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Effect of Geometric Design of the Flow Fields Plat on the Performance of A PEM Fuel Cell: A Review

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Abstract— The performance of the proton exchange membrane fuel cells depends on a lot of physical and chemical factors including the operation conditions, transport phenomena inside the cell and kinetics of the electrochemical reactions, membrane electrode assembling (MEA) but the design of the flow channels is one of the most important factors affecting the performance of fuel cells. The homogeneous distribution of the reactive gases over the flow fields channels and catalyst surface, it leads to improve the chemical reactions and thus to improve the performance of the cell**.** The aim of this work is to review the most important results conducted in recent years related to the effect of the different geometric design parameters of the flow field channels on the overall performance of a PEMFC.

Index Terms— *Fuel cell, hydrogen fuel, renewable energy, temperature*

1. Introduction

Fuel cells have been emerging as an alternative power source that are environmentally friendly and are more efficient than many generators and engines. The main advantage of using fuel cells as power sources is that it converts the chemical energy in the fuel cell directly to electrical energy. This direct conversion of energy allows for higher possible system efficiencies than engines. As the number of power generators using fossil fuel energy increases in all applications, the necessity for alternatives to the internal-combustion engine become even more obvious [1-6]. The efficiency of fuel cells is higher than the internal combustion engine and the only byproducts are water and heat, fuel cells are considered as prominent power sources for the future. [7-9]

2. Types of Fuel Cell

There are different types of fuel cells classified mainly by the type of the electrolyte used. They are proton exchange membrane fuel cells (PEMFCs), alkaline fuel cells (AFCs), phosphoric acid fuel cells (PAFCs), molten carbonate fuel cells (MCFCs), and solid oxide fuel cells (SOFCs). The operating temperature of fuel cell depends on the electrolyte that used in the fuel cell. The applications of fuel cells can be classified into portable power, transportation, and stationary uses. Among the above five types of fuel cells, the PEMFC operating at low temperature has proved its potential for wide applications, also we must be referring that PEMFC fuel cell has another advantage such as there are easy implementation, soundness of the system, longer lifetime, low emission and high power density when compared with other types of fuel cell [10],[11].

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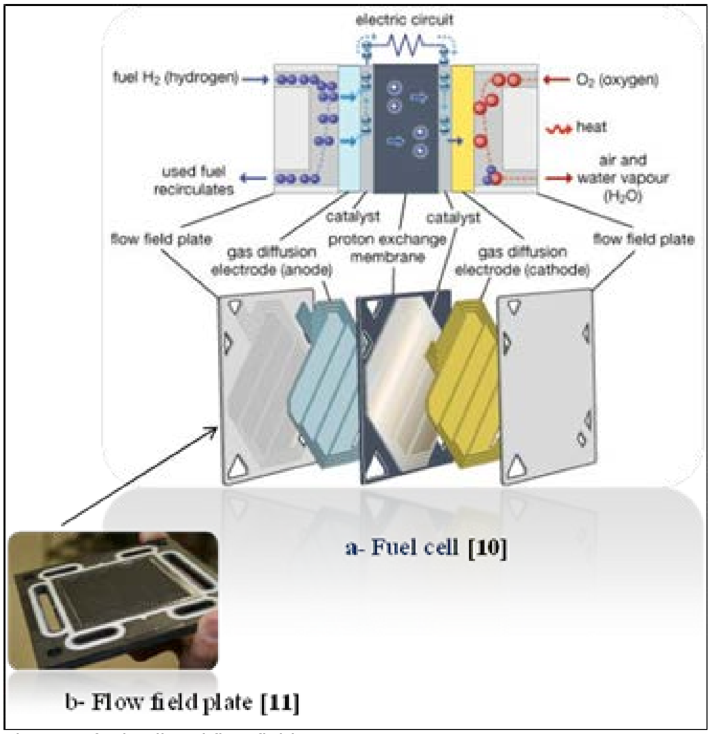
3. Compounds Of Fuel Cell

In general , fuel cell consist of two electrodes (anode and cathode) and electrolyte between them, each of electrodes consist of flow field plates ,gas diffusion layers (GDL) and catalyst layer shown in figure (1). The flow field plates, usually the most outer layer of the fuel cell, are responsible for distributing reactant gases evenly throughout the cell, removing excess water efficiently, and supplying a conduction route for the electrons from the external circuit. The GDL has a similar function to the flow field plate as the GDL further distributes reactant gases to the active sites on the catalyst layer, whilst facilitating the removal of water and providing and conductive path for electrons. The difference between the GDL and flow field plates is that the GDL is made of a porous carbon paper (or woven carbon cloth) that has been impregnated with a hydrophobic agent, Polytetraflouroethelyne (PTFE). PTFE makes some of the pores hydrophobic which causes them to repel water and allow a constant path for reactant gases to travel through. The catalyst used for PEMFC applications is platinum and allows for reaction of the hydrogen (proton) and oxygen to occur, providing a driving force that creates the electrical current. The electrolyte membrane is a fluorinated polymer that has been treated [12] to allow for proton conductivity and prevent electrons passing through. In general, the most popular membrane is Nafion® designed by DuPont. As a proton conductive membrane, Nafion® is partially hydrophilic and requires a certain amount of water saturation to function properly. Thus, there is a very fine balance to remove only the excess water from the catalyst area and not dry out the membrane. [13]



a- Fuel cell [10]

b- Flow field plate [11]

Figure 1. fuel vell and flow field

4. Bipolar plates

In general, the flow field plates have a significant effect on the improvement fuel cell performance and lifetime. They responsible for distributing reactant gases, removing excess water efficiently, and also giving a conduction route for the electrons from the external circuit [14-16]. Bipolar plates are plates that having flow fields on both sides of the plate i.e. one side of flow fields as the anode side and the other side as the cathode side. The other names of bipolar plates are separator plates due to separate two cells, so the connection of many fuel cells in series refer to the fuel cell stacks. Also, we must be referring that the bipolar plate cost, weight and volume in fuel cell have significant effect on the stack performance due to it constitutes more than 60% of the weight and over 30% of the overall cost in a fuel cell stack, so that the develop of the fabrication techniques, flow field layouts and selection metals are required for economic advantages and high performance [17-20].

The operation conditions (pressure drop and fluid flow distribution) in any designs for flow field channel of PEMFC fuel cell have a significant effects on the performance and the lifetime of the fuel cell .So the uniform flow distributions and low pressure drop are require for any designs in the fuel cell to achieve that the reactant gases arrive along the electrode surface area and that lead to achieve the reaction in all catalyst that found in electrode ,while the low pressure drop referring to the low losses happen when the reactant gases flow through channels from inlet plate to the outlet plate because of the high pressure drop occur when the loss happened as the friction loss or as the flow through the bends or others those lead to the non-uniform flow distribution and form accumulation water droplet. So the pressure losses using to overcome on these disadvantages.

5. Requirements of Bipolar plates

The necessary requirements in a bipolar plate are; a)- The ability to uniformly distribute the reactant gases over the special active electrode surfaces , b) Structurally strong , c) Cheap material and low cost for manufacturing bipolar plate d) Good corrosive resistance towards acids and bases , and e) High electrical conductivity, high thermal conductivity and high gas impermeability [17],[20],[33][34].

