were made for the parameter of the droplet terminal velocity, the pressure drop along the channel, and the new dimensionless parameter pumping efficiency. By comparing all the channel geometry the rectangular shaped channel with a width of1 mm and a depth of 0.5 mm, which shows the best water removal characteristics at a sensiblepressure drop and also the channel with hydrophilic walls is advantageous at higher droplet volumes.

Toshihiro Tanuma et al [18]have examined the effect of the hydrophobic/hydrophilic nature of the micro porous layer (MPL) on membrane electrode assembly (MEA) performance. Where the fuel cell with hydrophilic MPL shows abetter performance in wide range of pressure and humidity conditions than that using a hydrophobic MPL. The results obtained by viewing in mercury porosimeter shows that the hydrophilic MPL has larger pores than the hydrophobic MPL, which probably results from the difference in carbon materials used in the layer. The cell voltage of the MEA using a hydrophilic MPL is not as significantly affected by the pressure difference as that of the MEA employing a hydrophobic MPL. Then MEA with hydrophilic MPL exhibits high performance. The result of high-temperature operation of MEAs without humidification indicates that the MEA using a hydrophobic MPL shows a quick drop in cell voltage with anincrease in temperature. Then the MEA employing a hydrophilic single-layer MPL sustains a fairly high cell voltage even at 95°C, suggesting that the hydrophilic MPL helps avoiddehydrating out of the membrane under the dry condition.

CONCLUSION

From the above review paper it is clearly stated that the water management and heat management in PEM fuel cell can be effectively controlled by changing the design parameters of flow channel in flow field like by adding the number of flow passes for effective fuel flow in the PEM fuel cell. This helps in improving the homogenous flow in the system which results in improving the power density and current density values which is associated with the performance improvement in PEM fuel cell.The another important factor we consider here is the design and properties of the gas distribution layer in PEM stack, Here by changing the design and properties like inserting the micro porous layer in the cathode GDL, wet proofed GDL, the compression levels of GDL, and the material used. These are some of the main things that plays a key role in the reactant process. Here carbon paper with thickness as low as 90µm is used as a GDL material for effective utilization of the fuel flow in the system this helps in minimising the liquid water flooding in the system and also helps in improving the performance of the PEM fuel cell. These results are obtained numerically by using one of the commercial software CFD.

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