International Journal of Advance Research in Engineering, Science & Technology(IJAREST),
ISSN(O):2393-9877, ISSN(P): 2394-2444,
Volume 2,Issue 10, October -2015, Impact Factor: 2.125

Effect of Operating Parameters on Proton Exchange Membrane Fuel Cell: A Review

Saumyakumar G. Rana[1], Navnit J. Patel[2], Ravindra P. Rathod[3], Hardik K. Bhatt[4]

[1] Assistant Professor Mechanical Engineering Department, HJD ITER Kera Kachchh, ranasaumy@gmail.com
[2]Associate Professor Mechanical Engineering Department, HJD ITER Kera Kachchh, navnit_ahajoliya@yahoo.co.in
[3]Assistant Professor Mechanical Engineering Department, HJD ITER Kera Kachchh, ravindraprathod@gmail.com
[4]Assistant Professor Mechanical Engineering Department, HJD ITER Kera Kachchh, hardikbhatt39@gmail.com

Abstract

The review paper includes introduction, working principle of the PEM fuel cell and Description of water management problem in PEM fuel cell. The discussions are based on elimination of water management problem by proper design of fuel cell. The paper shows the various types of efficiency, polarization characteristics and power characteristics. It also describes the various parameters (pressure, temperature, and humidity) which affect the performance of fuel cell, its optimum range in which fuel cell operate safely and efficiently. This paper represents the recent work done for improvement of the performance of PEM fuel cell. Fuel cell performance is increased by proper water management on the membrane. Basic parameter which enhances the fuel cell performance is Relative humidity, Flow field design, Temperature, stoichiometric ratio. With the help of this studies, we observe that the fuel cell performance improve by Increasing the relative humidity, temperature, pressure , stoichiometric ratio and using the split serpentine flow field instead of single serpentine flow field. The objective of this study is to explore the research in the field of PEM fuel cell and to make it cost effective for sustainable power supply.

Key words *– Proton Exchange Membrane, Fuel Cell, operating parameters, Flow Field, Polarization curve.*

I. INTRODUCTION

In 1989 the fuel cell discover by Sir William Grove. Proton exchange membrane fuel cells were first used by NASA in 1960's as part of the Gemini space program, and used on scale, expensive and not commercially affordable. This fuel cell used pure hydrogen and oxygen as a reactant gases. NASA interested to future development of Fuel cells because of the energy crisis in 1973.For investigate the performance of the fuel cell the fundamental model of polymer electrolyte membrane fuel cell was developed in 1990 by Springer. In polymer electrolyte membrane fuel cell (PEMFC) ion exchange membrane (fluorinated sulfonic acid polymer) are used as a electrolyte, membrane has excellent proton conductor. Water management is the critical problem in PEM fuel cell because the conductivity of membrane is highly depend on the water content the membrane must be hydrate for efficient performance of fuel cell which depend on the reactant stream humidification , flow field of gas diffusion layer (GDL) and wetting property of GDL and polymer membrane.

A. Working of PEM fuel cell

Fuel cell is electrochemical device which converts chemical energy of reaction into the electrical energy. It consists of an electrolyte with anode (negative electrode) and cathode (positive electrode) on either side, when H_2 gas is fed to anode the H_2 is split into protons and electrons on anode catalyst layer the protons is allow to flow through the electrolyte to the cathode side but electrons are not allow to flow though the electrolyte so electrons are flow through the external circuit where electricity (discharge) are produced. When electrons and protons flow from anode to cathode simultaneously the O_2(from air) gas is fed to cathode after then electrons proton and O_2 react at cathode catalyst layer and produce water and heat as a byproduct. The fuel cell is work till the fuel is supplied continuously. Fig.1 shows the schematic diagram of PEM fuel cell