6. Flow Field Design of Fuel Cell

The flow fields design are one of the important obstacles to the spread of fuel cells, because of these flow fields have a significant effect on the flow distribution and pressure variation in PEMFC that lead to effect on the performance of fuel cell.. The PEMFC performance is generally based on energy efficiency and power density in studying. Despite of all the research and development efforts, the design of the flow fields and bipolar plate remain one of the important issues for cost reduction and performance improvement of PEM fuel cell. In general there are different types of the flow field layout design such as; pin-type, parallel/straight type , single and multiple serpentine flow fields and interdigitated flow fields ,and spiral type [17],[20],[33]. Bellow involves the principle work of most types of flow field design according to advantages , disadvantages and the flow through these channels;

7. Pin-Type Flow field

The first type of flow field layout design is pin type. In this type these pins are usually circular or cubical in cross-section. In this type the reactant gases flow through grooves around pins. It was found in this type the reactants flow through the paths with least resistance that lead to form stagnant areas and low reactant pressure drop , so the non-uniform reactant distribution and decreased water removal that lead to reduce fuel cell performance [17],[20],[33]. The figure (2) pins type flow field

8. Parallel/Straight Flow Field

Generally the parallel flow field can be classified into two kinds are Z-type and U-type according to the outlet flow rate of reactant gases, while the inlet is same . First the Z-type flow field in this type the inlet flow rate in one side, while the outlet flow rate in other side of flow field plate . Second the U-type flow field in this type the inlet and outlet of the flow rate of the reactant gases in the same side of flow field plate .The parallel flow field design consists of number of parallel channels and that design also is connected to the gas inlet and exit. In this type the reactant gas (for example hydrogen) tends to follow the path with least resistance and would likely follow the channels along the plate walls, neglecting the channels at the center of the plate leading to under-utilization of the plate (that lead to form stagnant areas in various areas in the plates). During the operation of the fuel cell the water droplets increasing (due to neglect some channel) that lead to accumulation liquid water in the channels and that caused to reduce cell performance. So the poor gas flow distribution and inadequate water removal lead to decrease cell performance, also several researchers found the low pressure drop in the flow channels because of the length of the channels of the parallel flow field relatively small , when the reactant gases pass through these channels [17],[20],[33]. The figure (3) shown parallel flow field in Z and U-type flow field.

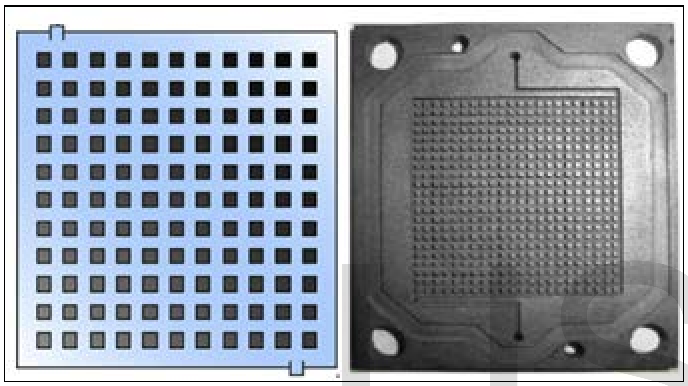


Figure 2 :a [35] & b [37] pin type flow field.

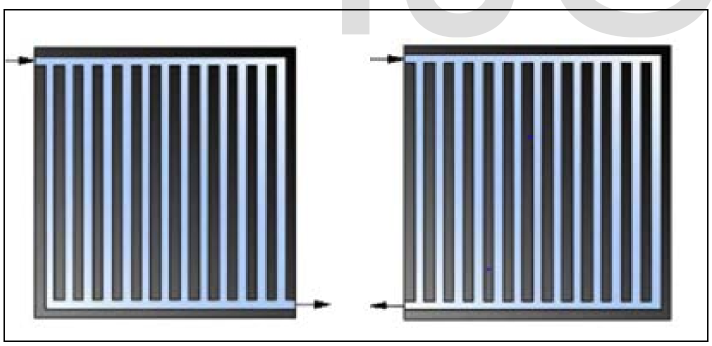
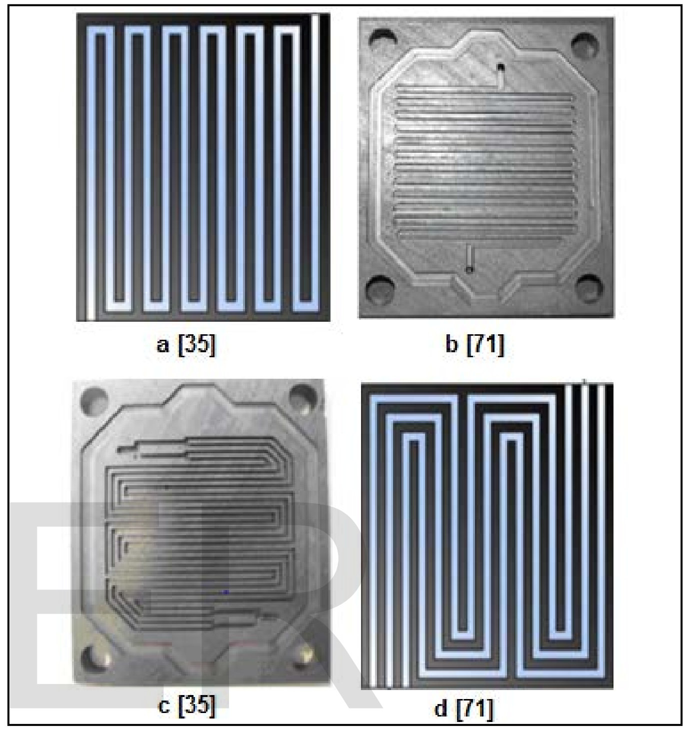


Figure 3. Z-and U-type parallel flow field [71].

9. Serpentine Flow Field

The properties of this type of the design as the following; a)- the continuous flow , b)- the inlet at one end and the outlet at the other end of plate and c)- the flow in the serpentine path . Usually this type of design used to supply reactant gases to the active area and turn eliminates stagnant areas caused by incorrect gas distribution. The high pressure drop occurs in this type due to the relatively long flow path from inlet to outlet , also one problem happen in this design represented in a getting blocked due to the formation of water droplets in the channels especially for higher current densities . So to avoid this problem and limit pressure drop must be use the multiple serpentine channels instead of a single serpentine channel to achieve the continued operation of the fuel cell even with blockage of one channel of fuel cell due to the presence of the other channels are open , in spite of a lower efficiency due to the blockage of one channel and decrease of the long flow path [17],[20],[33]. The figure (4) shown the single and multiple serpentine flow field.

Fig (4) a&b single serpentine and c&d multiple serpentine.



