MISSOURI S&T

CENTER FOR TRANSPORTATION INFRASTRUCTURE AND SAFETY

DESIGN OF METALLIC BIPOLAR PLATES FOR PEM FUEL CELLS

by

Isanaka, Sriram Praneeth, Austin Das, and Frank Liou

A National University Transportation Center at Missouri University of Science and Technology

Disclaimer

The contents of this report reflect the views of the author(s), who are responsible for the facts and the accuracy of information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program and the Center for Transportation Infrastructure and Safety NUTC program at the Missouri University of Science and Technology, in the interest of information exchange. The U.S. Government and Center for Transportation Infrastructure and Safety assumes no liability for the contents or use thereof.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NUTC R231		

4. Title and Subtitle	5. Report Date
Design Of Metallic Bipolar Plates for Pem Fuel Cells	January 2012
	6. Performing Organization Code

7. Author/s	8. Performing Organization Report No.
Isanaka, Sriram Praneeth, Austin Das, and Frank Liou	00022763

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Center for Transportation Infrastructure and Safety/NUTC program Missouri University of Science and Technology 220 Engineering Research Lab Rolla, MO 65409	11. Contract or Grant No. DTRT06-G-0014

12. Sponsoring Organization Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Research and Innovative Technology Administration 1200 New Jersey Avenue, SE Washington, DC 20590	Final
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This project focused on the design and production of metallic bipolar plates for use in PEM fuel cells. Different metals were explored and stainless steel was found out to be best suited to our purpose. Following the selection of metal, it was calculated that to produce 0.7 W of power, the bipolar plate should have an active surface of 25cm^2. The bipolar plates were designed with different flow field patterns and manufactured. Different flow field patterns that were used were the straight design, serpentine, multiple serpentine, pin-type, interdigitated design and other custom designs. These plates were then assembled along with MEA, gaskets and the end-clamp plates to construct a single-cell PEMFC which was then tested on a fuel cell test station. Different prototypes were designed with respect to the bipolar plates and the end plates to improve sealing and fuel cell performance. Appropriate loading was done on the single fuel cell to obtain the required power from the fuel cell.

17. Key Words	18. Distribution Statement
Fuel Cell, electrochemical device, metallic bipolar plate	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. Of Pages	22. Price
unclassified	unclassified	43	

Form DOT F 1700.7 (8-72)

DESIGN OF METALLIC BIPOLAR PLATES FOR PEM FUEL CELLS

By

Isanaka, Sriram Praneeth, Austin Das, and Frank Liou

Summary

This project focused on the design and production of metallic bipolar plates for use in PEM fuel cells. Different metals were explored and stainless steel was found out to be best suited to our purpose. Following the selection of metal, it was calculated that to produce 0.7 W of power, the bipolar plate should have an active surface of 25cm^2. The bipolar plates were designed with different flow field patterns and manufactured. Different flow field patterns that were used were the straight design, serpentine, multiple serpentine, pin-type, interdigitated design and other custom designs. These plates were then assembled along with MEA, gaskets and the end-clamp plates to construct a single-cell PEMFC which was then tested on a fuel cell test station. Different prototypes were designed with respect to the bipolar plates and the end plates to improve sealing and fuel cell performance. Appropriate loading was done on the single fuel cell to obtain the required power from the fuel cell.

TABLE OF CONTENTS

LIST OF FIGURES

1. Introduction

The fuel cell is an electrochemical device that enables the direct and efficient conversion of chemical energy stored in the fuel along with oxidant into electrical energy. Fuel cells have only recently started attracting the attention of energy-consuming device manufacturers. This is due to the advantages that fuel cell has over other types devices. However the widespread commercialization of fuel cell technology has not been possible due to the high cost of the fuel cell. Consequently, a lot of research and development effort are going on in a number of major companies as well as different universities around the world.

1.1. There are many types of fuel cells being currently researched today.

1. Polymer electrolyte membrane fuel cell (PEMFC)
2. Direct Methanol fuel cell (DMFC)
3. Solid Oxide Fuel cell (SOFC)
4. Molten Carbonate Fuel cell (MCFC)
5. Phosphoric Acid Fuel cell (PAFC)
6. Alkaline Fuel cell (AFC)

We shall explain each type briefly:

1. **Proton exchange membrane fuel cell** (PEMFC) design composes of a proton-conducting polymer membrane, (the electrolyte), separates the anode and cathode sides. On the anode side, hydrogen diffuses to the anode catalyst where it later dissociates into protons and electrons. These protons often react with oxidants causing them to become

what is commonly referred to as multi-facilitated proton membranes. The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit (supplying power) because the membrane is electrically insulating. On the cathode catalyst, oxygen molecules react with the electrons (which have traveled through the external circuit) and protons to form water — in this example, the only waste product, either liquid or vapor.

2. **Direct Methanol fuel cells** (DMFC) use a methanol solution to carry the reactant into the cell; common operating temperatures are in the range 50–120 °C, where high temperatures are usually pressurized. DMFCs themselves are more efficient at high temperatures and pressures, but these conditions end up causing so many losses in the complete system that the advantage is lost; therefore, atmospheric-pressure configurations are preferred nowadays. Because of the methanol cross-over, a phenomenon by which methanol diffuses through the membrane without reacting, methanol is fed as a weak solution: this decreases efficiency significantly, since crossed-over methanol, after reaching the air side (the cathode), immediately reacts with air; though the exact kinetics are debated, the end result is a reduction of the cell voltage. Cross-over remains a major factor in inefficiencies, and often half of the methanol is lost to cross-over. Other issues include the management of carbon dioxide created at the anode, the sluggish dynamic behavior, and the ability to maintain the solution water. The only waste products with these types of fuel cells are carbon dioxide and water.

3. **Molten Carbonate Fuel cells** can operate at 600 degrees Celsius and uses CO as the fuel at the cathode and hydrogen at the anode. The high temperature allows for carbon to be present, but also sulfur can poison the cell in small quantities. Carbonate ions are produced at the cathode and flow across the membrane to react with the hydrogen to form electrons, water and carbon dioxide. The temperature is high enough for additional power production through cogeneration of steam and low enough eliminate the need of expensive catalysts and containment required in the SOFC. The efficiency using this system has risen to 50% in a combined (electrical and steam) cycle. MCFC, like the SOFC, is also used for mega-watt size power plants because of its heat.

4. **Solid oxide fuel cells** (SOFC) which operate at the highest temperature (1000 - 1100 degrees Celsius) are not the most reactive because of the low conductivity of its ionic conducting .Many advances have been made in solid oxide fuel cell (SOFC) research to increase the chemical to electrical efficiency to 50%, but because of the conductivity and the heat, it has been used mainly in large power plants which can use the cogeneration of steam for additional power. Because of the high temperature, the cell requires no expensive catalysts, or additional humidification and fuel treatment equipment which exclude the cost of these items. The primary drawback to this type of fuel cell is the cost of the containment which requires exotic ceramics which must have similar expansion rates. SOFCs are now being considered for large power plants and for industrial applications because of its electrolytic resistance to poisoning which allows internal reforming of many carbon compounds into hydrogen to create power

5. **Phosphoric acid fuel cells** (PAFC) are the oldest type whose origins extend back to the creation of the fuel cell concept. Many different acids have been used in order to boost performance such as sulfuric, but when the temperature increases above 150 degrees Celsius, high rates of oxygen reduction are possible which enable phosphoric acid to perform best. The temperature allows the cell to tolerate 1-2% CO and a few PPM of sulfur in the reactant stream which benefits the steam reforming process by reducing the requirement of pure hydrogen input to the anode. The heat generated is not enough for cogeneration of steam, but is able to warm water and act as a heater for an increased overall efficiency. The electrolyte is flanked by porous graphite carbon coated with Teflon to allow gases to the reaction sites, but not allow the liquid electrolyte out. The efficiency of this system is much lower than that of other systems at 40%.

