Investigation of Flow Mal-distribution in Proton Exchange Membrane Fuel Cell Stack

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Abstract- During the operation of a fuel cell stack, a uniform distribution of reactants from the manifolds to each cell is desired. An uneven flow distribution results in uneven performance between the cells. Though desired, it is difficult to achieve uniform distribution in practice and it is of interest to analyze the nature and magnitude of those undesirable deviations from ideality. In this research work, an attempt is made to experimentally investigate those deviations using pressure drop in a Proton Exchange Membrane Fuel Cell (PEMFC) stack with different number of cells at various load and no load conditions. Fluctuations in pressure drop due to the effect of increase in number of cells and stochiometric flow rates of reactants are analyzed. In addition the impact of flow patterns such as U-type and Z-type are also discussed in this work.

Keywords- PEM Fuel Cell; Flow characterization; pressure drop; U-type and Z-type flow patterns.

1. Introduction

Simply stated, the fundamental principle of fuel cells is that they use the reverse process to water electrolysis. For water electrolysis, current is supplied to water containing an electrolyte, thereby generating hydrogen and oxygen. In a fuel cell with an electrolyte between electrodes, hydrogen is supplied to one electrode and oxygen to the other, thereby causing a chemical reaction which results in generation of water and electricity [1]. In PEMFCs, the direct conversion of the chemical energy of reactants to electrical energy is achieved with high efficiency and good environmental compatibility [2]. It is considered as the most appropriate type of fuel cell for both residential and transport applications [3]. It uses a solid polymer membrane as electrolyte. Its operating temperature is less than 800C. Compared to other types of fuel cells [4], PEMFC is more compact, lightweight and it generates a higher volumetric and gravimetric power-density [5]. These facts and the ability to rapidly change power output are some of characteristics that make PEMFC suitable for automotive power applications [6].

The basic reactions in PEM fuel cells are

At anode:

$$H_2 \rightarrow 2H^+ + 2e^- \quad (1)$$

At cathode:

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O \quad (2)$$

Over all reaction:

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O \quad (3)$$

At present, more and more research focus on the understanding of the thermodynamic phenomena and on the fluid mechanisms coupled with the electro-chemical processes within PEMFCs [7]. In order to improve fuel cell design and operation, it is necessary to learn more about the mechanisms that cause the performance losses; for example, the losses due to mass transfer limitation and fluid dynamic characteristics [8]. The flow pattern through a PEM fuel cell stack can be either a "U" type, where the inlet and outlet are at the same side of the stack and the flows in inlet and outlet manifolds are in opposite direction from each other, or a "Z" type, where the inlets and outlets are on opposite sides of the stack and the flows in inlet and outlet manifolds are parallel to each other [9].

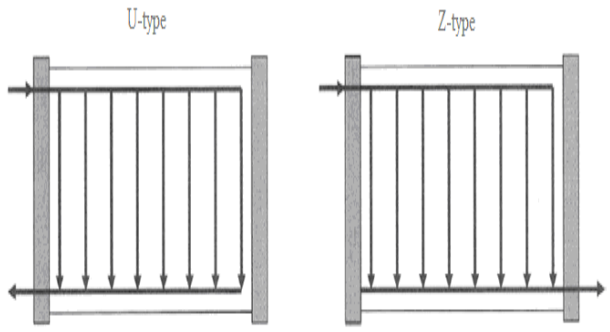


Fig.1. U-type, Z-type flow patterns

In most of the cases, mal-distribution occurs due to predomination of friction, momentum and kinetic energy, upstream disturbances, downstream disturbances or a non optimized manifold design. The undesirable and uneven flow distribution would result in uneven performance between the cells. We have observed from our experimental investigations that the first cell and last cell voltages deviates very much from other cell voltages. It is of interest to analyze the nature and magnitude of those undesirable deviations from ideality. There are several studies in the literature related to the PEMFC flow characteristics [10]. Most of the above studies mainly focused on water flooding and pressure drop characteristics in flow channels. Therefore the study of flow maldistribution is essential for more clear understanding of the design and optimization of fuel cell stack.

The principle and experimental procedure used to investigate the flow mal-distribution behavior of PEMFC are explained in section 2; Results obtained are analyzed in section 3; Conclusion about the flow mal-distribution in PEMFC is arrived in section 4.