10. Interdigitated Flow Field

In this type of the design they found the interdigitated flow field consists of multiple dead - ended flow channels .The principle of work of the interdigitated flow field is a forced gas flow through the adjacent gas diffusion layer (GDL) and then to the electrode when the reaction occur, while the excess reactant gases return through GDL to flow field channel for the outlet reactant gases through flow field plate. We must be referred that the accumulation of the products in GDL give a significant advantage because the adjacent GDL is electrode . In this type the pressure drop is depending on the properties of the GDL such as a porosity and hydrophobicity , so the lifetime and the performance of the fuel cell can be specified by these properties of GDL. This type of flow field is not very common in PEMFC fuel cell [17],[20],[33]. The figure (5) shown the interdigitated flow field

The above four types of flow field is the most common can be showed in PEMFC fuel cell, also must be referred that any types can be modified to give new design that shown in the effect of flow field design on the PEM fuel cell performance

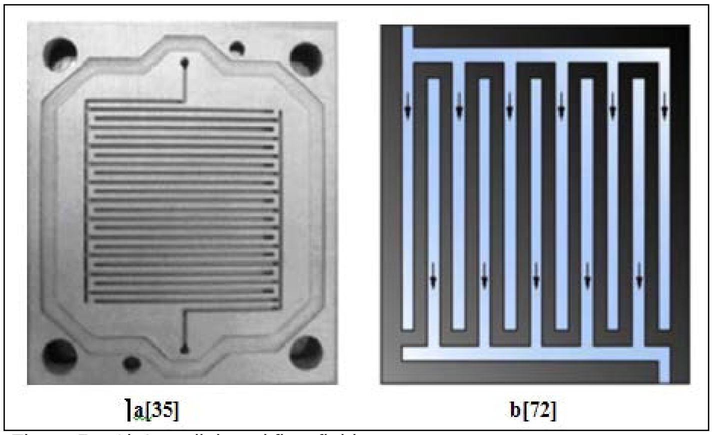


Figure 5. a&b Interdigitated flow field.

11. Spiral Flow Field Design

The spiral flow field design is one type of flow field plate in PEMFC fuel cell in this type gases flow in spiral path . Because of the remove inefficient water causes the low power output and that lead to lower performance[35] , so this type usually not used in fuel cell because of these disadvantage .The figure (5) shown spiral flow field

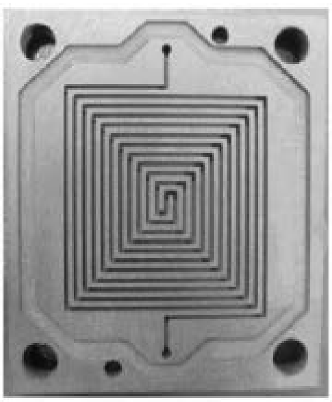


Fig (5) spiral flow field [35]

12. The Effect of Flow-Field Design

In general ,the design of special gas flow fields with uniform flow distribution and low pressure drop in the flow field plate of the PEM fuel cell are required for high absorption and easy removal of wastewater .So Liu et al. [35] experimentally investigated and compared the effect of various designs of gas flow fields on the PEM fuel cells and cell stack performance. They found that the effect of flow field design on performance is arrangement from best to worse as follow; a) - Serpentine having uniform distribution, acceptably pressure drop, acceptable water flooding and good humidity in the cathode channel, b) – First design of pin type (Pin VI) gives a larger interactive space which lead to improved mass transfer shown in figure (6) , c) – Two different designs of parallel flow field depend on the inlet and exit reactant in parallel types in these types water distribution is irregular and this leads to accumulate water in large areas shown in figure (6) , d) –Second design of pin type (PinV2) has the same reason in Pin (V1) shown in figure (6) , e) – Interdigitated having High pressure drop and this may lead to a flood on the cathode electrode due to the mechanism of transfer of H_2 and O_2 in the channels of the fuel cell, and f) - Spiral has the remove inefficient water causes the low power output. Due to experimental work results showed that over all other tested flow field design the serpentine flow field showed best performance while the spiral flow field design showed the worst performance. Also they found that the fuel cell stacks with single serpentine channel design and they symmetric four serpentine channel arrangement both worked better. They observed that the cathode plate water distribution of cell with symmetric double serpentine effectively utilized the MEA area without excessive water blocking the diffusion path. Therefore, the novel symmetry serpentine multiple flow channel arrangement is particularly recommended for large sized fuel cells.

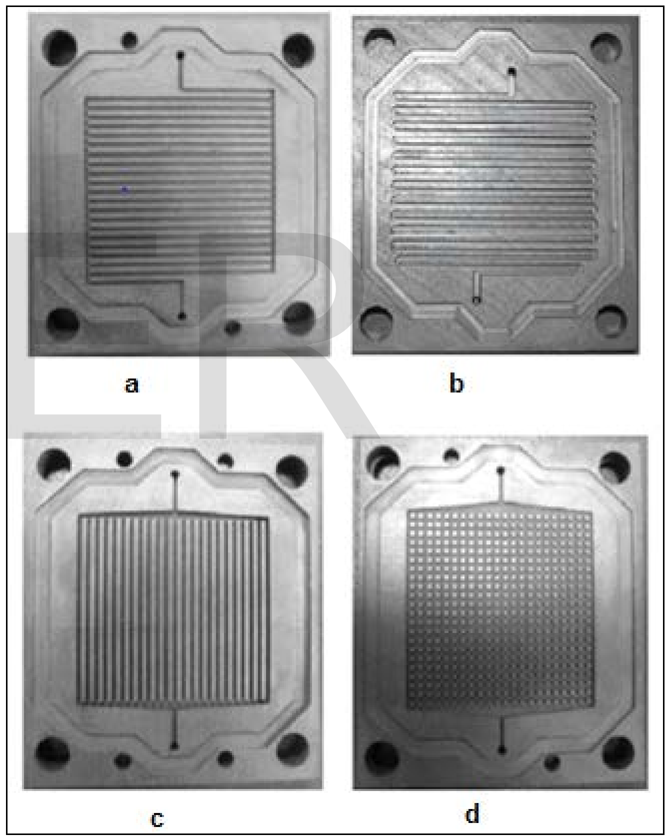


Fig (6) a- parallel V1 ,b- parallel V2, c-pin V1,and d-pin V2 flow [35].