6. **Alkaline fuel cells** (AFC) are the most temperamental of all fuel cells; it can produce the maximum amount of energy (80% efficiency when used as a water heating device). They use KOH (potassium hydroxide) electrolytes because it is the most conducting of all alkaline hydroxides, but this requires extremely pure hydrogen and oxygen input to avoid poisoning. The cell cannot internally reform any fuel because of the 80 degree Celsius cell operating temperature. Hydrogen at the anode reacts with the electrolyte creating water and two electrons which both meet at the cathode with oxygen to complete the circuit. The electrolyte constantly flows through the cell which provides cooling by convection the porous (and catalyzed) graphite electrodes from which it picks up hydroxyl ions and a small amount of water in the process. Because of the liquid

nature of the electrolyte, semi-permeable, Teflon coated carbon material is used as electrodes which are heavily catalyzed as compared with other types of fuel cells because of the low operation temperature

7.

For this project, we are basically concentrating on the PEMFC. The polymer electrolyte membrane fuel cell (PEMFC) is one of the most widely researched fuel cell technologies because it offers several advantages for transport, power for varying devices and many other applications. Its low-temperature operation, high power density, fast start-up, system robustness, and low emissions have ensured that a majority of major corporations are actively pursuing PEMFC research and development. However there are still some technical barriers to overcome before fuel cells are significantly able to be manufactured on a mass scale. The biggest challenge to the development of the Polymer Electrolyte Membrane (PEM) fuel cell for any application is the reduction in cost of the fuel cell stack components i.e. the bipolar/end plates, catalyst and electrolyte membrane.

Most of the research has been focused on PEMFC's with single cells and on their components, membrane electrolytes, catalysts and structure, electrochemical reaction mechanisms and kinetics, as well as electrode materials and preparation. Improvements in cell design and manufacturing have further increased power, while reducing manufacturing costs, which is quite essential if fuel cells are to compete with other power generating devices.

1.2. The main components of a fuel cell are

1. MEA (Membrane electrode assembly)
    a. GDL (Gas diffusion layer)

b. PEM membrane

2. Bipolar plates
3. Gaskets
4. Endplates

1.2.1. MEA (Membrane Electrode Assembly)

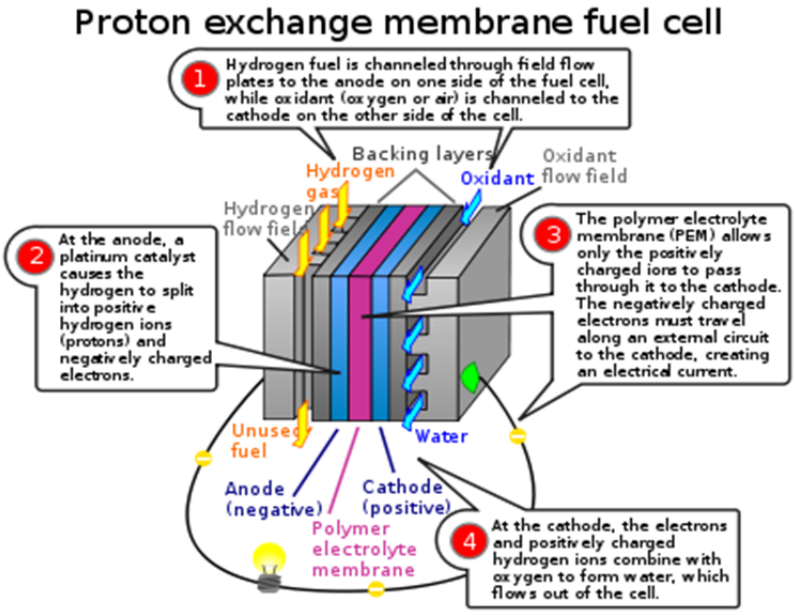


Fig1: Construction of a PEM fuel cell

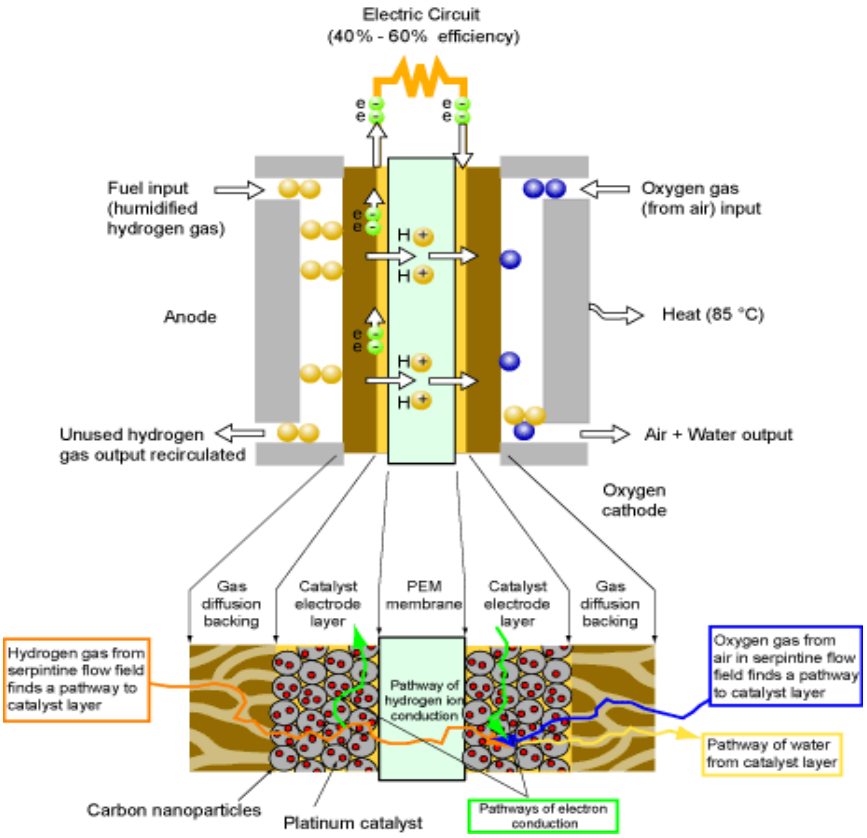


Fig2: Reactions between the hydrogen and oxygen in the MEA and GDL

The PEM is sandwiched between two electrodes which have the catalyst embedded in them. The electrodes are electrically insulated from each other by the PEM. These two electrodes make up the anode and cathode respectively. The PEM is a proton permeable but electrical insulator barrier. This barrier allows the transport of the protons from the anode to the cathode through the membrane but forces the electrons to travel around a conductive path to the cathode. The electrodes are heat pressed onto the PEM. Commonly used materials for these electrodes are carbon cloth or Toray carbon fiber paper. Platinum is one of the most commonly used catalysts; however other platinum group metals are also used. Ruthenium and platinum are often used together, if CO is a product of the electro chemical reaction as CO poisons the

PEM and impacts the efficiency of the fuel cell. Due to the high cost of these and other similar materials, research is being undertaken to develop catalysts that use lower cost materials as the high costs are still a hindering factor in the wide spread economical acceptance of fuel cell technology.

