CHAPTER 1

INTRODUCTION

1.1 Introduction

Fuel cells are expected to become a power source of the future. The interest in fuel cells is increasing during the past decade, due to the fact that the use of fossil fuels for power has resulted in many negative consequences. Some of these include severe pollution, extensive mining of the world's resources, and political control and domination of countries that have extensive resources. A new power source technology is focusing on energy efficient, low pollutant emissions, and has an unlimited supply of fuel. Therefore, fuel cells are clean power source now closer to commercialization than ever, and they have the ability to fulfill all of the global power needs while meeting the efficacy and environmental expectations.

There are only 30 additional years left of the supply of fossil fuels for energy use. Changing the fuel infrastructure is going to be costly, but steps should be taken now to ensure that the new infrastructure is implemented when needed. Since it is impossible to convert to a new economy overnight, the change must begin slowly and must be motivated by national governments and large corporations. Instead of using fossil fuels directly, they can be used as a "transitional" fuel to provide hydrogen that can be fed directly into the fuel cells. After the transition to the new economy has begun, hydrogen can then be obtained from cleaner sources, such as biomass, nuclear energy, and water.

Polymer electrolyte membrane (PEM) fuel cells are the most popular type of fuel cell, and traditionally use hydrogen as the fuel. PEM fuel cells also have many other fuel options, which range from hydrogen to ethanol to biomass-derived materials. These fuels can either be directly fed into the fuel cell, or sent to a reformer to extract pure hydrogen, which is then directly fed to the fuel cell.

This chapter discusses fuel cell basics and introduces the modeling of fuel cells with the following topics:

- What is a PEM fuel cell?
- Why do we need fuel cells?
- The history of fuel cells
- Mathematical models in the literature
- Creating mathematical models

These introductory fuel cell topics are discussed to relevance that fuel cell modeling has in addressing the global power needs.

A fuel cell consists of a negatively charged electrode (anode), a positively charged electrode (cathode), and an electrolyte membrane. Hydrogen is oxidized on the anode and oxygen is reduced on the cathode. Protons are transported from the anode to the cathode through the electrolyte membrane, and the electrons are carried to the cathode over the external circuit. In nature, molecules cannot stay in an ionic state, therefore they immediately recombine with other molecules in order to return to the neutral state. Hydrogen protons in fuel cells stay in the ionic state by traveling from molecule to molecule through the use of special materials. The protons travel through a polymer membrane made of persulfonic acid groups with a Teflon backbone. The electrons are attracted to conductive materials and travel through the load when needed. On the cathode, oxygen reacts with protons and electrons, forming water and producing heat. Both the anode and cathode contain a catalyst to speed up the electrochemical processes, as shown in figure 1.1.

A typical PEM fuel cell (proton exchange membrane fuel cell) has the following reactions:

Anode: $H_2\ (g) \rightarrow 2H^+\ (aq) + 2e^-$

Cathode: $1/2O_2\ (g) + 2H^+\ (aq) + 2e^- \rightarrow H_2O\ (l)$

Overall: $H_2\ (g) + 1/2O_2\ (g) \rightarrow H_2O\ (l)$ + electric energy + waste heat

The (aq) means the ion is dissolved in water. The ion is in an aqueous mixture.

Reactants are transported by diffusion and/or convection to the catalyzed electrode surfaces where the electrochemical reactions take place. The water and waste heat generated by the fuel cell must be continuously removed and may present critical issues for PEM fuel cells. The basic PEM fuel cell stack consists of a proton exchange membrane (PEM), catalyst and gas diffusion layers, flow field plates, gaskets and end plates as shown in Table 1.1. The actual fuel cell layers are the PEM, gas diffusion and catalyst layers. These layers are "sandwiched" together using various processes, and are called the membrane electrode assembly (MEA). A stack with many cells has MEAs "Sandwiched" between bipolar flow field plates and only one set of end plates.