Pal et al. [36] numerically analyzed the effect of three flow channel configuration (conventional, serpentine and pin type) on the cell performance. Also, investigated the effect of porosity of the carbon inserts on the cell performance for range from 0.6 to 0.9. Results showed that the performance of the flow channel with zigzag and uniformly positioned porous inserts is more than the conventional serpentine flow channel by 20.36% and 16.87% respectively. Also they found the reason for this increase is the removal of the accumulated water from the rib surface due to the capillary action of the porous carbon inserts. This helps in eliminating the stagnant water regions under the rib and there by helps in reducing liquid flooding. There is not much effect on the performance of the two new adopted designs with the variation in porosity level of the porous inserts from 0.6 to 0.9. A.P. Manso et al. [37] reviewed the effect of different geometric configurations (simple serpentine , multiple serpentine , simple parallel (Z-type and U-type) , parallel in series , symmetrical parallel in U and interdigitated flow field) on the performance of the PEM fuel cell. So in the different flow field layout design results showed these flow field has little effect on the overall PEM fuel cell performance at high operation condition while opposite happens at low operation condition because of these flow field have a significant effect on the PEMFC performance . Also they found that the flow fields with low pressure drop gives low performance of the fuel cell , while the opposite is happening in flow field with high pressure drop such as serpentine and interdigitated flow fields give more uniform reactant distribution and improve the elimination of condense water in the cathode side but that lead to increase the energy required to drive the gas , also must be referring the serpentine flow fields, longer straight channel segments between channel bends and narrower channels improve convection that lead to increase in the active area of the MEA and decrease in the current collection .Vijay Edupuganti [38] numerically investigated the effect of flow field plate geometry and design (serpentine and parallel Z-type) on the PEM fuel cell performance by using Computational fluid Dynamic (CFD) Modeling and Simulation .After running simulation he was found that the flow field geometry on the cathode side had a significant effect on the reactant distribution and water management, and the velocity results showed that the velocity in the serpentine design is relatively higher and uniform that lead to uniform diffusion of reactants and that minimized water accumulation , so the serpentine model can be represented the optimal model, also in serpentine flow field design, the pressure along the channel decreased evenly, while the pressure decreased in parallel flow field design was uneven . Sreenivasulu et al. [39] experimentally investigated the effect of the back pressure and the flow geometry (4-Serpentine flow, interdigitated flow and dual inlet single outlet flow) on PEM fuel cell performance. Results showed that the performance of the fuel cell increases with an increase in back pressure in the hydrogen flow channels due to an increase in residence time of hydrogen in the channel. As a result there is an increase in the diffusion rate of hydrogen across the GDL, and also found the 4-serpentine flow channel gives the higher power output both with and without back pressure, while at higher back pressures the dual inlet and single outlet flow channel performances better than the interdigitated channel. Glandt et al. [40] numerically studied the effect of single, and double pass serpentine flow field designs on temperature and local current density distributions. Conclusions showed that the local temperature and current density distributions become more uniform for serpentine flow field designs with a larger number of passes. Also they were found that the double pass flow-field gives less condensed liquid water on the cathode than the single pass flow-field. Maharudrayya et al. [41] developed algorithms to calculate the plate pressure drop and flow distribution in multiple (U and Z-type) parallel channel configurations used in PEM fuel cell stacks. They were found from comparison assessment of different channel configurations that serpentine channels exhibit a significantly higher pressure drop while parallel configurations have a significantly high flow non-uniformity index .The parallel channel configurations can be reduced by using multiple-U type configurations without significant increase in pressure drop, while multiple Z-type configurations have, in general, a lower flow non-uniformity index but may have much higher pressure drop .Wang [42] developed analytical model based on mass and momentum conservation to solve the pressure and flow distribution in parallel-channel configurations of fuel cells: U-type arrangement. His model takes both of friction effect and inertial effect into account ,while existing models neglected either inertial effect or friction effect. Therefore he was found the friction and momentum effects work in opposite directions, the former tending to produce a pressure drop , while the latter tending to produce a pressure rise. The proper balance between the two effects can result in less non-uniformity and an optimal design of the U-type fuel cell stacks.

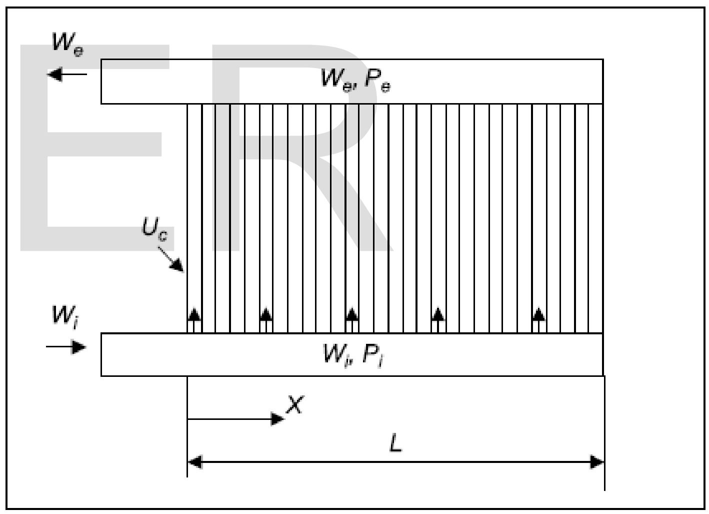


Fig. (7) – Schematic diagram of U-type arrangement

Wang [43] has been developed a theoretical model based on mass and momentum conservation to solve the pressure and flow distribution in parallel-channel configurations of fuel cells: Z-type arrangement ,also he taking into consideration friction and inertial effects. Results showed that the analytical solution is fully explicit that it is easily used to predict pressure drop and flow distribution for Z-type layers or stacks and provide easy-to-use design guidance under a wide variety of combination of flow conditions and geometrical parameters to investigate the interactions among structures, operating conditions and manufacturing tolerance and to minimize the impact on stack operability. It can also be used for the design guidance of flow distribution and pressure drop in other manifold systems, such as plate heat exchanges, plate solar collectors, distributors of fluidized bed and boiler headers .For determining the performance of different layout configuration of Z-type arrangement .

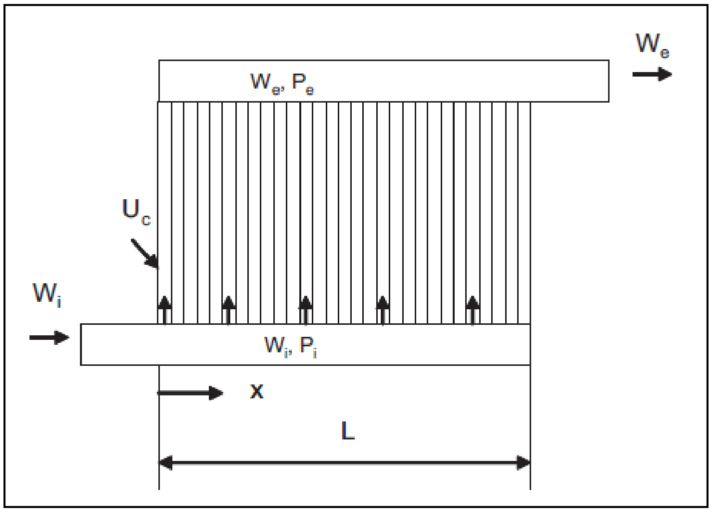


Fig. (8) – Schematic diagram of Z-type arrangement.

Wang [44] was extended his theoretical model of Z-type arrangement to different layout configuration of Z-type arrangement, including single serpentine, multiple serpentine, parallel straight and interdigitated layouts using the physical parameters of the structure; ratio of length to diameter and ratio of all the channel area to head area. He was found the generalized theory has unique capacities to compare directly, systematically and quantitatively different configurations, existing models and methodologies; also the theory makes a step forward in flow field designs, and provides practical guideline and measures to ensure uniform flow distribution in various configurations.

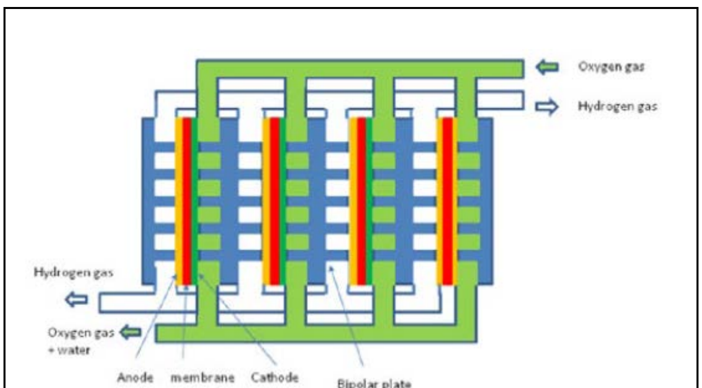


Figure (9) Schematic Diagram of Fuel Cell Stack and Bipolar Plates with Main Component [44]

Wang et al. [45] developed model to investigate the effects of the cathode flow channel configuration on the local transport phenomena and cell performance for parallel and interdigitated flow fields in proton exchange membrane (PEM) fuel cells. The effect of liquid water formation on the reactant transport is taken into account in this model. Results showed that for operating voltages greater than 0.7 V, the electrochemical reaction rates are low with a small amount of oxygen consumption and liquid water production, and all cell designs provide sufficient oxygen for the electrochemical reactions. Thus, the flow channel aspect ratio and the flow channel cross-sectional area have little effect on the cell performance, while for operating voltages lower than 0.7 V, as the operating voltage decreases the electrochemical reaction rates gradually increase with a large amount of oxygen consumption and liquid water production, so the cell performance is strongly dependent on the flow field design. For the parallel flow field design, lower flow channel aspect ratios and flow channel cross-sectional area are as improve liquid water removal, thus, decreasing both improves cell performance. However, the interdigitated design has an optimal aspect ratio of 1.00 and an optimal cross-sectional area of 1.000 mm × 1.000 mm.