2. Experimentation

As the flow rate is always proportional to pressure drop, it is possible to study the flow mal-distribution experimentally by monitoring the pressure drop across each cell in the stack. The experimental set up consists of fuel (hydrogen) supply unit, oxidant (air) supply unit, mass flow controllers for hydrogen and air, PEM fuel cell stacks of active area 300 cm^2, and an electronic load bank. All the bipolar plates of the fuel cell stack are provided with pressure tapings on their edges at the inlet and outlet of the multi-channel serpentine flow fields [11].

Air and hydrogen flow rates required to give 30A, 50A , 70A load with the stoichiometry ratio two and three are determined for single cell, four cell , six cell and eight cell stack according to Faraday's Law [12,13]. The reactants are fed to their corresponding inlets in U-type and Z-type flow pattern [14, 15] at the predetermined flow rates using mass flow controllers. The pressure transmitter is connected to the inlet and outlet tapings of each cell to observe the existing pressure drops. The experiment is carried out in single cell, 4, 6, 8 cell stacks with the above said flow patterns and flow rates. Pressure drops against the cell numbers are recorded and analysed.

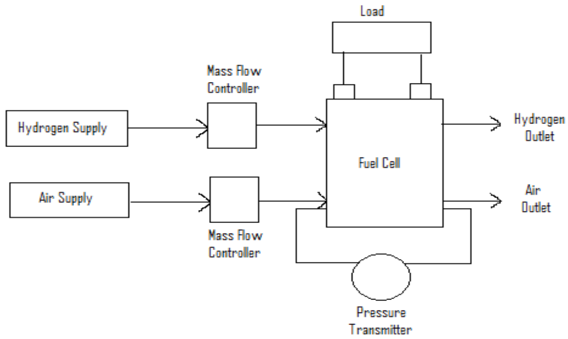


Fig.2. Schematic Diagram of a PEMFC setup

3. Results and Discussion

The pressure drops during each experimental runs in two flow patterns are measured and plotted in Fig.3 to 8. The flow mal-distribution in PEMFC are analyzed from the plots. For the single cell, reactants flowrates (Q_1, Q_2,and Q_3) are calculated at a particular current output of 30A, 50A & 70A with stoichiometry ratio two. The pressure drop corresponding to the respective flow rates are plotted in Fig. 3 and Fig. 4.

Fig.3 shows the pressure drop of single cell at various time intervals. It seems that pressure drop fluctuates with time is due to formation and removal of miscellaneous dynamics of water droplets [16,17]. It is also observed that the prediction of the rate of formation, size, residence time of these water droplets and the magnitude of additional pressure drop caused by them, are very tricky.