For a given membrane electrode assembly (MEA), the power density of a fuel cell stack can be significantly increased by reducing the profile of the bipolar plates. A key prerequisite for many power applications is the production of compact and lightweight PEMFC stacks which may be achieved with appropriate selection of materials. Bipolar plate designs as a whole, and flow channel layout configuration are potential areas of research.

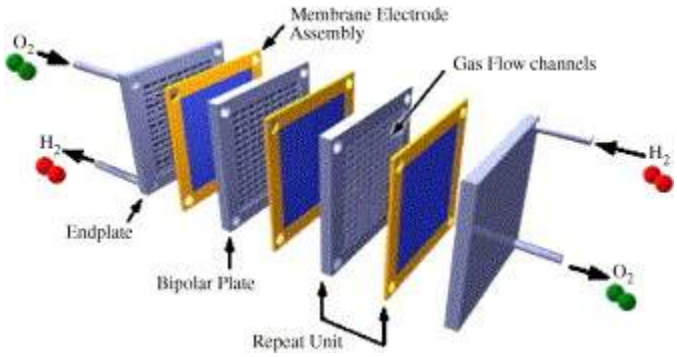


Fig 3: Stack components of fuel cell [5]

1.2.2. Bipolar plates

The bipolar plates for PEMFCs are explained in detail later on in the report.

1.2.3. Gaskets

A gasket is expected to create and maintain a seal for a specified lifetime, while remaining impervious to relevant liquids/gases and compatible with the specific environment in which it is used.

Gasket Types

1) Dynamic: seals moving parts
2) Static: seals non-moving parts (movement still occurs through vibration, shock, temperature changes, pressure changes, etc.)

Gasket Forms

(1) Conventional compression pre-forms or cut forms
(2) Formed-in-place (high viscosity mastic type)
    (a) Liquids cured by activation once in place and exposed to a radiation source, i.e. microwave, heat, UV light, etc.
    (b) Sheets/Films applied to the parts either pre-cut or cut-in-place and then cured with secondary radiation.

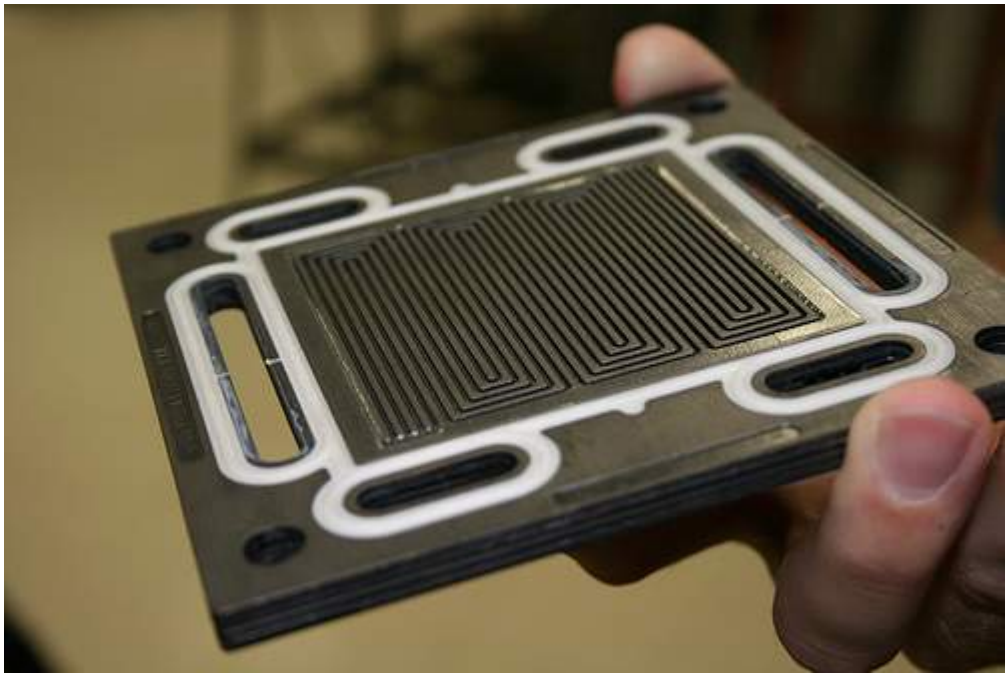


Fig 4: Gaskets used in fuel cells [5]

1.2.4. End Plates/ Clamp Plates

End plates or otherwise called clamp plates are needed at either end of the stack to apply pressure on the cells to maintain the structure as well as to prevent the gases from escaping from between the plates. The end plates would have the holes for the bolts as well as for the inlet and outlet manifolds.

Fig 5: End Plates for fuel cells [6]

2. Bipolar plates

2.1. Design

Bipolar plates account for the bulk of the stack, hence it is desirable to produce plates with the smallest possible dimensions permissible (i.e. <3mm in thickness). Bipolar plates constitute more than 60% of the weight and over 30% of the overall cost in a fuel cell stack. For this reason, the weight, volume and cost of the fuel cell stack can be significantly reduced by improving layout configuration of the flow field and use of lightweight materials. Different combinations of material, flow field layouts and fabrication techniques have been developed for these plates with the aim of obtaining high performance and economic advantages. Bipolar plates are plates 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 cathode side would serve the adjacent cell. The bipolar plates are also otherwise called as separator plates. Sometimes for larger capacity fuel cells, cooling becomes an issue for the performance of the fuel cell. Therefore, in such cases cooling is achieved by accommodating separate cooling plates after a few cells in series. In some designs, one of the reactants flows on one side of a plate, while a cooling fluid flows on the other side of the same plate in order to remove the waste heat generated in the cell. Also very importantly , these bipolar plates collectively along with the use of gaskets would have to keep the fuel and oxidant apart, preventing them from mixing with each other, otherwise the performance of the fuel cell would depreciate leading to sometimes safety concerns. Bipolar plates have been made usually out of graphite but lately focus has been on developing metallic bipolar plates. In developing metallic plates, different factors and

properties had to be taken into account. The chosen metal should be a good electrical conductor, structurally strong, good corrosive resistance towards acids and bases, high gas impermeability and easy to machine for the purpose of mass manufacture [3]. The metals chosen were stainless steel, aluminum and copper.