So the comparative analysis of various flow field geometric configuration is repeated in several studies, both in steady state and in transient state[46-58], the results showed that the flow field geometric configuration (straight parallel or Z-type parallel, pin-type and cascade) with smaller pressure drop that lead to mal-distribution over the active surface area of the MEA and that causes decreasing electrochemical reaction efficiency and PEMFC performance, while the flow field geometric configuration (serpentine and interdigitated flow field) with higher pressure drop that lead to improve uniform reactants distribution over the catalytic layers, increasing both, the current density values and performance of the PEM cell. But the higher pressure drop lead to increase the energy required to drag gas that causes low of the global performance of the system, while the under rip convection and the elimination of the residual water in the cathode side improves , so the overall efficiency of the electrochemical reaction increases and thus the overall efficiency increases for PEM fuel.

13. Geometric Parameters of the Flow Channel Cross Section

In general several researchers such as Isanaka et al.[17] , X. Li and I. Sabir[20] and others were found that the rectangular or square in cross-section typically used as the fluid flow field channels of the bipolar plate although other arrangement cross-section such as triangular, semi-circular and spherical due to the lower pressure losses when rectangular or square cross section used at the same flow rate that lead to increase the performance of PEMFC fuel cell although the hydrogen consumption is lower when compared with triangular, semi-circular and spherical cross section [17], [20] ,[59],[60]. The dimensions of flow field channels have significant effects on the cell performance and lifetime of PEMFC fuel cell and operation condition that must be explains and these dimensions are channel width, channel depth and land width or rip width (the distance that separate between two channels).So Isanaka et al . [17] numerically showed that to reduce the fluid pressure loss due to friction losses should be the range of channel width about 1 to 2mm and depth as low as possible (1mm) . The land width has a significant effect represented by the collection of the electron from the reactions taking place in the

MEA, so the specification land width is very important due to when the land width is bigger than that lead to reduce the active area of the MEA available for absorption of the reactant gas and that lead to reduce cell performance ,while when the land width is lower than that lead to increase the active area of the MEA available for absorption of the reactant gas and reduce the collection of electron that effect on cell performance of PEMFC fuel cell . So must find the balance between channel width and land width , also must be referring that larger channel size width (such as channel width about 5mm) lead to that the reactant gases have turbulent flow that effects on the flow of the gas reactant through channels also effect on the absorption of the gas into the MEA. Kumar and Reddy [61] numerically investigated the effect of geometric parameters (channel width, rib width and channel depth) on the consumption of hydrogen at the anode side .They were found when the values of the channel width, rib width and channel depth were 1.5, 0.5 and 1.5 mm, respectively, that lead to the greatest hydrogen consumptions (80%) happen. Also the results showed that when used the hemispherical and triangular shaped cross-section for channels , the hydrogen consumptions increased with 9% at the anode side that lead to increase fuel cell efficiency. In [63] numerically simulated the effect of the three different (rectangular, trapezoidal and parallelogram) channel cross sections on a straight flow channel at high current densities. Results showed that the rectangular section channel given the higher cell potentials, while the trapezoidal cross section given more uniform current density distributions .The three different channel cross section shown in figure (10). Many researchers found that the rectangular cross section channel design for bipolar plates is still the most commonly used ,while other shapes of cross section may show enhancements in some specific aspects of the fuel cell operation [63] ,[64].

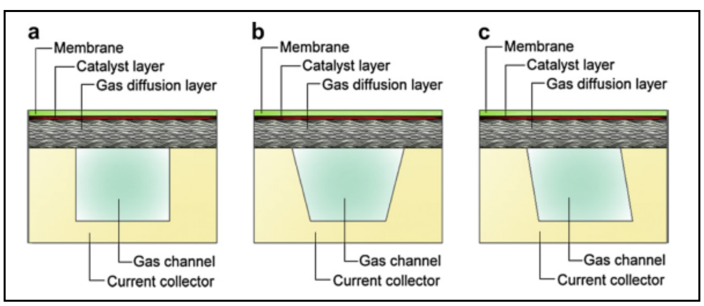


Fig (10) Cross-sectional view of different geometrical configurations analyzed: a- Rectangular, b- Trapezoidal, c- Parallelogram [57].

Many researchers investigated the effect of channel and rib widths on the performance of the PEM fuel cell in numerical analyzed [65-68]. Results showed that the geometric parameters (channel and rib widths) have a more significant effect when the fuel cell operating at the low potentials ,also the optimal fuel cell configuration given maximizes the fuel cell performance. They found that the optimal rib width largely depends on the type of oxidizing agent used and PEM fuel cell operation conditions . So the fuel cell operating with air as oxidizing agent , the rib width should be shorter than that for fuel cell operating with pure oxygen . On the other hand for fuel cell operating at high potentials that lead to give better performance with wider ribs. While the few studies can be found in literature having investigated the effect of channel depth on the cell performance. Also we must be referring the effect of various channel depth has a significant effect when operating at low potentials and increasing the current densities. The pressure drop in this case increases , so that lead to decreases the overall cell performance(overall system efficiency) [69], [71].So Shimpalee and Van Zee [69] numerically investigated the effect of the geometric parameters (channel and rib widths) on the reactants distribution and PEMFC performance on a 25 cm2 fuel cell with serpentine gas flow channel . Conclusions showed that for the narrower gas flow channels give better results due to improve heat transfer from MEA toward collector as well as increased the pressure drop. On contrast when the channel configuration with wider channel and narrower ribs that lead to non-uniform local distribution of the reactants, despite of the global distribution of reactants kept uniform. Liu et al.[70] numerically investigated the effect of the reduction in channel height on the fuel cell performance along the cathode stream wise direction shown in the figure (11). Results showed that for low operating voltages ,that lead to improve the mass transport towards the gas diffusing layers and catalyst layer ,improve the electrochemical reaction ,enhance water elimination ,so the cell efficiency increases and give better result for cell performance.

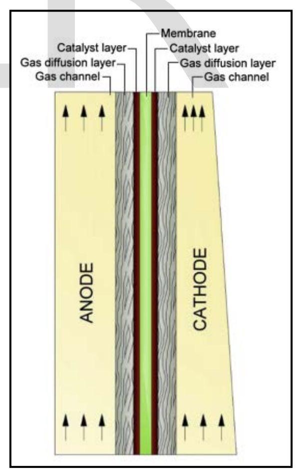


Fig (11) Schematic diagram of the 2D PEMFC model [70].