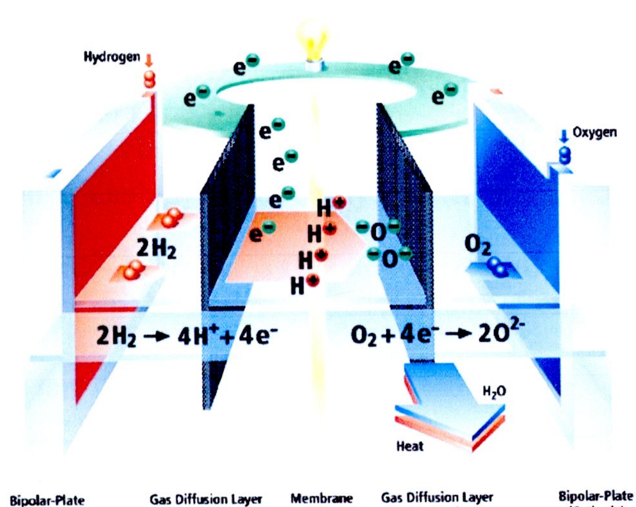

Figure 1.1 Schematic diagram of PEMFC
: http://www.princeton.edu/.../ Hydrogen/fuelcells.html

Table 1.1 Basic PEM Fuel Cell Components

Component	Description	Common Types
Proton Exchange Membrane	Enables hydrogen protons to travel from the anode to the cathode.	Persulfonic acid membrane (Nafion 112, 115, 117)
Catalyst layers	Breaks the fuel into protons and electrons. The protons combine with the oxidant to form water at the fuel cell cathode. The electrons travel to the load.	Platinum/carbon catalyst
Gas diffusion layers	Allows fuel/oxidant to travel through the porous layer, while collecting electrons	Carbon cloth or Toray paper
Flow field plates	Distributes the fuel and oxidant to the gas diffusion layer	Graphite, stainless steel
Gaskets	Prevent fuel leakage, and helps to distribute pressure evenly	Silicon, Teflon, Rubber
End plates	Holds stack layers in place	Stainless steel, graphite, polyethylene, PVC

Some advantages of fuel cell systems are as follows:

- Fuel cells have the potential for a high operating efficiency.
- There are many types of fuel sources, and methods of supplying fuel to a fuel cell.
- Fuel cells have a highly scalable design.
- Fuel cells produce no pollutants.
- Fuel cells are low maintenance because they have no moving parts.
- Fuel cells do not need to be recharged, and they provide power instantly when supplied with fuel.

Some limitations common to all fuel cell systems include the following:

- Fuel cells are currently costly due to the need for materials with specific properties. There is an issue with finding low-cost replacements. This includes the need for platinum and Nafion material.
- Fuel reformation technology can be costly and heavy and needs power in order to run.
- If another fuel besides hydrogen is fed into the fuel cell, the performance gradually decreases over time due to catalyst degradation and electrolyte poisoning.

1.2 Literature Review

The objective of this thesis is to study the behavior and performance of PEMFC using CFD and experimental technique. Literature review can be divided into three related areas as following :