2.2. Functions

Bipolar plates constitute one of the most important components in PEMFC stacks and must perform a number of functions well and must do so simultaneously in order to achieve good stack performance and lifetime. Bipolar plates supply the reactant gases through the flow channels to the electrodes and also electronically connect one cell to the other in the electrochemically stack. These plates also provide structural support for the thin and mechanically weak MEAs and also as a means to facilitate water management within the cell. Also sometimes in the absence of dedicated cooling plates, the plates also facilitate heat management. Plate designs (flow field designs) and materials facilitate these functions. Bipolar plate topologies can include straight, serpentine, or interdigitated flow fields, internal manifolding, internal humidification and integrated cooling. Therefore optimal design must be found for the bipolar plates because the above functions have conflicting requirements on the bipolar plate design.

2.3. Requirements

The essential requirements for a bipolar plate is the ability to uniformly distribute the reactant gases over the respective active electrode surfaces, high electrical conductivity, high mechanical strength for stack integrity, impermeability to reactant gases for safe operation,

resistance to corrosion in severe cell environment over its lifetime, cheap materials, easy and automated fabrication for low cost.

2.4. Customer Requirements

The customer for this project was the US Air force which had the following requirements; the fuel cell should be portable for the purpose of recharging portable devices like mobiles and the like. Therefore for this purpose, the fuel cell should give out an output of around 5W. Another requirement was to keep the cost of development of the fuel cell as low as possible.

2.5. Conceptual design

Our first step in developing bipolar plates for the PEM fuel cell was to study various designs and shapes for the overall plate. This was done to determine the ease of designing and manufacturing the BPP plate, ease to assemble the plates for making stacks and also to reduce the amount of material that would be wasted during manufacture. Some of the designs that were studied for the bipolar plate were circular, triangle, square, rectangle, pentagon, hexagon and octagon. Below are some of the designs for the overall plate. For each design we designed three variations i.e. having pin-type, straight and serpentine flow fields. The below designs were drawn with the purpose of simulating the flow in Ansys, therefore channels are only modeled as solids.

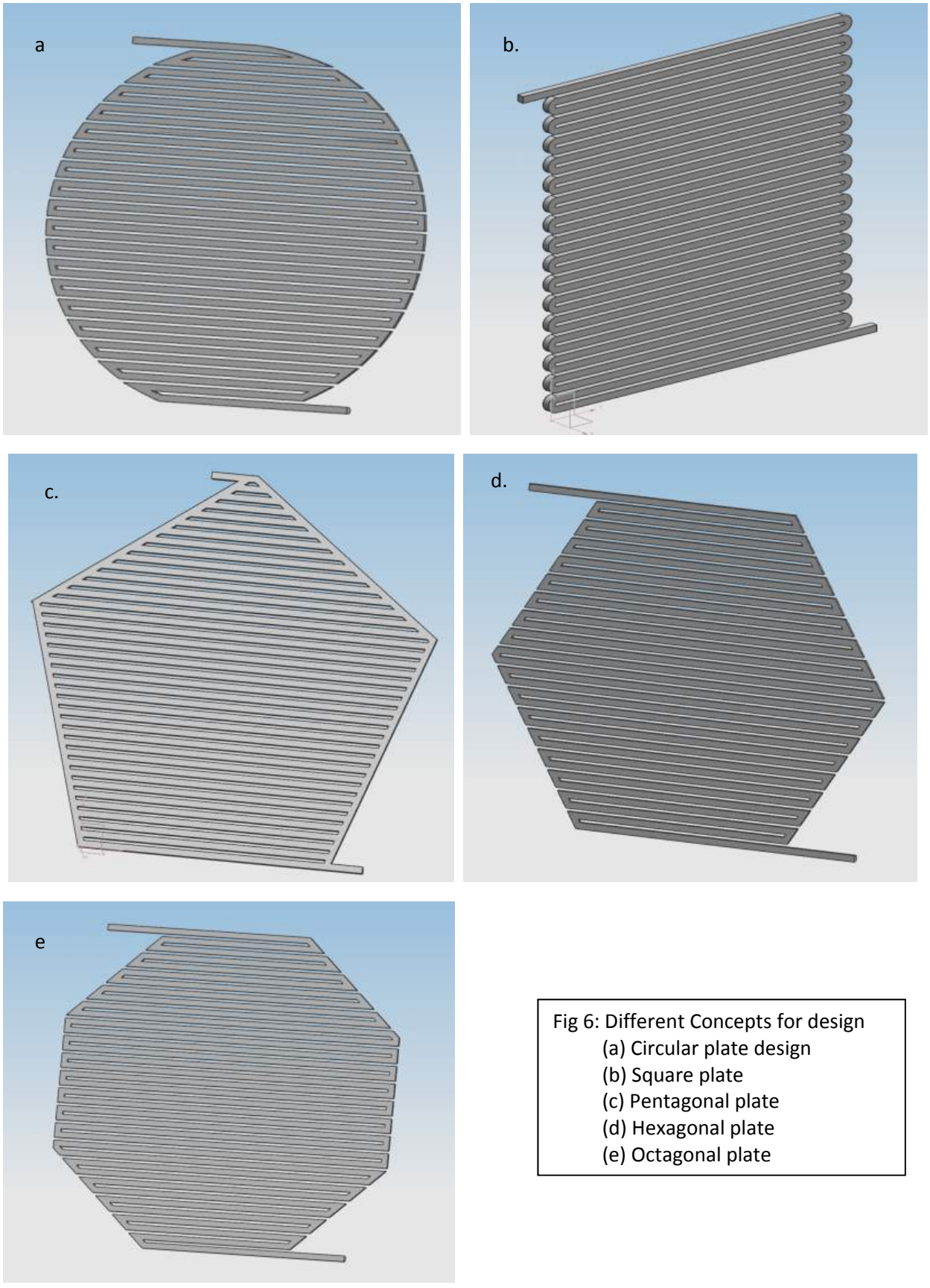


Fig 6: Different Concepts for design
(a) Circular plate design
(b) Square plate
(c) Pentagonal plate
(d) Hexagonal plate
(e) Octagonal plate

For the purpose of making the fuel cell portable, it was decided to develop an air-breathing fuel cell i.e. the anode side would be open to the environment instead of carrying oxygen in a cylinder. Storing oxygen in a cylinder is an expensive process which would drive up the cost of the fuel cell, therefore the need of an air-breathing fuel cell.

2.6. Channel cross-section

The fluid flow channels of the bipolar plate are typically rectangular or square in cross-section, even though other configurations like triangular, semi-circular and spherical have been explored. The flow channel dimensions range from a fraction of about 1 to 2mm in width and depth as low as possible (1mm) so as to reduce the fluid pressure loss due to friction losses. The land width i.e. the unmachined section between two adjacent channels was also considered as this is the area which attracts the electrons from the reactions taking place in the MEA. If we design the plate having bigger land widths, then the active area of the MEA available for absorption of the reactant gas is reduced which in turn reduces the performance of the fuel cell and if we reduce the land width, the collection of electrons is reduced. Therefore when designing the active area of the BPP, we should have a fine balance between the area under the flow field and the land. The most common method of machining the fluid flow channels on the bipolar plates requires the engraving or milling of the flow channels onto the bipolar plate surface. It also has been found that having larger channel size causes the reactant gas to have a turbulent flow which is to be avoided as it would interfere both in the flow of the gas through the channels as well as the absorption of the gas into the MEA.