Choi et al.[71] and A.P. Manso et al.[72] numerically analyzed the effect of aspect ratio (height to width ratio of channel cross section) on the cell performance . Results showed that the performance of the fuel cell for serpentine gas flow channel can be enhanced with increasing aspect ratio at high operating voltages (due decrease channel width and increase rip width) . Maharudrayya et al. [73] numerically investigated the effect of the geometric parameters (channel width , rip with and channel depth) and Reynolds number on the flow pattern and the pressure loss characteristics in PEMFC of single and multiple serpentine flow field plate . They were found that here is a significant effect of Re on the bend loss coefficient, which is also influenced by the curvature ratio and the aspect ratio as well as the presence of an upstream bend. Her et al. [74] experimentally studied the effect of the channel and rib geometric scale (channel to rib width ratio) affects of flow channel plates/bipolar plates on the performance of micro PEM fuel cell stacks. Copper metals were used to make bipolar plates. Results showed that the dimensions of the channel and their spacing have affected on the reactant gas access to gas diffusion layer and also provide wide area for water removal from the gas diffusion layer for this increase in proton conductivity. Also they were found when the ratio of cannel to rip width is smaller that lead to reduce the active area of the MEA available for absorption of the reactant gas and that lead to reduce cell performance, while when the ratio is higher that lead to increase the active area of the MEA available for absorption of the reactant gas and reduce the collection of electron that effect on cell performance of PEMFC fuel cell .So must be found the balance between channel width and land width .In fact , the optimum channel to rib width ratio in the range of the present study of 0.5-2 was found to be 1.

CONCLUSIONS

Bipolar plate is one of the key components in PEM fuel cell stacks. In practice, PEM fuel cell stack design often boils down to bipolar plate design, which in turn is basically the design of flow channels formed on the two surfaces of the bipolar plates, because the requirements on carrying out the bipolar plate functions optimally are often met by the appropriate design of flow channels. Throughout this review it has been shown that the geometric parameters of the flow fields can have great influence on the overall PEMFC behavior. Many of the PEMFC drawbacks discussed here may be overcome by appropriately choosing the flow field design. Thus, problems in mass transport, water management, and mal-distribution of reactants can be solved by efficiently design the BP flow fields and so, enhance PEMFC performance. For instance, homogeneous gas distribution in the flow channel can provide a uniform current density throughout the active area and, therefore, a uniform temperature distribution, causing less mechanical stresses in the MEA and prolonging the PEMFC lifetime. Therefore, flow field design is crucial for achieving high performance of the PEM fuel cell.

A variety of flow channel configurations and layouts have been proposed in different designs, including pins, straight channels, serpentine channels, integrated channels, interdigitated channels and channels formed from sheet metals. These different flow field designs have pros and cons associated with them which in turn make them suitable for different applications. Improvements in the design of bipolar plates can help achieve the set goals of cost and performance for the commercialization of PEM fuel cell.

14. REFERENCES

[1] *Hayder Abed Dhahad, Measurement of Temperature Profile in Non-Premixed Turbulent Flame of Lean LPG/Air mixture, Proceedings of POWER2008 ASME Power 2008 July 22-24, 2008, Orlando, Florida, USA .*

[2] *Hayder A. Dhahad, Kamal Ch. Khalil, The Effect Of Isolated Air Mass And Fuel/Air Ratio On The Efficiency Of Isolated Combustion And Diluted Expannsion (Icade) I. C. Engine Cycle, Asme International Mechanical Engineering Congress And Exposition, Octobar 31- November ,2008 Boston Massachusetts.*

[3] *Hayder A. Dhahad, Mohammed A. Abdulhadi, Ekhlas M. Alfayyadh, T. Megaritis, Experimental Combustion Characteristics, Nanoparticles and Soot-NOx trade off in a Common-Rail HSDI Diesel Engine running on ULSD and HFO Fuels, World Research & Innovation Convention on Engineering & Technology 2014, Putrajaya, Malaysia, 25-26 November 2014.*

[4] *Hayder A. Dhahad, Mohammed A. Abdulhadi, Ekhlas M. Alfayyadh, T. Megaritis, An Investigation of the Relation Between Combustion Phase and Emissions of ULSD & RME Biodiesel with a Common-Rail HSDI Diesel Engine,ASME 2014 12th Biennial Conference on Engineering Systems Design and Analysis, June 25-27, 2014, Copenhagen, Denmark*

[5] *Hayder A. Dhahad, Mohammed A. Abdulhadi, Ekhlas M. Alfayyadh, T. Megaritis, The Influence of Injection Timing on Combustion and Emission Characteristics of HSDI Diesel Engine, Eng. & Tech. Journal ,Vol.32, Part (A), No.9, 2014.*

[6] *Hayder A. Dhahad, Mohammed A. Abdulhadi, Ekhlas M. Alfayyadh, T. Megaritis, Effects of Injection Pressure on Combustion, Nanoparticles and Gaseous Emissions Characteristics from a Common-Rail HSDI Diesel Engine running on ULSD and RME, Proceedings of the ASME 2014 Internal Combustion Engine Division Fall Technical Conference, October 19-22, 2014, Columbus, IN, USA.*

[7] *Karrar H. Fahim, Ekhlas M.Alfayydh. Hayder A. Dhahad, Effect Of Geometric Design Of The Flow Fields Plat On The Performance Of A PEM Fuel Cell:A Review, World Research & Innovation Convention on Engineering & Technology, Langkawi, Kedah, Malaysia, 24-25 October 2016.*

[8] *Hayder A. Dhahad, Wissam H. Alawee, Eiman Ali Eh. Sheet, Experimental Study Of The Operating Temperature Effect On The Performance of PEM Fuel Cell, World Research & Innovation Convention on Engineering & Technology 2016, Langkawi, Kedah, Malaysia, 24-25 October 2016.*

[9] *Dr. Hayder Sabah. Abad Al-Amir Dr. Hayder Abed Dahd Eiman Ali Eh. Sheet, Modeling and Control of Fuel Cell Using Artificial Neural Networks, Journal of Engineering, No. 12, Vo. 21, 2015.*

[10] *Yong-Song Chen2009.[A Segmented Model for Studying Water Transport in a PEM Fuel Cell]. Ph.D, dissertation in Mechanical Engineering Department. University of Michigan,USA.*

[11] *Maher AR, Al-Baghdadi Sadiq 2008.[CFD models for analysis and design of PEM fuel cells]. Nova Science Publisher, Inc.;*

[12] *Z. Q. Ma, P. Cheng, and T. S. Zhao 2003. [A palladium-alloy deposited nafion ® membrane for direct methanol fuel cells]. Journal of Membrane Science, vol. 215, no. 12, pp. 327–336, 4/15*

[13] *F. Barbir2005.[PEM Fuel Cells: Theory and Practice]. 1st edation. New York: Academic Press, USA.2005.*

[14] *Etim S. Udoetok 2008.[AN INVESTIGATION INTO FUEL CELLS AND FLOW CYTOMETERS OPTIMAL DESIGN] . Ph.D, dissertation in The Department of Mechanical Engineering. Louisiana State University, USA.*

[15] *G Hoogers2003,[Fuel Cell Technology Handbook]. New York: CRC Press: p.4.10-4.15. 2003.*

[16] *J.H. Hirschenhofer, D.B. Stauffer, R.R. Engleman, and M.G. Klett1998.[Fuel Cell Handbook]. U.S. Department of Energy, Morgantown, WV, fourth edition,USA.1998.*

[17] *www.britannica.com2007*

[18] *Vlad-
mir Gurau , Michael J. Bluemle , Emory S. De Castro , YuMin Tsou , Thomas A. Za*