1.2.1 The Study of Mathematical Modeling

1.2.1.1 The study of design flow field

Design flow field was studies parameters of dimension and shape gas channel and design patterns flow fields. In 2003 Atul Kumar and Ramana G. Reddy studied effect of channel dimensions and shape in the flow-field distributor on the performance of polymer electrolyte membrane fuel cells. This work focused on improvement of the polymer electrolyte membrane fuel cell (PEMFC) performance through channel dimensions and shape optimization of the gas flow-field. Single-path serpentine flow-field design was used for studying the effect of channel dimensions on the hydrogen consumption at the anode. Simulations were done ranging from 0.5 to 4 mm for different channel width, land width and channel depth. Optimum values for each of the dimensions (channel width, land width and channel depth) were obtained. For high hydrogen consumptions (80%), the optimum dimension value for channel width, land width and channel depth was close to 1.5, 0.5 and 1.5 mm, respectively. Studies on the effect of channel shapes showed that triangular and hemispherical shaped cross-section resulted in increase in hydrogen consumption by around 9% at the anode. Consequently, their use would lead to improved fuel cell efficiency. In studied the effects of channel configurations of flow field plates on the performance of a PEMFC. Effects of widths of rib, channel of a flow field plate, gas diffusion and electric conduction on the performance of a polymer electrolyte membrane fuel cell (PEMFC) were studied in an effort to optimize the dimensions of rib and channel of the flow field plates. Performances were measured on the single cells, using four different kinds of flow field plates. The rib width of flow field plates was varied from 0.5 to 3 mm. The narrower the rib width, the performance of a cell becomes improved in the range investigated. In addition, the magnitude of improvement is larger at high currents, indicating that the higher channel area portion is beneficial to the high power operation of a cell. From the results, gas diffusion was suggested to be a more important factor than electric conduction for the better cell performance (Young-Gi Yoon et al. 2004, 2005). Dewan Hasan Ahmed and Hyung Jin Sung (2006) studies effects of channel geometrical configuration and shoulder width on PEMFC performance at high current density. Computational fluid dynamics analysis was employed to investigate the performance of proton exchange membrane fuel cells (PEMFCs) with different channel geometries at high operating current densities. A 3D, non-isothermal model was used with a single straight channel geometry. Both anode and cathode humidifications were included in the model. In addition, phase transportation was included in the model to obtain the total water management for systems operating at different current densities. The simulation results showed that a rectangular channel cross-section gave higher cell voltages compared with trapezoidal and parallelogram channel cross-sections shown in figure 1.2. However, the trapezoidal channel cross-section facilitated reactant diffusion, leading to more uniform reactant and local current density distributions over the reacting area, and thus to a lower cathode overpotential of the cell. Simulations of the three different channel cross-sections using the same boundary conditions showed that among the cell geometrical parameters, the shoulder width is one of the most influential in terms of its impact on cell performance. Simulations using different channel–shoulder width ratios showed that at high operating current densities, ohmic losses significantly increase with decreasing shoulder width. In contrast, a smaller shoulder width facilitates the distribution of reactants and helps to reduce concentration losses. The simulations disclosed the existence of an optimum channel–shoulder width ratio that gives the highest cell voltage under high current density operating conditions. Under such conditions, however, the cell performance deteriorated dramatically with decreasing shoulder width, even when higher reactants flow rates and inlet velocities were used. S. Shimpalee et al. (2006) studied the impact of channel path length on PEMFC flow-field design. Distributions in reactant species concentration in a PEMFC due to local consumption of fuel and local transport of water through the membrane cause distributions in current density, temperature, and water concentration in three dimensions in a PEMFC. These distributions can lead to flooding or drying of the membrane that may shorten the life of an MEA. Changing the cell's flow-field pattern to distribute the gas more evenly is this method. This paper investigates how 200 cm^2 serpentine flow-fields with different number of gas paths, and thus different gas path lengths, affect performance and species distribution. The results show how the local temperature, water content, and current density distributions become more uniform for serpentine flow-field designs with shorter path lengths or larger number of channels. These results may be used to develop universal heuristics and dimensionless number correlations in the design of flow-fields and stacks. And effect of cathode inlet manifold configuration on performance studied by Seo Young Kim and Won Nyun Kim (2007). A 10-cell proton-exchange membrane fuel cell (PEMFC) stack with 10 cathode flow channels is employed to investigate the effect of airflow inlet manifold configuration on the overall performance. Four different types of airflow inlet manifold with a 90° turn are considered. The flow patterns according to the manifold configuration are numerically sought. The computational result for the improved inlet manifold predicts about 8.5% increase in the uniformity of the airflow distribution. The experiments are carried out to confirm the numerical predictions by measuring actual airflow distributions through the fuel cell stack. The polarization curve and the power curve for the 10-cell PEMFC are also obtained to determine the effect of inlet manifold configuration on the actual performance. The maximum power output increases by up to 10.3% on using the improved airflow inlet manifold.

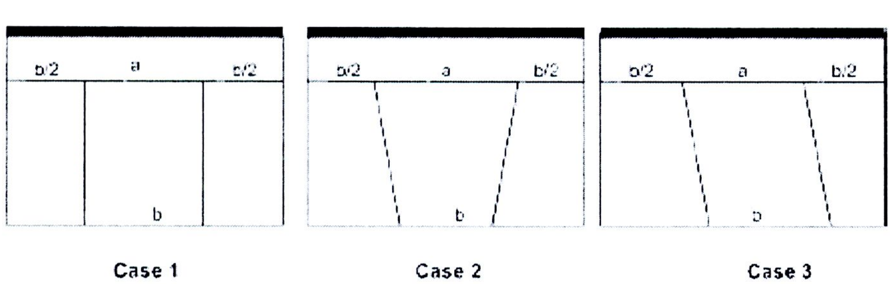

Figure 1.2 Cross-sectional view of different geometrical configurations of Dewan Hasan Ahmed et.al. was researched.