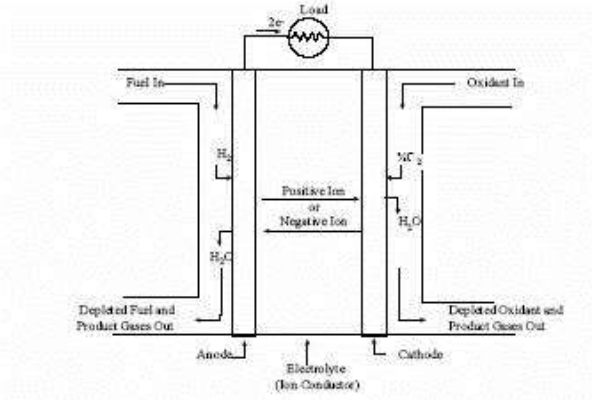

Fig. 1 Schematic PEM Fuel Cell

B. Components and design of PEM Fuel Cell

Design of PEM includes design of its components

(a) Electrolyte Membrane

Fuel cell membrane have relatively high proton conductivity, it provide a barrier to mixing of fuel and reactant gases. It is made of perfluorocarbon-sulfonic acid ionomer (PSA). The main property of the membrane is

proton conductivity which is the function of water content and temperature.

(b) Electrode-catalyst layer

Electrode is essentially made of a thin catalyst layer pressed between the ionomer membrane and a porous electrically conductive substrate. In this electrode catalyst layer electrochemical reaction take place.

(c) Gas diffusion layer (GDL)

GDL plays crucial role in PEM fuel cell, it distribute the reactant gases homogeneously from the flow field to the catalyst layer through it for the electrochemical reaction. It prevents local hotspot and catalyst flooding by removing heat and excess water from the electrode. It is made of carbon fiber material such as carbon fiber paper and woven cloths.

(d) Flow field plates

After the MEA (membrane electrode assembly) has been pulled together, the cell(s) placed in cell to distribute fuel hydrogen and oxidant air/oxygen to the cells evenly. In single fuel cell, there are no bipolar plate (only one-sided flow field plate). In fuel cells with more than one cells, there is typically at least one bipolar plate (flow fields on both side of the plate).

Bipolar plate performs many role in fuel cell. They distribute oxidant and fuel within the cell, separate the individual cells in the stack, collect the current and carry water away from each cell.

In order to simultaneously perform these function, specific plate materials and design are used. Commonly use design can include straight, serpentine, parallel, interdigitated or pin-type flow fields as shown in Fig.2

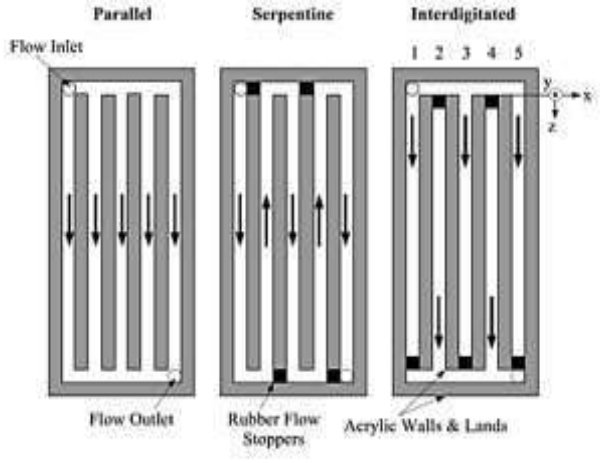

Fig. 2 Various designs of flow field plates

Based upon resistance to corrosion, chemical compatibility, density, cost, electronic conductivity, manufacturability, stack volume/kW, gas diffusivity/impermeability, thermal conductivity, and material strength the materials are chosen. The material most often used are nonporous graphite, titanium, stainless steel and doped polymer. Several composite material has been researched and are beginning to be mass produced.

C. Performance of PEM fuel cell

Polarization Curves

These is measure of characterizing a fuel cell performance is through a polarization curve – which is a plot of current density versus cell potential. This current-voltage curve is the most common and effective method for characterizing fuel cell efficiency and typically used for comparing to other published data. The polarization curve shows the V-I relationship with respect to operating condition such as applied load, cell temperature, humidification, and fuel/oxidant flow rate. Figure 3 shows a typical polarization curve for a single Proton Exchange Membrane fuel cell, and the region of importance.

As shown in Figure 3, the polarization curve can be separated into three regions:

1. The region of activation overpotential,

2. The region of ohmic overpotential, and

3. The region of concentration overpotential.

The activation overpotential region

Voltage losse occurs when the electro-chemical reaction is slow in being operating from equilibrium to current produce.