2.7. Flow-field layout design

One of the main obstacles towards large scale commercialization of fuel cells is the gas flow fields and the bipolar plates which include the development of low-cost lightweight construction materials, optimal design and fabrication methods and their impact on the PEMFC performance. The PEMFC performance is generally studied on the basis of its energy efficiency and power density. In spite of all the R&D 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 cells.

A variety of different designs have been developed. Some of the design that have been used are

1. Pin-type flow field
2. Parallel/Straight flow field
3. Serpentine flow field
4. Multiple Serpentine flow fields
5. Inter-digitated flow fields
6. Other miscellaneous flow field designs

2.7.1. Pin-type Flow field

The flow field network in this type of design is formed by many pins arranged in a regular pattern. These pins are usually cubical or circular in cross-section. Usually, both the cathode and anode flow field plates would have the regularly spaced pins protruding from the plate and

the reactant gases would be made to flow across the plates through the intervening grooves formed by the pins. As a result of this type of flow, there is a low reactant pressure drop. However, reactants flowing through such flow fields tend to follow the path of least resistance which may lead to the formation of stagnant areas, thus causing uneven reactant distribution, inadequate water removal causing poor fuel cell performance.

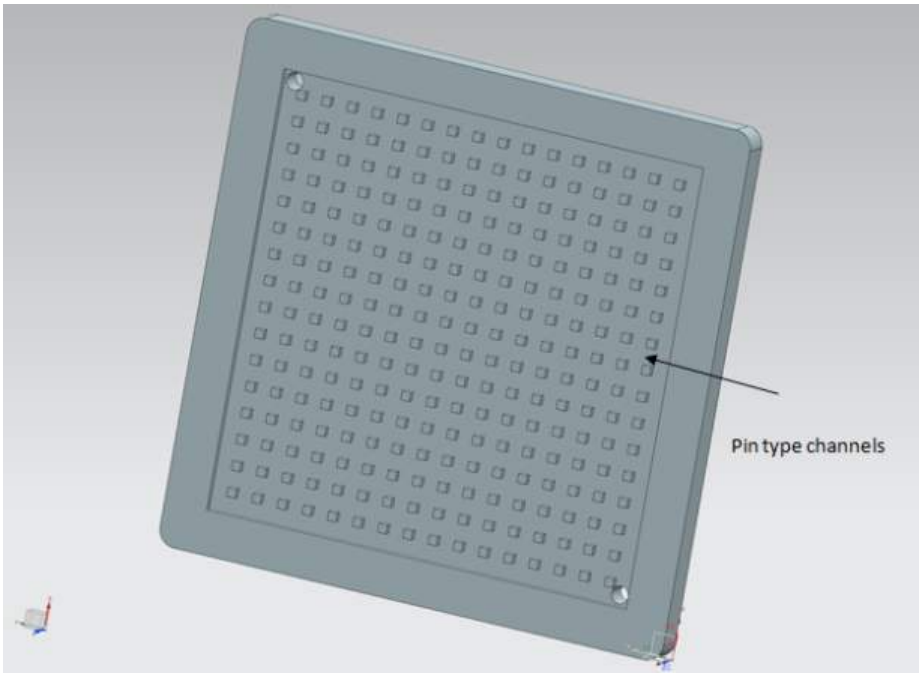


Fig 7: Bipolar plate with pin-type flow field design

2.7.2. Parallel/Straight flow fields

This type of flow field design entails the gas flow field plate having a number of parallel flow channels which are also connected to the gas inlet and exhaust. It has been seen that using this type of design over extended periods of operation causes low and unstable cell voltages

because of the gas flow distribution and the water management. The hydrogen gas tends to follow the path of least resistance and would likely follow the channels along the plate walls, ignoring the channels at the centre of the plate leading to under-utilization of the plate i.e. stagnant areas are being formed at various areas in the plate. During the operation of the fuel cell, water droplets get also accumulated in the channels leading to decreased performance as a separate force would be required to push the water droplets through the channel out of the plate. Therefore due to the poor gas flow distribution and inadequate water removal, the performance of the fuel cell is affected.

Another aspect in this type of design is that there is low pressure loss in the flow channels due to their being small in length.

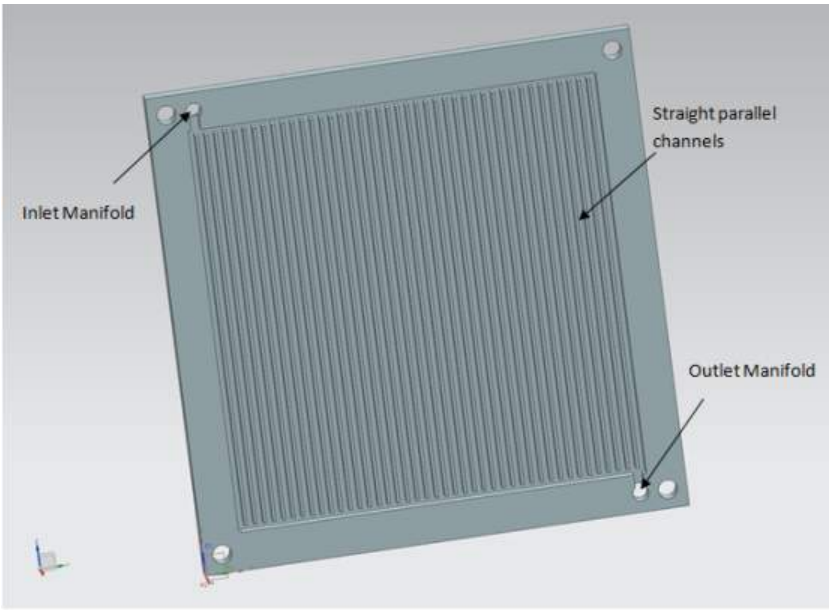


Fig 8: Bipolar plate with straight/parallel type flow field design

2.7.3. Single Serpentine Flow field design

In this type of design, we used a continuous flow type design having an inlet at one end and an outlet at the other end and which follows a serpentine path. Using this type of serpentine flow field forces the reactant gases to flow across the entire active area (in this case 25cm^2) of the bipolar plate which in turn eliminates stagnant areas caused by improper gas distribution. However this type of serpentine flow field forces the gas to follow a relatively long flow path which causes a large pressure drop along the channels from the inlet to the outlet. But one problem with having a single serpentine channel is this type of flow field is more prone to getting blocked due to the formation of water droplets in the channels especially for higher current densities.