The research of flow field patterns and design flow fields for PEMFC was studies by many researchers. A review of flow field designs on bipolar plates in PEM fuel cells. Bipolar plate is a vital component of PEM fuel cells, which supplies fuel and oxidant to reactive sites, removes reaction products, collects produced current and provides mechanical support for the cells in the stack. Bipolar plates constitute more than 60% of the weight and 30% of the total cost in a fuel cell stack. For this reason, the weight, volume and cost of the fuel cell stack can be reduced significantly by improving layout configuration of flow field and use of lightweight materials. Different combinations of materials, flow-field layouts and fabrication techniques have been developed for these plates to achieve aforementioned functions efficiently, with the aim of obtaining high performance and economic advantages. Present paper presents a comprehensive review of the flow-field layouts developed by different companies and research groups and the pros and cons associated with these designs (Xianguo Li and Imran Sabir, 2004). The study flow patterns and flow channel design was studied behavior of flow patterns scaling a model. Fuel cell flow channel scaling behavior has been investigated on three different arch types, interdigitated, serpentine, and spiral interdigitated, by employing computational fluid dynamics (CFD). Range of investigation covers flow channels of macro feature size (>500 μm) to micro feature size (<100 μm). Each flow pattern arch type exhibits unique scaling behavior. For most flow pattern arch types, optimal feature size occurs at an intermediate channel dimension. Extremely small flow channels do not optimize performance despite improved mass transport. Pressure drop loss and flow travel path in the cathode compartment are major factors determining the optimal size. The scaling phenomena are explained in conjunction with the details of oxygen distribution in the cathode flow channels and gas diffusion layer (S.W. Cha et al., 2004). And it was studied a flow channel design with effective water removal. A design procedure has been developed for flow channels on bipolar plates that can effectively remove water from the PEM fuel cells. The main design philosophy is based on the determination of an appropriate pressure drop along the flow channel so that all the liquid water in the cell is evaporated and removed from, or carried out of, the cell by the gas stream in the flow channel. At the same time, the gas stream in the flow channel is maintained fully saturated in order to prevent membrane electrolyte dehydration. Sample flow channels have been designed, manufactured and tested for five different cell sizes of 50, 100, 200, 300 and 441 cm2. Similar cell performance has been measured for these five significantly different cell sizes, indicating that scaling of the PEM fuel cells is possible if liquid water flooding or membrane dehydration can be avoided during the cell operation. It is observed that no liquid water flows out of the cell at the anode and cathode channel exits for the present designed cells during the performance tests, and virtually no liquid water content in the cell structure has been measured by the neutron imaging technique. These measurements indicate that the present design procedure can provide flow channels that can effectively remove water in the PEM fuel cell structure (Xianguo Li et al., 2006). Puneet K. Sinha et al. (2007) studied the effect of flow field design on the performance of elevated-temperature polymer electrolyte fuel cells. In our previous work, operation of polymer electrolyte fuel cell (PEFC) at 95 ^{o}C was investigated in detail and it was found that dry operation of PEFC at elevated temperatures makes the parallel flow field design a viable design option for high temperature applications such as for automobiles. In this work, a three dimensional, non-isothermal PEFC model is used to compare the performance of a 25 cm^2 fuel cell with serpentine and parallel flow field design operated at 95 ^{o}C under various inlet humidity conditions.