The reduction of oxygens are the electro-chemical reaction these are responsible for activation over potential. As the PEM fuel cell produce more current, the activation loss increases at a slow rate than the ohmic loss.

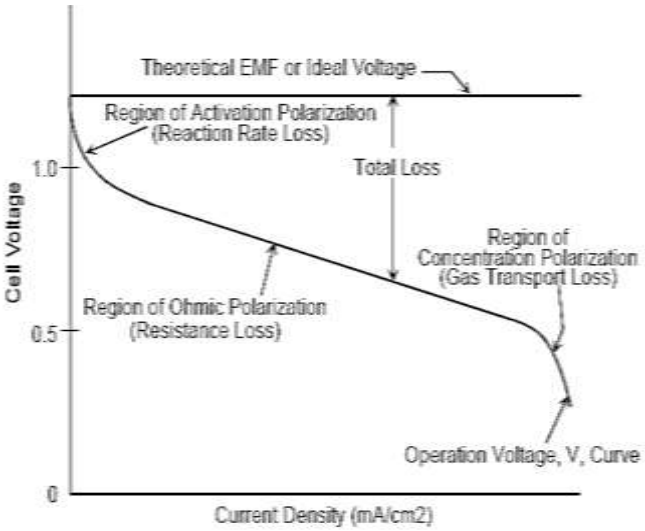

Fig. 3 Polarization curve

The ohmic overpotential

Ohmic losse is due to the movements of charge from the electrode where they produce, to the load where is they consumed.

The two major type of charge particle is electron and ion, and both electronic and ionic losses occur in the fuel cell.

The electronic loss happen in electronic circuit between the bipolar, cooling and contact plate is due to the degree of contact that the plates make with each other. Ionic transports are far more difficult to predict and model than the fuel cell electron transport. The ionic charge losses occurs in the fuel cell membrane when H^+ ions travel from the electrolyte.

The Concentration overpotential

The concentration overpotential are due to mass transport limitations; the rate of the electro-chemical reaction are hindered by a lack of reactant. The mass transport limitation is because of both diffusional limitation in the electrode backing layer and water flood in the CCL cathode catalyst layer. At high current density, the amount of liquid water produce in the cathode catalyst layer becomes larger than the amount of water that can be remove from the flow in the gas channel.

D. Operating parameters

The fuel cell performances are determine by the humidity, pressure, and temperature based upon the application requirement, and improve(depending on type of fuel cell) by increase the pressure, temperature, humidity and optimize other variable.

E. Modelling of PEM fuel cell using commercially available CFD softwares

Many computational fluid dynamics polymer-electrolyte-membrane fuel cell models have been presented over the last few decades. A literature overview of these models is presented.

These different CFD softwares are FLUENT, COMSOL Multiphysics (FEMLAB), STAR-CD, and CFD-ACE+. These have been used for PEMFC modeling along with excellent toolboxes.

II. LITERATURE REVIEW

These are the research reviews subjected to use of various experimental models, Numerical models as well as commercially available CFD packages for design and development of PEM fuel cell and to determine effect of various operating parameters on the performance of fuel cell.

A. Sukkee Um,C.-Y. Wang, K. S. Chenb 2000 [1]

They investigate a transient, multidimensional model has been developed to simulate proton exchange membrane fuel cells. The model accounts simultaneously for electrochemical kinetics, current distribution, hydrodynamics, and multicomponent transport. A single set of conservation equations valid for flow channels, gas-diffusion electrodes, catalyst layers, and the membrane region are developed and numerically solved using a finite-volume-based computational fluid dynamics technique. The numerical model is validated against published experimental data with good agreement.

The CFD model was able to predict the experimental polarization curves as well as the detailed reactant and product distributions inside the cell. In addition, the CFD model was used to understand the hydrogen dilution effect when the reformate gas is used as the anode feed. Hydrogen dilution leads to a much lower cell current density that is limited by the diffusive transport of hydrogen to the reaction site.