*wodzins-
ki Jr., J. Adin Mann Jr. 2007 .[Characterization of transport properties in gas diffusion layers for proton exhange membrane fuel cells]
. Journal of Power Sources 165 ,pp. 793 - 802 .2007*

[19] *Hayder A Dhahad, Mohammed A Abdulhadi, Ekhlas M Alfayyadh, T Megaritis, An Investigation of the Relation Between Combustion Phase and Emissions of ULSD & RME Biodiesel with a Common-Rail HSDI Diesel Engine, ASME 2014 12th Biennial Conference on Engineering Systems Design and Analysis.*

[20] *Hayder Abed Dhahad, A Cognitive Neural Linearization Model Design for Temperature Measurement System based on Optimization Algorithm, Iraqi Journal of Computers, Communication and Control & Systems Engineering, Vo.15, Issue 1, Pages 61-71,2015.*

[21] *Adel S. Hamadi, Hayder A. Dhahad, Riyadh M. Noaman, Thamera Kidher, Safaa Suhail ,Quraish abass, An Experimental Investigates To Study The Effect Of Zinc Oxide Nanoparticles Fuel Additives On The Performance And Emissions Characteristics Of Diesel Engine, The Iraqi Journal For Mechanical And Material Engineering, Special Volume Babylon First International Engineering Conference Issue (B), 2016.*

[22] *Space Shuttle / Rocket Launch / NASA | SD Stock Space Shuttle, Rocket Launch.*

[23] *F. Barbir 2005. [PEM Fuel Cells: Theory and Practice], 1st edition . New York: Academic Press.*

[24] *Isanaka, Sriram Praneeth, Austin Das, and Frank Liou 2012 . [DESIGN OF METALLIC BIPOLAR PLATES FOR PEM FUEL CELLS] . A National University Transportation Center at Missouri University of Science and Technology.*

[25] *H. Tsuchiya and O. Kobayashi 2004. [Mass production cost of PEM fuel cell by learning curve. International Journal of Hydrogen Energy]. 29(10), 985-990.*

[26] *S. Karimi, N. Fraser, B. Roberts, and F. R. Foulkes 2012 .[A Review of Metallic Bipolar Plates for Proton Exchange Membrane Fuel Cells: Materials and Fabrication Methods].*

[27] *Xianguo Li and Imran Sabir2005.[Review of Bipolar plates in PEM fuel cells: Flow Field designs], International Journal of Hydrogen Energy , Pages 359 - 371*

[28] *G. O. Mepsted and J. M. Moore2010. [Performance and durability of bipolar plate materials, in Handbook of Fuel Cells], John Wiley & Sons, Ltd New York .*

[29] *K. Roßberg and V. Trapp2010 . [Graphite–based bipolar plates, in Handbook of Fuel Cells], John Wiley & Sons, Ltd New York .*

[30] *R. C. Makkus, A. H. H. Janssen, F. A. de Bruijn, and R. Mallant 2000.[Use of stainless steel for cost competitive bipolar plates in the SPFC]. Journal of Power Sources, 86(1-2), 274-282.*

[31] *A. J. Sedriks1996.[Corrosion of stainless steel], 2. edition. Other Information: PBD: 19961996. Medium: X; Size: [200] p.*

[32] *B. D. Cunningham, J. Huang, and D. G. Baird 2007. [Review of materials and processing methods used in the production of bipolar plates for fuel cells]. International Materials Reviews,. 52(1), 1-13.*

[33] *J. Wind, A. LaCroix, S. Braeuninger, P. Hedrich, C. Heller, and M. Schudy 2010.[Metal bipolar plates and coatings, in Handbook of Fuel Cells], John Wiley & Sons, Ltd New York .*

[34] *Mohammad Dehsar, Farshad Kimiaghalam, Bahram Ghorbani and Majid Amidpour 2013.[Experimental Study on the effect of Bipolar Plates Substance on the Performance of Poroton Exchange Membrane Fuel Cells].*

[35] *Xianguo Li and Imran Sabir2005.[Review of Bipolar plates in PEM fuel cells: Flow Field designs], International Journal of Hydrogen Energy , Pages 359-371371*

[36] *Vaibhav Pal, P. Karthikeyan, R. Anand 2015.[Performance Enhancement of the Proton Exchange Membrane Fuel Cell Using Pin Type Flow Channel with Porous Inserts].Journal of Power and Energy Engineering, 3, 1-10*

[37] *A.P. Manso, F.F. Marzo, J. Barranco, X. Garikano, M. Garmendia Mujika 2012 . [Influence of geometric parameters of the flow fields on the performance of a PEM fuel cell. A review].international journal of hydrogen energy 37 , 15256e15287*

[38] *Vijay Edupuganti 2012 .[An Investigation of the Impact of the Proton Exchange Membrane Fuel Cell Flow Field Plate Geometry and Design Using Computational Fluid Dynamic Modeling and Simulation] .*

[39] *B. Sreenivasulu, G. Vasu, V. Dharma Rao, and S. V. Naidu 2013. [Effect of Back Pressure and Flow Geometry on PEM Fuel Cell Performance - An Experimental Study].International Journal of Applied Science and Engineering ,11, 1: 1-11*

[40] *Jeffrey Glandt, Sirivatch Shimpalee, Woo-kum Lee, and John W. Van Zee 2002. [MODELING THE EFFECT OF FLOW FIELD DESIGN ON PEM FUEL CELL PERFORMANCE].Prepared for presentation at the Spring National Meeting, New Orleans, LA, March 10-14*

[41] *S. Maharudrayya, S. Jayanti, A.P. Deshpande 2006.[Pressure drop and flow distribution in multiple parallel-channel configurations used in proton-exchange membrane fuel cell stacks] .Journal of Power Sources 157 , 358–367*

[42] *Junye Wang 2008.[Pressure drop and flow distribution in parallel-channel configurations of fuel cells: U-type arrangement].international journal of hydrogen energy 33 , 6339–6350*

[43] *Junye Wang2010.[Pressure drop and flow distribution in parallel-channel configurations of fuel cells: Z-type arrangement].international journal of hydrogen energy 35 ,5498–5509*

[44] *Junye Wang 2011.[Flow Distribution and Pressure Drop in Different Layout Configurations with Z-Type Arrangement]. Energy Science and Technology Vol. 2, No. 2, pp. 1-12*

[45] *Xiao-Dong Wang,Yuan-Yuan Duan,Wei-Mon Yan, Xiao-Feng Peng 2008 . [Effects of flow channel geometry on cell performance for PEM fuel cells with parallel and interdigitated flow fields.Department of Thermal Engineering]. journal homepage: Electrochimica Acta 53 5334–5343*

[46] *Ferng Yuh Ming, Su Ay 2007. [A three-dimensional full-cell CFD model used to investigate the effects of different flow channel designs on PEMFC performance]. International Journal of Hydrogen Energy;32:4466e76.*

[47] *Jeon DH, Greenway S, Shimpalee S, Van Zee JW 2008. [The effect of serpentine flow-field designs on PEM fuel cell performance]. International Journal of Hydrogen Energy;33:1052e66.*

[48] *Zhang Weigang, Hu Peng, Lai Xinmin, Peng Linfa 2009.[Analysis and optimization of flow distribution in parallel-channel configurations for proton exchange membrane fuel cells]. Journal of Power Sources;194:931e40.*