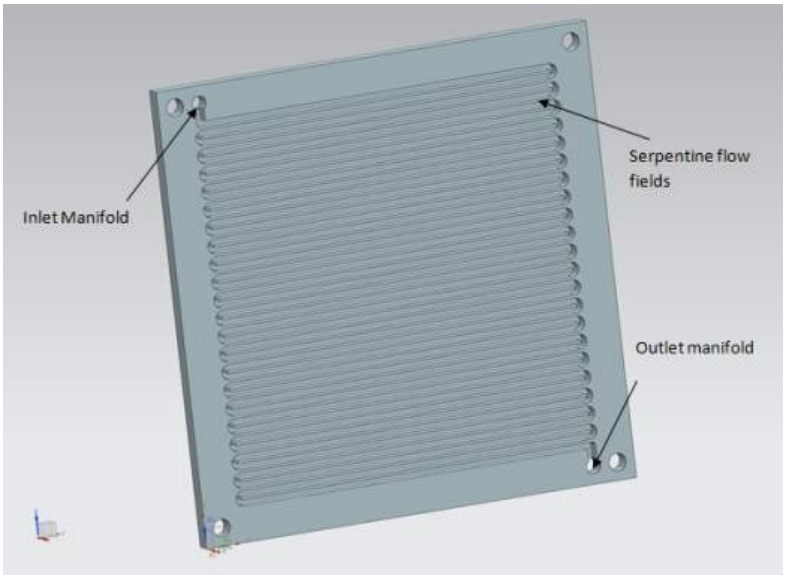


Fig 9: Bipolar plate with Single Serpentine flow field design

Therefore, for a higher current density operation or if a large active area is present , it would be better to have multiple serpentine channels instead of a single channel which in turn would

limit the pressure drop along the channels and also help in the water management. Here, even if one channel is blocked, the fuel cell can still operate due to the presence of the other channel although with a lower efficiency.

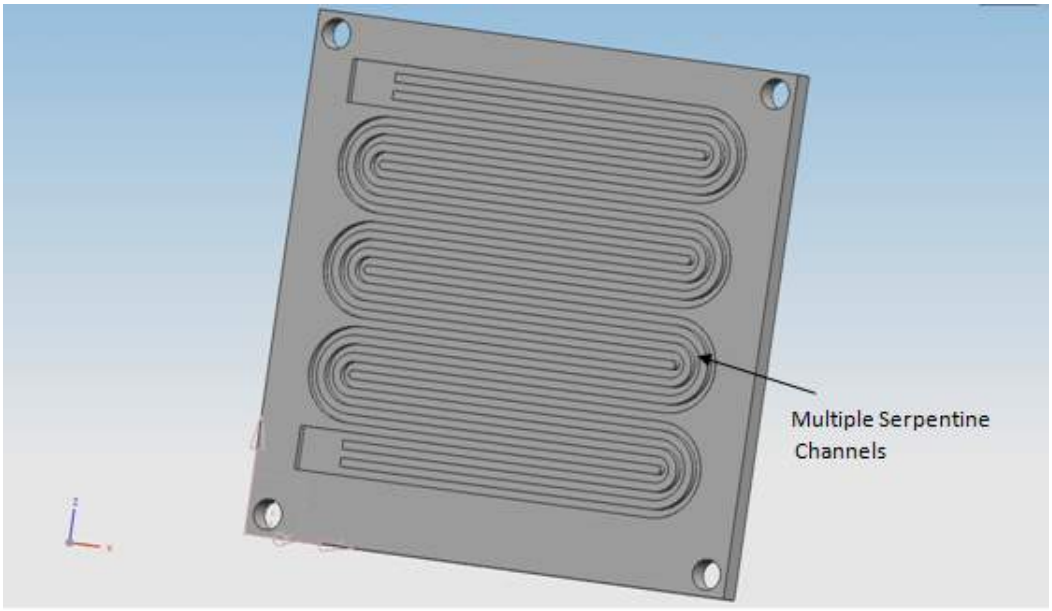


Fig 10: Bipolar plate with multiple serpentine flow field design

2.8. Preliminary Flow Field Simulations

Before going forward on further designs, we have to analyze the flow parameters of the reactants through the bipolar plate. This was done by using the Fluent Software. The model of the bipolar plate was created along with Gas diffusion layer (GDL) and the MEA. We used the following assumptions for both the GDL and MEA: the viscous permeability of $0.44 * 10^{-12}$ (m^2) and inertial permeability of $34 * 10^{-8}$ (m) [7].

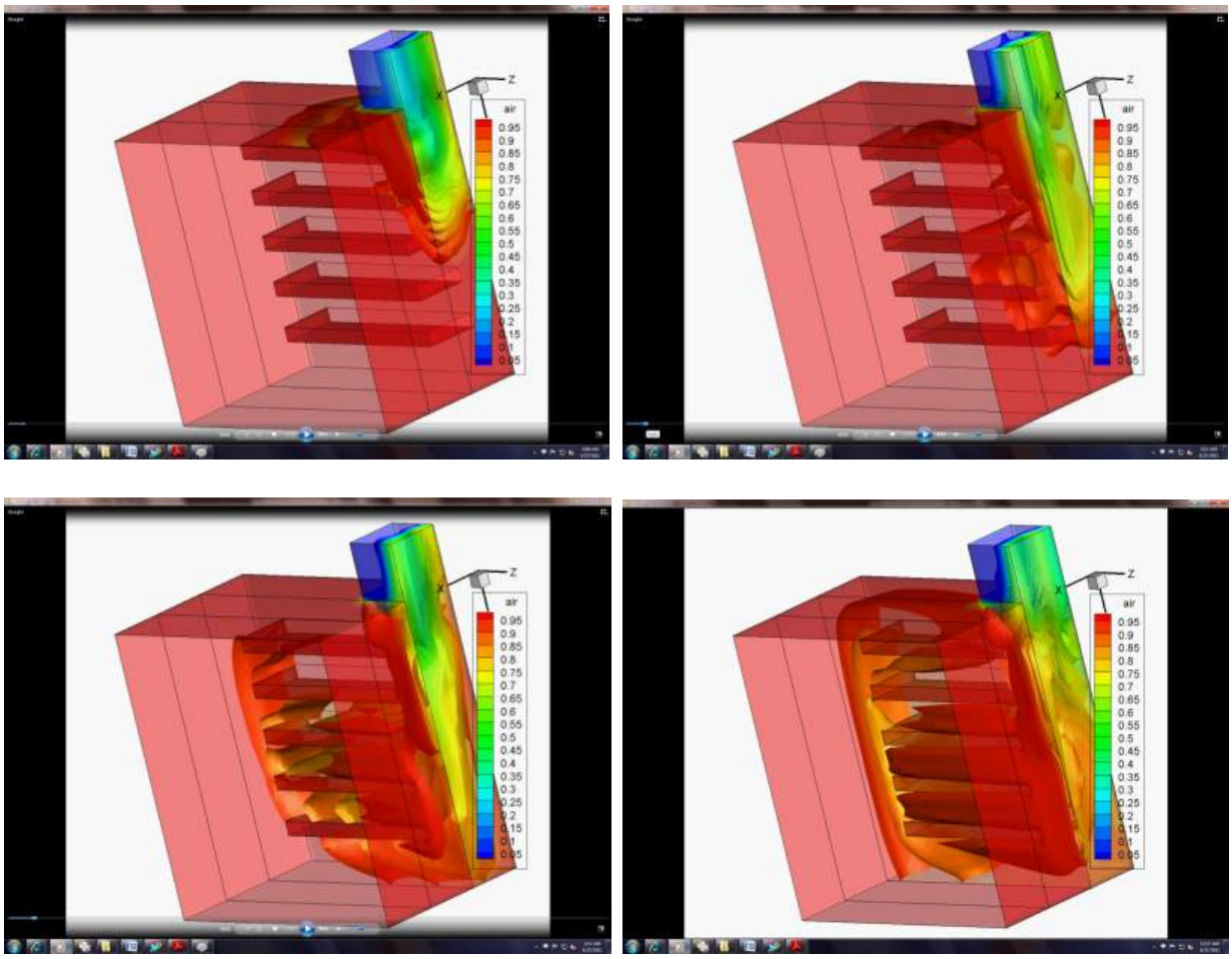
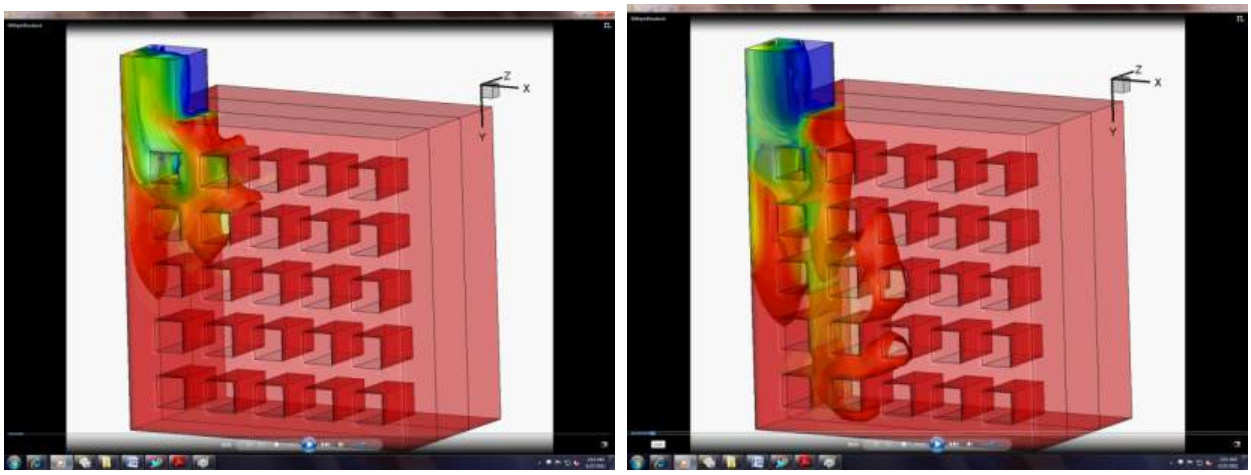