B. S. Shimpalee, S. Dutta 2000 [2]

A numerical three-dimensional model is developed that includes the energy equation to forecast the temperature distribution inside a straight channel proton exchange membrane (PEM) fuel cell; A control volume approach is used. Model also accounts the effect of heat produced by the exothermic electrochemical reactions on fuel cell performance.

Predictions shows that the fuel cell performance depends on the inlet humidity condition, cell voltage, and membrane thickness and the temperature rise inside fuel cells.

Including multiphase and heat transfer the three-dimensional flow simulation is created to comprehend the physics inside a straight channel PEM fuel cell for initially. To obtain the pressure distribution and velocity along the flow channels, the complete three-dimensional Navier Stokes equation have been solved.

The previous studies of most of the model focused on two-dimensional and one-dimensional product in the flow channels and flow with transport of the reactants across the membranes. Only few models highlighted the three-dimensional fuel cell simulation. But, those model did not contain the heat transfer effect on the PEM fuel cell performance.

C. Wang L, Husar A., Zhou T, Liu H. 2003 [3]

Three-dimensional fuel cell model is presented and the modeling results are compared with experimental data.

Parameters studied by author are Cell Temperature T (◦C) from 50◦C to 80◦C Electrode humidification Temperatures kept Constant at 70◦C; Anode And Cathode Humidification Temperature (◦C) From 25◦C,40◦C to 80◦C Another Electrode and Cell Temperature constant at 70◦C. Operating Pressure Constant at 3 bar; Operating Pressure 1 to 3.72 (bar) Mass flow Rate H2 1200 and O2 2200 (sccm) .

The main factor affecting the cell performance is fuel cell temperature. Shows that the performance of the fuel cell

improves with the increase of the fuel cell temperature. When fuel cell Temperature > Humidification Temperature at 80◦C the performance of the fuel cell can decrease. This is especially true in the low current density region. The performance of the fuel cell increases with the increase of pressure.

D. T. Berning∗, N. Djilali. 2003 [4]

In a PEM Fuel Cell the 3D Computational analysis of transport phenomena. The Parametric Study. Multi Component-Single Phase Model.

Here effect of Independent Parameters on Performance of PEM Fuel Cell is studied by author and Parameters Considered are

1) Temperature, 2) Pressure, 3) Stoichiometric flow ratio, 4) Effect of GDE porosity, 5) Effect of the channel width 6) Effect of GDE thickness.

The material properties such as the porosity, GDE thickness and the channel width compared to the land area have been investigated. It was found that there is a strong effect on the limiting current density by the porosity of the gas diffusion layer. To properly assess the impact of channel width and porosity on performance, the estimate the extend of contact resistance inside the fuel cell was necessary..

E. M.G.Santarelli,M.F.Torchio 2007 [5]

Experiment on Single PEM Fuel Cell.

Fuel cell Operational temperature with anode flow temperature in dry conditions and saturation and cathode flow temperature in saturation and dry conditions. Combine of humidity and operating pressure.

Parameters studied by author are Cell Temperature T (◦C) from 50◦C and 80◦C; Anode And Cathode Humidification Temperature (◦C) From 50◦C and 80◦C Another Electrode and Cell Temperature constant at 70◦C. Operating Pressure 1, 1.5, 2, 2.5, and 3.1(bar); Mass flow Rate H_2 140 to O_2 720 (millilitre/min).

The higher cell temperature increases the conductivity of membrane and the exchange current density with the improvement of the cell behavior. The increase in reactant saturation temperature its leads to a better performance, especially in case of medium and low loads. It is better to reduce the water inlet mass flow rate at the high loads to avoid electrode flooding, in the case of a low cell temperature. The maximum of the power curve shift to higher current densities with the increase of the reactant operating pressure.

F. J Zhang, Y Tang, C Song, X Cheng,J Zhang , H Wang 2007 [6]

In this paper the performance of the fuel cell investigated with dry hydrogen and air in the temperature range of 23°C to 120°C ,relative humidity, temperature, pressure and reactant flow rate evaluated researchers found that the performance of the fuel cell was better with 100% relative humidity compared to the 0% relative humidity at inlet.