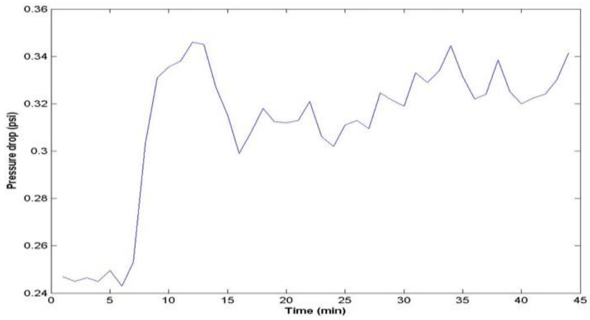


Fig. 3. Pressure drop of single cell at various time intervals at Q1 flowrate

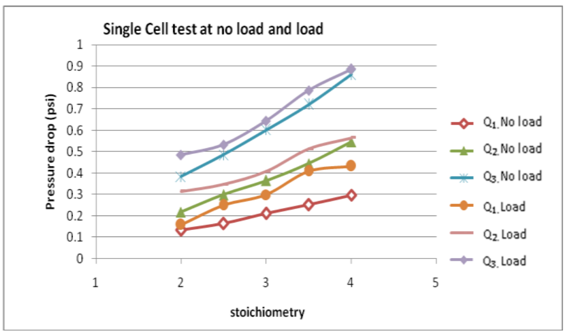


Fig. 4. Pressure drops profiles of a single cell at Q_1, Q_2,and Q_3 flow rates*

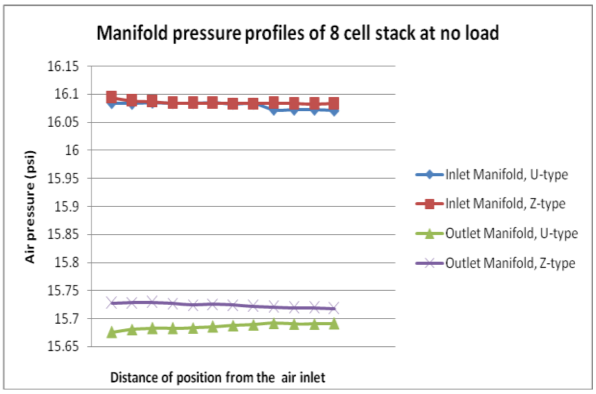
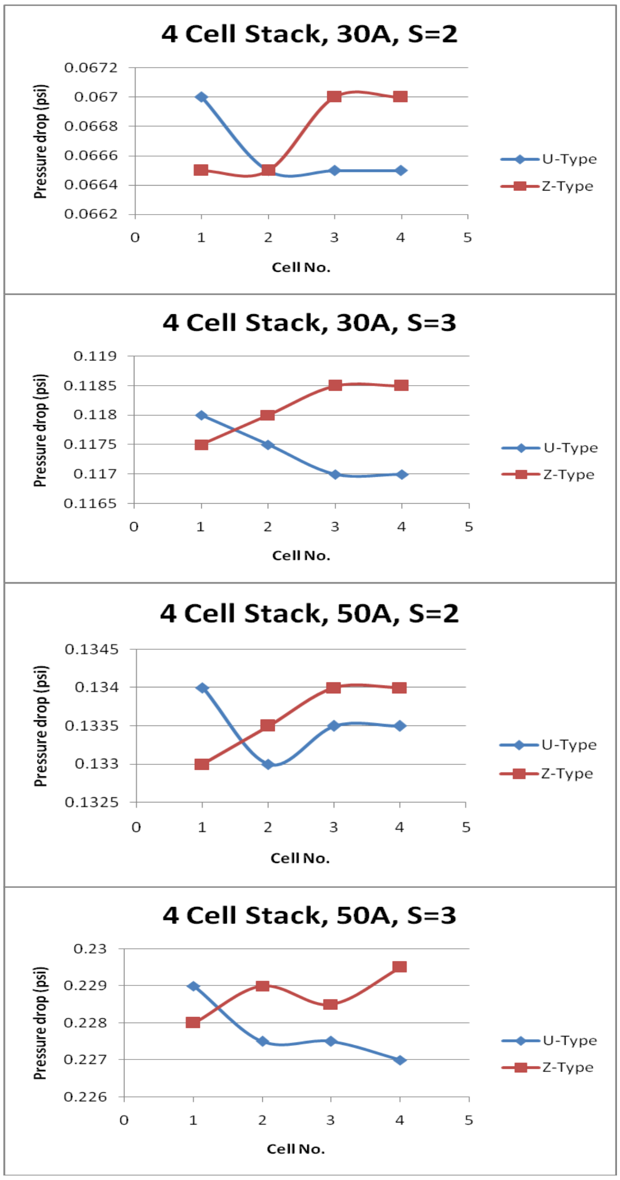