Numerical results show that the parallel flow field provides better and more uniformly distributed performance over the whole active area which makes the parallel flow field a better design compared to the serpentine flow field for PEFCs operated at elevated temperature and low inlet relative humidity. The effect of gas flow-field design in the bipolar/end plates on the steady and transient state performance of polymer electrolyte membrane fuel cells by Atul Kuma and Ramana G. Reddy (2006). Simulations in this work were performed with different flow-field designs. (1) serpentine; (2) parallel; (3) multi-parallel; and (4) discontinuous. The steady-state voltage at fixed current density of 5000 Am^{-2} was highest for discontinuous design. For studying the transient response, the average current density was increased suddenly from 5000 to 8000Am^{-2}. It was seen that when the load level was increased, the voltage level suddenly dropped and then with time leveled off to a value slightly higher than the dropped value. This time for serpentine, parallel, multi-parallel and discontinuous flow-fields were 9.5, 7.5, 8.0 and 16.5 s, respectively. While it was seen that the steady-state performance of the discontinuous type of design was the maximum, its transient response was slow. On the other hand in case of parallel type of design the steady-state performance was low, but the transient response was high. The multi-parallel design offers a unique advantage of both of these properties. high steady-state performance with good transient response, and therefore should perform better than the other designs chosen in this study.

A new design flow fields was studied by N. Jaruwasupant and Y. Khunatorn (2006) in the three-dimensional model and experiment of new flow field for proton exchange membrane fuel cell (PEMFC) using CFDRC®. This research is to study the gas distribution within the PEMFC that using the homebuilt developed flow field. This flow field combines curve header together with parallel-serpentine in order to extend the reaction area. A 3D numerical modeling of PEMFC was set up and solved by using commercial computational fluid dynamics (CFD) software, the "CFDRC®". The affect of gas flow field on the gas distribution caused by the chemical reaction inside the fuel cell were numerically studied. The result shows the developed flow field has the density of electric power about 81.25 mA/cm^2 and the conventional flow field fuel cell is about 69.22 mA/cm^2 which is better around 17.5%. From the test of developed fuel cell with the temperature and the flow rate, found that at the work in temperature; 50 °C and the flow rate at 150 sccm gave the best density of electric power. In 2007 C. Xu and T.S. Zhao studied new flow field design for polymer electrolyte-based fuel cells. This present a new flow field design, termed convection-enhanced serpentine flow field (CESFF), for polymer electrolyte-based fuel cells, which was obtained by re-patterning conventional single serpentine flow fields. The theoretically show the CESFF induces larger pressure differences between adjacent flow channels over the entire electrode surface than does the conventional flow field, thereby enhancing in-plane forced flow through the electrode porous layer. This characteristic increases mass transport rates of reactants and products to and from the catalyst layer and reduces the amount of liquid water that is entrapped in the porous electrode, thereby minimizing electrode flooding over the entire electrode surface. The research applied this new flow field to a single direct methanol fuel cell and demonstrated experimentally that the new flow field resulted in substantial improvements in both cell performance and operating stability as opposed to the conventional serpentine flow field design.