It was demonstrated that operating a fuel cell using a commercially available membrane (Nafion® 112) is feasible under certain conditions without external humidification. However, the cell performance at 0% RH decreased with increasing operation temperature and reactant gas flow rate and decreasing operation pressure.

G. D.H. Jeon, S. Greenway, S. Shimpalee, J.W. Van Zee 2008 [7]

CFD simulations were performed for four 10cm2 serpentine flow-fields single channel, double channel, cyclic-single channel, and symmetric single channel patterns to investigated the effect of flow field design. Researchers have taken two operating conditions with high relative humidity and low relative humidity and evaluated over potential, Current density distribution, water content at different cell voltage. Detailed descriptions of the inlet regions and local current density profiles were provided for analyzing the phenomena. The contribution of cathode overpotential was dominant at low current density, but that of ohmic loss was increased to considerable amount at low inlet humidity due to low membrane water content. For high inlet humidity, the double channel flow-field was found to have the highest performance (2–3% higher performance than the others) and to have most uniform current density distribution. However, for low inlet humidity, there were little difference on performance and current density uniformity among four serpentine flow-fields. The current density distribution of cyclic-single channel and symmetric-single channel flow-fields showed periodically similar plots. The current density distributions of single channel and double channel flow-fields were gradually varied. Considering low pressure drop of cyclic-single channel and symmetric-single channel flow-fields, these flow-fields would be advantageous for the larger scale system and low inlet humidity operation. However, for the practical use, there should be a compromise between manufacturing cost and performance. It conclude that At high relative humidity double channel flow field give better performance and uniform current density distribution and at low relative humidity cyclic single channel and symmetrical single channel give better performance and uniform current distribution.

H. A Iranzo, M Mun˜ oz, F Rosa,J Pino. 2010 [8]

They developed and simulated a 50 cm^2 fuel cell with parallel and serpentine flow field bipolar plates based on commercial software and its results validated against experimental measurements. The water and heat management and the distribution of reactants are analyzed. In different flow fields, the membrane temperature and the distribution of reactants (both in anode and cathode) on the interface of diffusion layer-catalyst layer are researched, the liquid water content of the interface of cathode catalyst-membrane, proton conductivity of membrane and the whole current density distribution are analyzed, and then the pressure drop along flow channel direction is calculated. A

discussion on different validation issues and model parameters is provided. The results of numerical model agree with the experimental measurements. It is found that the performance of parallel flow field is not as good as that of the serpentine flow field in which the reactants humidification will improve the cell performance because it will prevent the membrane electrode from drying. The best performance is obtained when the cell is operated with full humidification and pure oxygen, as concentration polarization is minimized and exchange current density increases. However, inaccuracies in the results in the mass transport polarization region were observed, presumably when liquid water in the channels produces a blockage effect that cannot be modeled with the multiphase flow model currently implemented.

I. S.O. Obayopo, T. Bello-Ochende, J.P. Meyer 2010 [9]

This study shows a three dimensional optimization study for a PEM fuel cell under different operating conditions and channel geometries.

Solver Ansys Fluent® with pre-processor Gambit® is used .The strategy of solution was based on the SIMPLE algorithm (Pantakar, 1980). The Momentum equation was as solved for the velocity followed by solving the continuity equation, after which updates the flow rate and pressure. For convergence the results Results then verified.

Obtained polarization curves obtained from the model at several operating temperatures from 65 to 90 ^{o}C a stochiometry ratios of 1.2 and 2.0 respectively for the anode and the cathode. The curve indicates that the fuel cell performance is an optimum at temperatures at approximately 65 to 75 ^{o}C.

Operating pressure was varied from 1 to 5 atm at a constant operating temperature of 70 ^{o}C. The fuel cell performance also improved. There was a significant increase in the fuel cell performance from 1 atm to 3 atm; however after 3 atm the increase was minimal. Increasing pressure improves the reactants interaction with the electrolyte hence increasing fuel cell performance. At a constant operating temperature of 70 ^{o}C and pressure of 3 atm. Reduction in porosities of the gas distribution electrodes results in a decrease in fuel cell performance. Though not quite discernable in the figure, reducing porosity from 0.6 to 0.4 resulted in a 3.3 % decrease in the average current density for a fuel cell operated at 0.75 V.