Fig. 5. Pressure profile of 8 cell stack with no load at the flow rate Q 70A,S=2



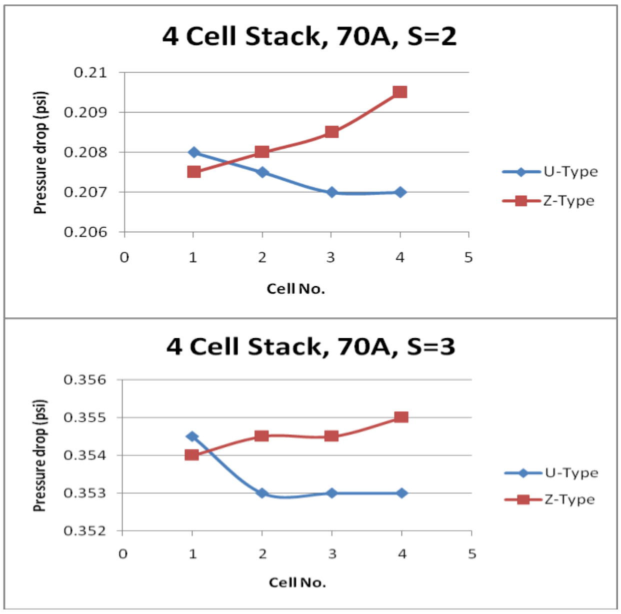
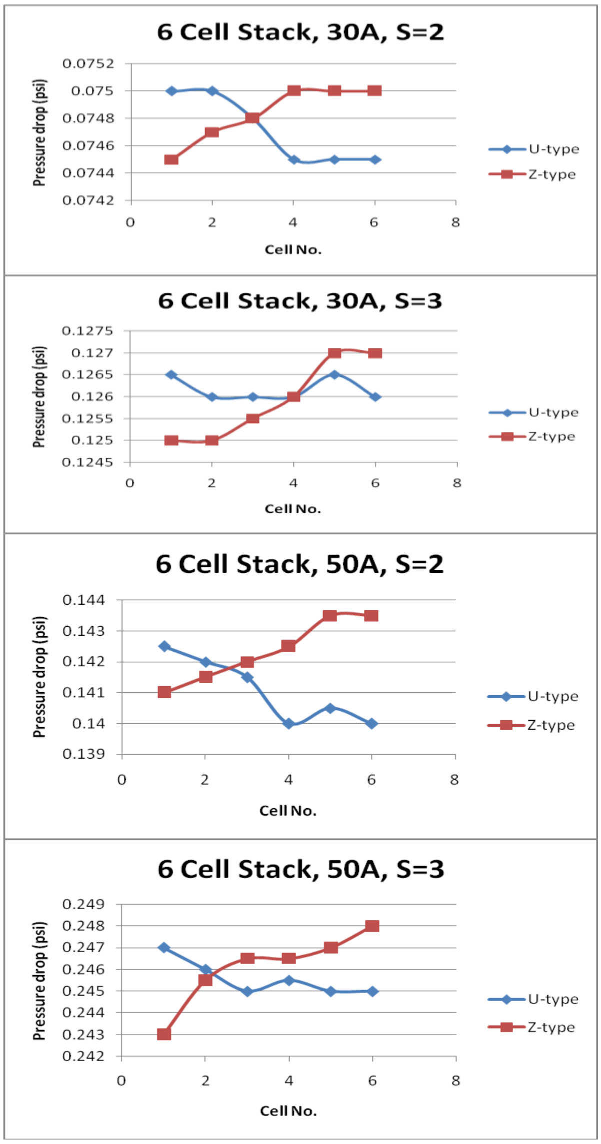