Fig 11: Reactant flow in Straight/parallel flow field design



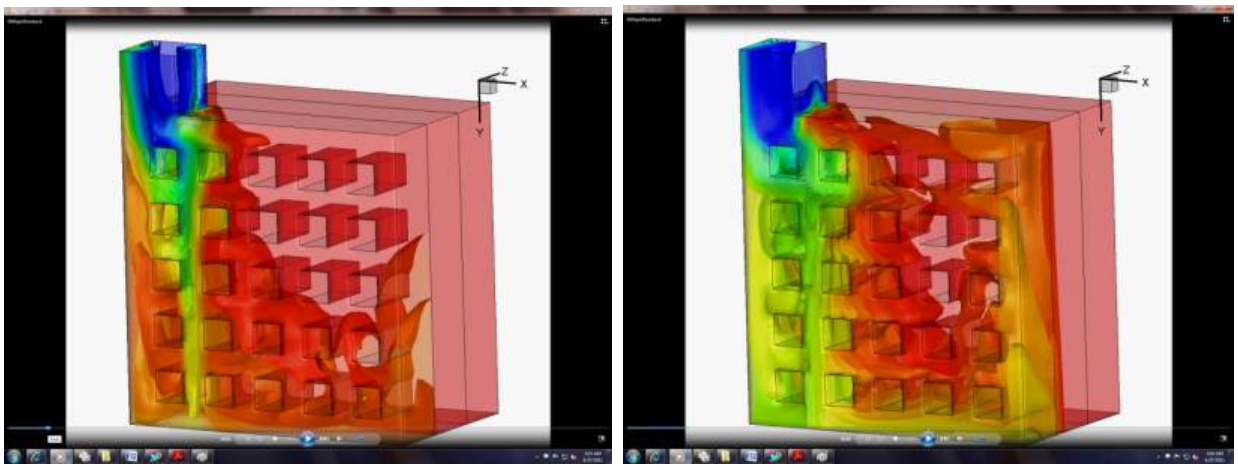


Fig 12: Reactant flow in pin-type flow field design

The above figures show the flow into bipolar plates both a straight/parallel flow field design and a pin-type design which then is forced into the GDL and then MEA. For this analysis we wanted to find the effect the width of the channel would have on the type of flow, therefore we designed the plate having wider channels (about 5mm). The image shows the mass fraction of the reactant i.e. in this case air. From the analysis, we can see that due to the wider channels, the reactant gas had a turbulent flow through the channels which in turn would affect the rate of diffusion on the gas into the GDL and MEA. This is unacceptable for us so therefore, we should aim to keep the channel width to a range of (2mm – 3mm). We also notice that the reactant gas doesn't flow into the area in the GDL at the land areas i.e. the straight/parallel obstructions or the pins in the corresponding plates as can be seen below. The depth of the channels seems to have an effect on the flow of the reactants. Deeper the channel, the better it is for easier flow of the reactant gas [8]. For portable applications, it's better to keep the channels having a depth range of around (1mm – 4mm).

The above conclusions are similar to the conclusions reached at the University of Alabama research team. These results are for a serpentine flow field.