J. W Yuan, Y Tang, M Pan, Z Li, B Tang 2010 [10]

They developed the 3D model to predict the effects of operating parameters on the performance of PEM fuel cells. It evaluates operating pressure, fuel cell temperature, relative humidity of reactant gases, and air stoichiometric ratio and find out that Cell performance improve with increase of operating pressure, temperature and stoichiometric ratio at RHa=100% the output of the fuel cell reaches maximum power density at RHc= 50% the fuel cell achieve the best performance.

The performance of a PEM fuel cell increases with the increase of operating pressure because of enlarged partial pressure and concentration of reactant gases in the effective reaction area. Nevertheless, Some crucial issues such as parasitic power, operating cost and system volume have to be taken into account especially when choosing high-pressure operation in engineering practice.

The anode humidification has more significant effects than the cathode humidification because the membrane on the anode side always tends to dry out due to electro-osmotic mechanism. The best performance occurs at low air relative humidity and high hydrogen relative humidity.

III. CONCLUSION

This study concludes that fuel cell performance be governed by the inlet humidity state, initial setup, membrane thickness and cell voltage and the temperature increase inside the model. Because of that the fuel cell model, counting the energy equation, gives lesser performance than the model without the heat transfer consideration.

It was observed that the current density had not been sensitive to any variations in the mass flow rate of the anode gases unlike the cathode gases'.

Higher temperatures result in improved fuel cell performance.

With a high cell temperature and rise in humidification improves the performance.

The increase of operating pressure does not give a noteworthy improvement when the reactants were dry.

REFERENCES

[1] Sukkee Um,C.-Y. Wang, K. S. Chenb. "Computational Fluid Dynamics Modeling of Proton Exchange Membrane Fuel Cells", Journal of the Electrochemical Society, vol. 147-12, 2000, pp. 4485-4493.

[2] S. Shimpalee, S. Dutta: "Numerical prediction of temperature distribution in pem fuel cells, Numerical Heat Transfer, Part A: Applications": An International Journal of Computation and Methodology, vol. 38:2, 2000, pp. 111-128.

[3] Wang L, Husar A., Zhou T, Liu H. "A parametric study of PEM fuel cell performances". Int J Hydrogen Energy, vol. 28-11, 2003, pp.1263–72.

[4] T. Berning, N. Djilali, "Three-dimensional computational analysis of transport phenomena in a PEM fuel cell—a parametric study", Journal of Power Sources, vol.124, 2003, pp. 440–452.

[5] M.G.Santarelli,M.F.Torchio, "Experimental analysis of the effects of the operating variables on the performance of a single PEMFC", Energy Conversion and Management, vol. 48, 2007, pp. 40–51.

[6] F. J Zhang, Y Tang, C Song, X Cheng,J Zhang , H Wang, "PEM fuel cells operated at 0% relative humidity in the temperature range of 23–120 ˚C", Electrochimica Acta, vol. 52, 2007, pp. 5095–5101

[7] G. 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, 2008, pp. 1052 – 1066.

[8] A. Iranzo, M. Muñoz, F. Rosa and J. Pino, "Numerical model for the performance prediction of a PEM fuel cell. Model results and experimental validation", International Journal of Hydrogen Energy, vol. 35, 2010, pp. 11533 – 11550

[9] S.O. Obayopo, T. Bello-Ochende, J.P. Meyer. "Thermodynamic Optimization of Proton Exchange Membrane Fuel Cell System." Proceedings of the First Postgraduate Renewable Energy Symposium, NCRS2010, Paper no. NCRS017, 2010, pp. 1-15. Stellenbosch, South Africa, 11-12 November 2010.

[10] J. W Yuan, Y Tang, M Pan, Z Li, B Tang," Model prediction of effects of operating parameters on proton exchange membrane fuel cell performance", Renewable Energy vol. 35, 2010, pp. 656–666.

[11] Review on Design and Development of Proton Exchange Membrane Fuel Cell, IJSRD, Vol 3, Issue 6. 2015, Saumyakumar G. Rana