1.2.1.2 The study of numerical modeling

The numerical modeling use predict behavior of working in PEMFC, which it has mass conservation, momentum conservation, energy conservation and electro chemical module. In 2005 J. Ramousse et al. studies the modeling of heat, mass and charge transfer in a PEMFC single cell. The aim of this study is the understanding of the main phenomena governing fuel cell performances. Fuel cell model present takes into account gas diffusion in the porous electrodes, water diffusion and electro-osmotic transport through the polymeric membrane, and heat transfer in both the Membrane Electrodes Assembly (MEA) and bipolar plates. This model is constructed by combining independent descriptions of heat and mass transfers in the cell with a third description of coupled charge and mass transfers in the electrodes, considered porous. The results show that thermal gradients in the MEA could lead to thermal stresses at high current densities. The feeding gas temperature influence on the cell temperature is also important. Then, studies in complete 3-D model in PEMFC – model formulation, validation and parametric studies. A steady-state, three-dimensional model of a complete polymer electrolyte membrane fuel cell (PEMFC), including both the anode and cathode, is formulated and solved using a finite volume computational fluid dynamics (CFD) code, Fuel3D, developed at Loughborough University. The model is first validated against data obtained from the literature on a global basis. It is further validated on a local basis using experimental data obtained from a segmented cell. Excellent agreement is obtained. The validated model is then used to study the effect of electro-osmotic drag and diffusion of water across the membrane. Overall transport of water across the membrane is seen to take place from the anode to the cathode side. Finally, the model has been used to carry out some parametric studies, such as variation of electrode thickness, shoulder width, degree of permeability and oxidant concentration, to provide a clearer understanding on how changes in parameters affect the cell performance (Kah Wai Lum and James Joseph McGuirk, 2005). The research numerical modeling was studies of gas flow and pressure distribution in proton exchange membrane fuel cell from numerical modeling. The objective of this research is to study the affect of gas flow fields, parallel, serpentine, serpentine-parallel, within proton exchange membrane fuel cell on velocity field and pressure distribution. A 3D numerical model of a PEMFC was setup and solved by using commercial computational fluid dynamics software, the "CFDRC®". The result of the parallel flow field shows that the top and bottom channels have high flow rate. However, the central region experiences low flow rate, which result in water management difficulty within the flow field. Total pressure drop in this flow field is 22 Pa. Serpentine flow field has high flow rate and pressure drop, its represent the good water management within the cell due to single gas flow path and steady pressure drop. Total pressure drop in this flow field about 978 Pa. Parallel - serpentine flow field also presents high flow rate and pressure drop, which also promises good water management on top and bottom, because the accumulation of parallel flow fields. Total pressure drop in this flow field about 103 Pa. This research presents that the serpentine and parallel - serpentine flow fields have higher efficiency than the parallel flow field in the perspective of flow and pressure distribution. Consequently their use would lead to improve fuel cell efficiency (Nattawoot Jaruwasupant et al., 2005). And it use for prediction of concentration and current distributions in PEMFC using CFDRC®. This research present a rigorous 3-D mathematical model, to treat prediction and analysis of proton exchange membrane fuel cells (PEMFC) species concentration and current density distributions in different flow field patterns and operating conditions. The model is based on the solution of the conservation equations of mass, momentum, species and electric current in a fully integrated finite-volume solver using the CFDRC commercial code. The polarization curve of serpentine flow pattern is well correlated with experimental data. The cell performance with parallel straight, serpentine and interdigitated flow patterns are calculated and compared. The simulation results reveal that serpentine and interdigitated flow patterns show strong convection and high mass transfer. However, they also have larger pressure loss. In addition, the effects of operating temperature and relative humidity are also studied. Non-uniform distributions of concentration and current density appear at high temperature, high current density and low humidity operation, which could lead to an unstable cell performance (Fang-Bor Weng et al., 2005). In 2006 Maher A.R. Sadiq Al-Baghdadi et al. studies the parametric and optimization study of a PEM fuel cell performance using three-dimensional computational fluid dynamics model. A full three-dimensional, non-isothermal computational fluid dynamics model of a proton exchange membrane (PEM) fuel cell with straight flow field channels has been developed. This comprehensive model accounts for the major transport phenomena in a PEM fuel cell: convective and diffusive heat and mass transfer, electrode kinetics, and potential fields. The new feature of the algorithm developed in this work is its capability for accurate calculation of the local activation overpotentials, which in turn results in improved prediction of the local current density distribution. The model is shown to be able to understand the many interacting, complex electrochemical, and transport phenomena that cannot be studied experimentally. This model is used to study the affects of several operating, design, and material parameters on fuel cell performance. Detailed analyses of the fuel cell performance under various operating conditions have been conducted and examined. The analysis helped identifying critical parameters and shed insight into the physical mechanisms leading to a fuel cell performance under various operating conditions. The three-dimensional CFD model used to investigate the effects of different flow channel designs on PEMFC performance studies by Yuh Ming Ferng and Ay Su (2006). A three-dimensional "full-cell" computational fluid dynamics (CFD) model is proposed in this paper to investigate the effects of different flow channel designs on the performance of proton exchange membrane fuel cells. The flow channel designs selected in this work include the parallel and serpentine flow channels, single-path and multi-path flow channels, and uniform depth and step-wise depth flow channels. This model is validated by the experiments conducted in the fuel cell center of Yuan Ze University, showing that the present model can investigate the characteristics of flow channel for the PEMFC and assist in the optima designs of flow channels. The effects of different flow channel designs on the PEMFC performance obtained by the model predictions agree well with those obtained by experiments. Based on the simulation results, which are also confirmed by the experimental data, the parallel flow channel with the step-wise depth design significantly promotes the PEMFC performance. However, the performance of PEMFC with the serpentine flow channel is insensitive to these different depth designs. In addition, the distribution characteristics of fuel gases and current density for the PEMFC with different flow channels can be also reasonably captured by the present model.