[49] *Wang Xiao-Dong, Zhang Xin-Xin, Yan Wei-Mon, Lee DuuJong, Su Ay 2009. [Determination of the optimal active area for proton exchange membrane fuel cells with parallel, interdigitated or serpentine designs]. International Journal of Hydrogen Energy;34:3823e32.*

[50] *Wang Xiao-Dong, Xu Jin-Liang, Yan Wei-Mon, Lee DuuJong, Su Ay 2011. [Transient response of PEM fuel cells with parallel and interdigitated flow field designs]. International Journal of Heat and Mass Transfer;54:2375e86.*

[51] *Li Hung-Yi, Weng Wen-Chung, Yan Wei-Mon, Wang Xiao- Dong 2011. [Transient characteristics of proton exchange membrane fuel cells with different flow field designs]. Journal of Power Sources;196:235e45.*

[52] *Lobato Justo, Can˜ izares Pablo, Rodrigo Manuel A, Pinar F Javier, U beda Diego 2011.[Study of flow channel geometry using current distribution measurement in a high temperature polymer electrolyte membrane fuel cell]. Journal of Power Sources;196:4209e17.*

[53] *Ramos-Alvarado Bladimir, Hernandez-Guerrero Abel, Juarez-Robles Daniel, Li Peiwen 2012. [Numerical investigation of the performance of symmetric flow distributors as flow channels for PEM fuel cells]. International Journal of Hydrogen Energy;37:436-48.*

[54] *Wissam H. Alawee Jafar M. Hassan, Thamer A. Mohamed, Wahid S.Mohammed, Modeling the Uniformity of Manifold with Various Configurations, Journal of Fluids, Hindawi Publishing Corporation, 2014, http://dx.doi.org/10.1155/2014/325259.*

[55] *Wissam H. Alawee Jafar M. Hassan, Wahid S. Mohammed, Thamer A. Mohamed, Review on Single-Phase Fluid Flow Distribution in Manifold, International Journal of Science and Research, Volume 3, Issue1, Pages 325 – 330, 2014.*

[56] *Wahid S. Mohammad Wissam H. Alawe, Jafar M. Hassan, Effect of Recirculation Ratio on the Uniformity Flow in a High Area Ratio of Outlets Pipe at Different Entrance flow rates, Journal of Engineering, Volume 21, Issue 9, Pages 169 – 184, 2015.*

[57] Wissam H. Alawee Jafar M. Hassan, Thamer A. Mohamed, Wahid S. Mohammed, EXPERIMENTAL AND NUMERICAL STUDY ON THE IMPROVEMENT OF UNIFORMITY FLOW FOR THREE-LATERAL DIVIDING MANIFOLD, International Journal of Engineering and Technology, Volume12, Issue1, Pages 29 – 37, 2015.

[58] Wissam H. Alawee Jafar M. Hassan, Thamer A. Mohamed, Wahid S. Mohammed, Experimental and Numerical Study on the Improvement of Uniformity Flow for Three-Lateral Dividing Manifold, World Research & Innovation Convention on Engineering & Technology 2014, Putrajaya, Malaysia, 25-26 November 2014.

[59] Atul kumar, Ramana G. Reddy 2003.[Effect of channel dimensions and shape in the flow -field distributor on the performance of polymer electrolyte membrane fuel cells]. Journal of Power Sources 113, pp. 11–18

[60] Yutaka Tabe, Sang-Kyun Park, Kazushige Kikuta, Takemi Chikahisa, Yukio Hishinuma 2006. [Effect of cathode separator structure on performance characteristics of free -breathing PEM FCs].Journal of Power Sources 162 ,pp. 58-65

[61] Kumar Atul, Reddy Ramana G 2003.[Effect of channel dimensions and shape in the flow field distributor on the performance of polymer electrolyte membrane fuel cells]. Journal of Power Sources;113:11e8.

[62] Ahmed Dewan Hasan, Jin Sung Hyung 2006.[Effects of channel geometrical configuration and shoulder width on PEMFC performance at high current density].Journal of Power Sources;162:327e39.

[63] Owejan JP, Trabold TA, Jacobson DL, Arif M, Kandlikar SG 2007. [Effects of flow field and diffusion layer properties on water accumulation in a PEM fuel cell]. International Journal of Hydrogen Energy;32:4489e502

[64] Yoon Young-Gi, Lee Won-Yong, Park Gu-Gon, Yang Tae- Hyun, Kim Chang-Soo 2005.[Effects of channel and rib widths of flow field plates on the performance of a PEMFC]. International Journal of Hydrogen Energy;30:1363e6.

[65] Sun Wei, Peppley Brant A, Karan Kunal 2005.[Modeling the influence of GDL and flow-field plate parameters on the reaction distribution in the PEMFC cathode catalyst layer]. Journal of Power Sources;144:42e53.

[66] Ying Wang, Yang Tae-Hyun, Lee Won-Yong, Ke J, Kim Chang-Soo 2005.[Three-dimensional analysis for effect of channel configuration on the performance of a small airbreathing proton exchange membrane fuel cell (PEMFC)]. Journal of Power Sources;145:572e81.

[67] Lee Sungho, Jeong Heeseok, Ahn Byungki, Lim Taewon, Son Youngjin 2008.[Parametric study of the channel design at the bipolar plate in PEMFC performances]. International Journal of Hydrogen Energy;33:5691e6.

[68] Higier Andrew, Liu Hongtan 2010.[Optimization of PEM fuel cell flow field via local current density measurement]. International Journal of Hydrogen Energy;35:2144-50.

[69] Shimpalee S, Van Zee JW 2007.[Numerical studies on rib & channel dimension of flow-field on PEMFC performance]. International Journal of Hydrogen Energy;32:842-56.

[70] Liu HC, Yan WM, Soong CY, Chen Falin, Chu HS 2006.[Reactant gas transport and cell performance of proton exchange membrane fuel cells with tapered flow field design]. Journal of Power Sources ;158:78e87.

[71] Choi Kap-Seung, Kim Hyung-Man, Moon Sung-Mo 2011.[Numerical studies on the geometrical characterization of serpentine flow-field for efficient PEMFC]. International Journal of Hydrogen Energy ;36:1613-27.

[72] Manso AP, Marzo FF, Garmendia Mujika M, Barranco J, Lorenzo A 2011.[Numerical analysis of the influence of the channel cross-section aspect ratio on the performance of a PEM fuel cell with serpentine flow field design]. International Journal of Hydrogen Energy ;36:6795-808

[73] S. Maharudrayya, S. Jayanti, A.PDeshpande 2004 . [Pressure losses in laminar flow through serpentine channels in fuel cell stacks] .Journal of Power Sources 138 1–13

[74] Bing –Shyan Her, Shou- Shing Sieh ,and Jyun –Hong Chen 2009 .[Channel to Rip width Ratio Effect of Flow Field Plates in the Performance of Micro PEM fuel cell Stack]. National Sun Yat –Sen University , Kaohsiung , Taiwan 8024,ROC.ISBN 978-1-4398-1784-1 VOL .3,.

[75] Wissam H. Alawee Jafar M. Hassan, Wahid S. Mohammed, Thamer A. Mohamed, CFD Simulation for Manifold with Tapered longitudinal Section, International Journal of Emerging Technology and Advanced Engineering, Volume 4, Issue 2, Pages, 28-35.

[76] Wissam Hameed Alawee, Improve the productivity of single effect double slope solar still by simple modification, Journal of Engineering, Volume 21, Issue 8, Pages, 50-60.