Fig. 6. Pressure profiles of 4 cell stack in U-type, Z-type flow patterns



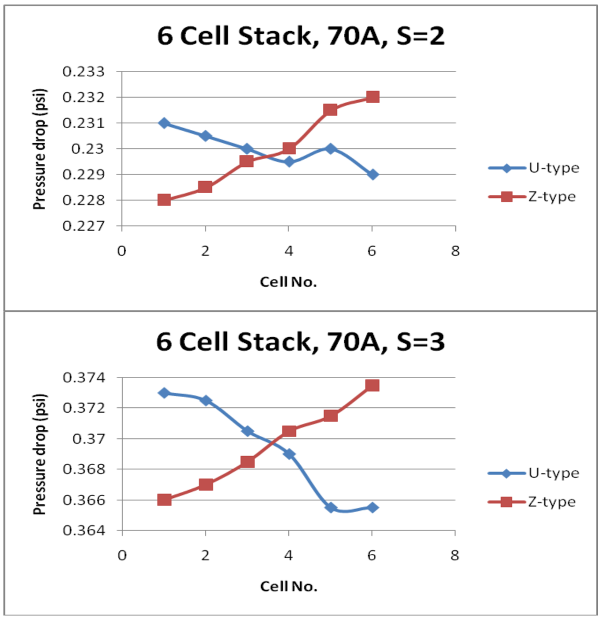


Fig. 7. Pressure profiles of 6 cell stack in U-type, Z-type flow patterns

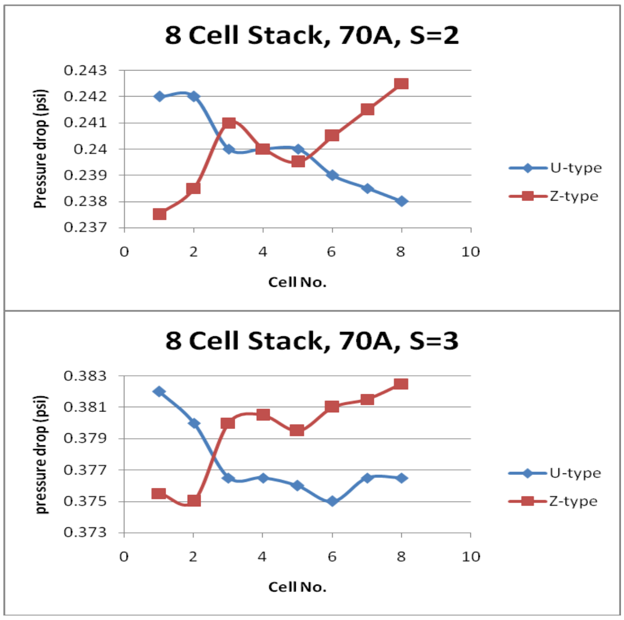


Fig. 8. Pressure profiles of 8 cell stack in U-type, Z-type flow patterns

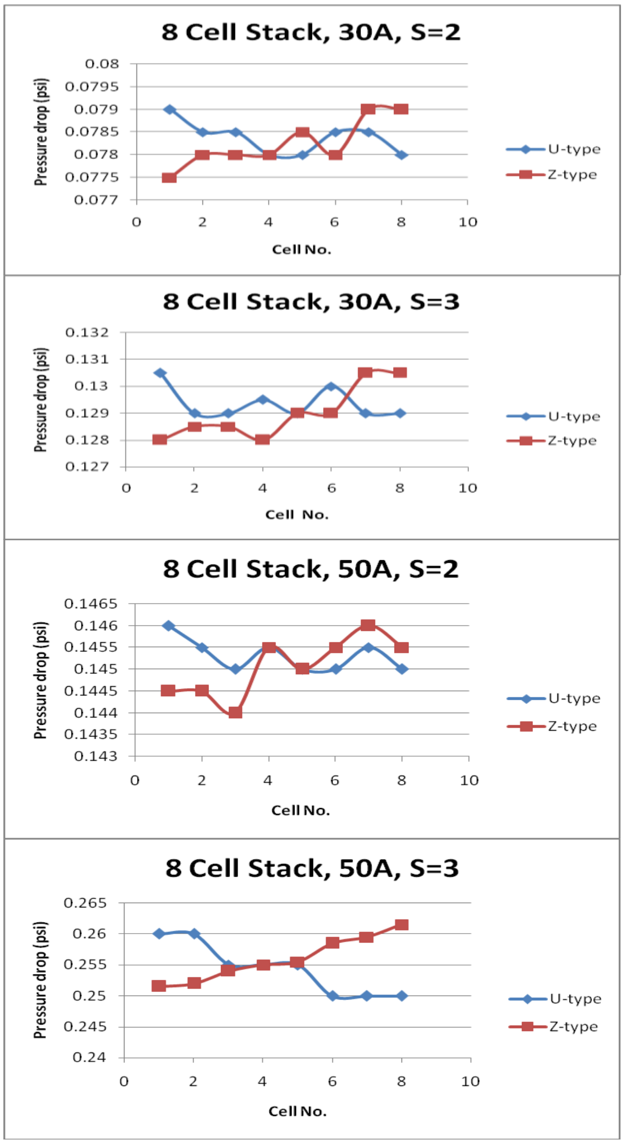


Fig. 4 gives the results related to the pressure drops corresponding to the calculated flow rate* (Q_1=$Q_{30A,S=2}$, Q_2=$Q_{50A,S=2}$ and Q_3=$Q_{1,\ 70A,S=2}$) for a single cell. It is operated at no load and load conditions and noted that the pressure drop is marginal at load condition as compared to no load condition. In Fig.5 the manifold pressure profile of 8 cells stacks at no load conditions are recorded against distance from the reactants inlet in U-type and Z-type flow pattern. Fig.6 to 8 show the experimental results of pressure drops in 4, 6, 8 cell stacks with load condition in U-type and Z-type flow pattern. İn this studies the outcome of inlet and outlet length at manifold is also analyzed with two types of flow patterns in Fig.5. It is identified that the pressure drop decreases along the length of the inlet manifold in both flow patterns. But it is reverse in the case of outlet manifold.

The experimental results clearly indicate the existence of pressure drop variation between first and last cells in the stack and also show that the extent of flow mal-distribution increases with the number of cells and stoichiometric ratio of reactants. The flow patterns play an important role in pressure drop. From the experimental studies, it is observed that pressure drop in Z-type flow pattern increases with cell numbers while it is reverse in U-type flow pattern. This implies that there is more flow of reactant in first cell next to inlet in the U-type flow pattern and there is more flow of reactant in the cell adjacent to outlet in Z-type flow pattern, which may lead to cell voltage variations.