1.2.2 The Study of Performance Testing

The performance testing was used in numerical modeling and experiment for found well conditions for testing PEMFC. There was researched from Wei-Mon Yan et al. (2005) studies the experimental studies on optimal operating conditions for different flow field designs of PEM fuel cells. In this work, the main focus is to measure the optimal cathode fuel flow rate effects with different flow field designs. In addition, the effects of different flow field designs (flow channel number, flow channel length, corner numbers and baffle effects) on the cell performance of the PEM fuel cells under the different operating conditions are examined. The experimental results reveal that the temperature effects generate the same trend in the five cathode flow field designs. When the cell temperature increases from 50 to 70 ◦C, the proton exchange membrane experiences an insufficient hydration which causes an increase in ionic transport resistance. Therefore, the cell performance decreases with an increase in the cell temperature. In addition, increasing the cathode humidification improves the cell performance through enhancing the hydration level of the membrane and hence its ionic conductivity. For the effects of the cathode fuel flow rate on the cell performance, the PEM fuel cell with interdigitated flow field shows a better cell performance than that with the conventional flow field due to the baffle effect which forces the reactant gas through the gas diffuser layer. Furthermore, compared with conventional flow field, the PEM fuel cell with an interdigitated flow field can reach the same cell performance with a lower fuel consumption rate. Under the optimal fuel flow rate conditions, the PEM fuel cell with a parallel flow field with baffle provides the best cell performance among the five flow field designs. Next year, Mehdi Amirinejad et al. (2006) studies the effects of operating parameters on performance of a proton exchange membrane fuel cell. The performance of a proton exchange membrane fuel cell under various operating conditions was investigated experimentally using dry and humidified hydrogen and oxygen as reactant and oxidant gases, respectively. Experiments have been carried out on a single PEM fuel cell with the active area of 5 cm^2. The results showed that the most important factor affecting the performance of PEMFC is the mass transport limitation including the transport of reactant and oxidant gases to active sites of catalyst layer, the transport of the proton from the anode side to the cathode side through the membrane, and the transport of produced water from the cathode side to the anode side by back diffusion mechanism. Operating parameters that examined in this paper i.e. temperatures, pressures, and humidity of reactant gases could decrease these limitations and improve the performance of the fuel cell. Based on these investigations, the optimum conditions are operation at higher pressure and elevated temperature with the humidified reactant gases. Furthermore, pressurized cathode side has better affected on the performance of the PEM fuel cell than pressurized anode side. And M.G. Santarelli and M.F. Torchio (2006) studied the experimental analysis of the effects of the operating variables on the performance of a single PEMFC. Its shows and discusses the results obtained after an experimental session devoted to characterization of the behavior of a single proton exchange membrane fuel cell with variation of the values of six operation variables: cell temperature; anode flow temperature in saturation and dry conditions; cathode flow temperature in saturation and dry conditions; and reactants pressure. The fuel cell employed for the experiments is a single PEMFC with a 25 cm^2 Nafion_115 membrane. As expected, a higher cell temperature increases the membrane conductivity and the exchange current density with an improvement of the cell behavior. An increase in the reactant saturation temperature also leads to a better performance, especially in the case of low and medium loads. Conversely, in the case of a low cell temperature, it is better to reduce the water inlet mass flow at high loads to avoid electrode flooding. With an increase of the reactant operating pressure, the maximum of the power curve shifts to higher current densities, and this could be linked to the corresponding shift of the limiting current density. A combined effect of humidification and operating pressure was observed: the increase of operating pressure did not offer a significant improvement when the reactants were dry, while leading to improvements when a partial humidification (only at the anode) was adopted. The best improvements due to a pressure increase were observed when both anode and cathode are humidified. Finally, some tests of other authors at the same operation conditions have been considered, and a comparison has been done.

Table 1.2 Conclusion of Literature Review.

Reference	**Parametric Studies**						
Design of flow field	**Model**	**New Type**	**Dimension**	**Inlet**	**Length**	**Shape**	**Radius**
K.Atul	3D	-	✓	-	-	✓	-
S.W. Cha	3D	✓	✓	-	-	-	-
Y.Young-Gi	3D	-	✓	-	-	-	-
N. Jaruwasupant	3D CFDRC®	✓	-	✓	-	-	-
Xianguo Li	3D	-	✓	-	✓	-	-
A.H. Dewan	3D	-	✓	-	-	✓	-
S. Shimpalee	3D StarCD	-	-	-	✓	-	-
S.K. Puneet	3D	-	✓	-	-	-	-
C. Xu	3D	✓	-	-	-	-	-
K.Y. Seo	2D	-	-	✓	-	-	✓
Numerical modeling	**Model**	**Chemical Reaction**	**Concen-trate**	**Humid**	**Charge**	**Heat**	
W.B. Fang	3D CFDRC®	✓	✓	✓	✓	-	
J. Ramousse	2D	✓	✓	✓	✓	✓	

Table 1.2 Conclusion of Literature Review. (Continues)

Reference	**Parametric Studies**					
Numerical modeling	**Model**	**Chemical Reaction**	**Concentrate**	**Humid**	**Charge**	**Heat**
N. Jaruwasupant	3D CFDRC®	✓	✓	✓	-	-
L.W. Kah	3D	✓	✓	✓	✓	-
M.A.R.S.A Baghdadi	3D	✓	✓	✓	✓	✓
M.F. Yuh	3D	✓	✓	-	✓	-
Performance testing	**Pressure**	**Tempera-ture**	**Flow rate**	**Humid**	**Control**	**Different Flow Field**
Y. Wei-Mon	✓	-	✓	-	✓	✓
A. Mehdi	✓	✓	✓	✓	-	-
M.G. Santarelli	✓	✓	✓	✓	✓	-

The all research in this chapter can be results on table 1.2. This present review can be divided in to three main terms, it cover (i) design of flow field (ii) numerical modeling (iii) performance testing. A many research on single parameter of affects design gas flow field, but most of them focus on couple parameters. This makes flow field design task very difficult. Therefore, it is a new challenge to study on couple parameters for design flow field and focus on the gas dynamic within the gas channel using CFD technique. In addition, three dimensional modeling of PEMFC will provide understanding the effect of flow field pattern design on performance of the fuel cell. This will lead us to a better design of gas flow field. The experiments will be set up to confirm the numerical predictions. This research will provide the additional information to design gas flow filed taking into couple parameter and chemical reaction for develop cell performance.

1.3 Objectives of Research

The objectives of this research are:

1.3.1 Examine a relationship among dimension of channel, channel length, radius
curve and inlet manifold with pressure drop, velocity distribution and polarization curve.

1.3.2 Improve proton exchange membrane fuel cell performance based on the flow field aspects using CFD commercial software.

1.3.3 Model the proton exchange membrane fuel cell including flow, heat, species, an electron transfer modeling.

1.3.4 Simulate the performance of proton exchange membrane fuel cell.

1.4 Scope of Research

1.4.1 Design the flow field of proton exchange membrane fuel cell using CFD commercial software.

1.4.2. Develop the numerical modeling the proton exchange membrane fuel cell using CFD commercial software.

1.4.3 Simulate the gas flow in proton exchange membrane fuel cell with CFD commercial software using the experiment data as a base reference of boundary conditions.

1.4.4 To experimentally investigate the effect of ambient conditions.

1.4.5 Gas flow rate conditions are controlled in constant anode and cathode in 200-500 sccm.

1.4.6 Temperature conditions are controlled in range of 60 to 80 ^{0}C.

1.4.7 Humidity conditions are controlled in range of 50 %RH to 100 %RH.

1.4.8 Sizing of reaction area on PEMFC is 10×10 cm^2.

1.5 Significance of Research

1.5.1 The numerical modeling will benefit researchers in designing of proton exchange membrane fuel cell.

1.5.2 The numerical modeling can reduce time and cost in designing the bipolar plate and proton exchange membrane fuel cell before prototype construction begins.

1.5.3 The numerical modeling will help researchers in depth understand in a proton exchange membrane fuel cell

1.5.4 Guideline of flow field design on proton exchange membrane fuel cell.