4. Conclusion

The flow mal-distribution behaviour in PEMFC are analysed and it is observed that the miscellaneous dynamics of accumulation of water droplets in the flow field channels cause a lot of fluctuations in pressure drop and the extent of flow mal-distribution increases with number of cells and stoichiometric ratio of reactants. Hence a sensible design of flow field is needed for uniform cell voltage distribution in a Proton Exchange Membrane Fuel Cell Stack.

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References

[1] FranoBarbir, “PEM Fuel Cells: Theory and Practice”, Elsevier Academic Press, 2005.

[2] Joon-Ho Koh, Hai-Kyung Seo, Choong Gon Lee, Young-Sung Yoo, Hee Chun Lim, “Pressure and flow distribution in internal gas manifolds of a fuel-cell stack”, Jn. of Power Sources, Vol.115,54-65, 2003.

[3] S. Pandiyan, A. Elayaperumal, N. Rajalakshmi, K. S. Dhathathreyan, N. Venkateshwaran ,”Design and analysis of a proton exchange membrane fuel cells”,Jn of Renewable Energy Vol 49, 161-165, January 2013.

[4] Robert L. Pigford, Ashraf, Muhammad, Miron, Yvon D , “Flow distribution in piping manifolds”, Ind. Eng. Chem. Fundam.,Vol.22, 463-471, 1983.

[5] Li Xi Anguo,Sabir Imran., “Review of Bipolar Plates in PEM Fuel Cells: Flow-Field Designs”, Int. Jn. Hydrogen Energy, 30, 359 - 371, 2005.

[6] Wenzhong Cao, “Performance comparison of a fuel cell-battery hybrid power train and a fuel cell-ultra capacitor hybrid power train”, IEEE Trans. on Vehicular Technology, Vol.54, No.3,846-855, 2005.

[7] S.Um, C. Y.Wang, K. S. Chen, ,“ Computational fluid dynamics modeling of proton exchange membrane fuel cell”, Jn. of Electrochem. Soc., Vol. 147, 4485-4493, 2000.

[8] D. Singh , D.M. Lu, N. Djilali “A two-dimension analysis of mass transport in proton exchange membrane fuel cells”, Int. Jn. Eng. Sci., Vol. 37, 431-452, 1999.

[9] Junye Wang, “Flow distribution and pressure drop in different layout configurations with z-type arrangement”. Energy science and technology, Vol. 2, No. 2, 1-12, 2011.

[10] Paul A.C. Changa, “Flow distribution in PEM fuel cell stacks”, Jn. of Power Sources, Vol.162, 340-355, 2006.

[11] D.Spernjak, A. K. Prasad, S. G. Advani., “Experimental Investigation of Liquid Water Formation and Transport in a Transparent Single- Serpentine PEM Fuel Cell,” Jn. Power Sources, 2, 334-344,2007.

[12] J.Y.Wang, “Theory of Flow Distribution in Manifolds”, Chemical Engineering Jn, Vol 168, 1331-1345, 2011.

[13] Suman Basu, “Two-Phase Flow mal distribution and Mitigation in Polymer Electrolyte Fuel Cells”, Journal of Fuel Cell Science and Technology, Vol. 6 /1,2009.

[14] J.Y.Wang, “Pressure Drop and Flow Distribution in Parallel-Channel of Configurations of Fuel Cell Stacks: U-Type Arrangement”, Int. Jn. of Hydrogen Energy, Vol 33(21), 6339-6350, 2008.

[15] J.Y.Wang, ”Pressure Drop and Flow Distribution in Parallel-Channel of Configurations of Fuel Cell Stacks: Z-Type Arrangement ”, Int. Jn. of Hydrogen Energy, Vol 35, 5498-550, 2010.

[16] X.Li, I.Sabir, J.Park,“A Flow Channel Design Procedure for PEM Fuel Cells With Effective Water Removal,” Jn. Power Sources, Vol 163,2, 933-942, 2007.

[17] John Bachman, Maxime Charvet, Anthony Santamaria, Hong-Yue Tang, Jae Wan Park, Ronald , “Experimental investigation of the effect of channel length on performance and water accumulation in a PEMFC parallel flow field”, International Journal of Hydrogen Energy,In Press, Corrected Proof , September 2012.