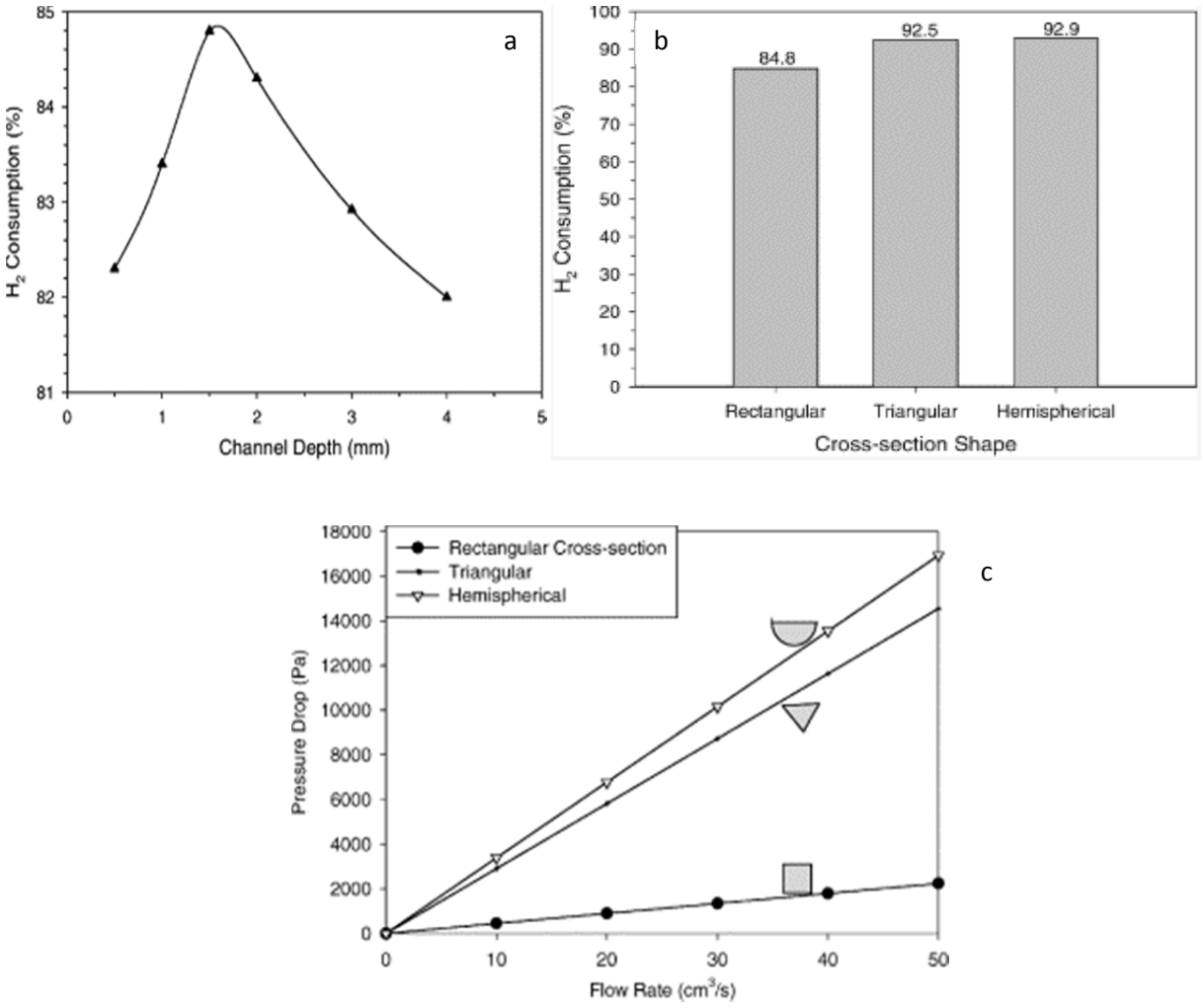


Fig 13: Effect of different design parameters on H_2 absorption and pressure drop [9]

(a.) Hydrogen consumption due to channel depth

(b.) Hydrogen consumption due to Channel cross-section

(c.) Pressure drop for different cross- sections

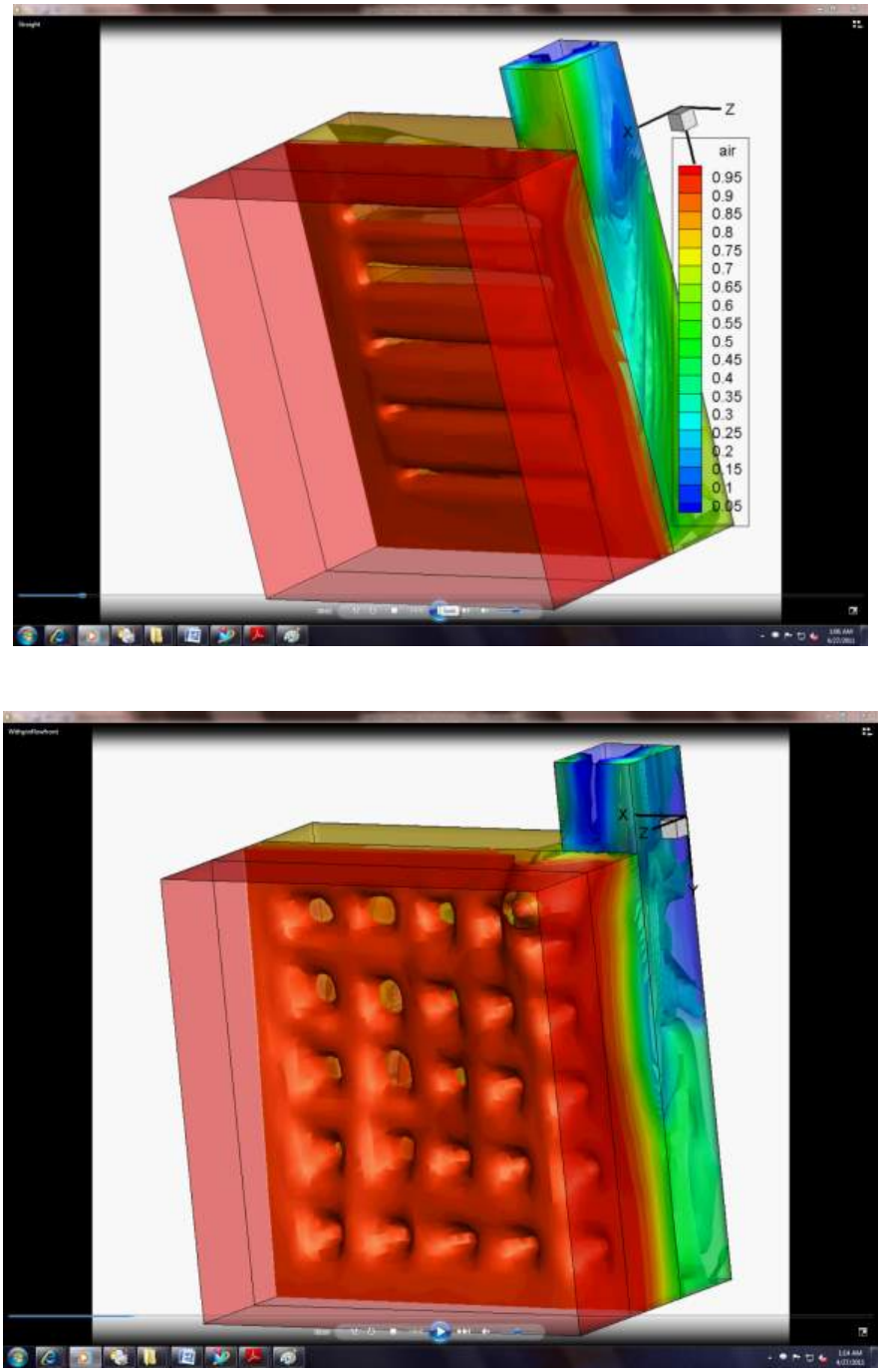


Fig 14: Reactant flow into the MEA from the bipolar plate

Therefore this phenomenon causes parts of the MEA to be inactive leading to decrease in performance of the fuel cell. The above images suggest that we also have to reduce the amount

of cross-sectional area of the land areas. But this would have to be a balancing act as having too thin or small land areas like too small pins or tin parallel sections would cause tear in the MEA and GDL. Therefore we have to choose an optimum measurement of about 2mm – 4mm. Taking into consideration, the above results and observations, i.e. using thinner channels for the flow field, balancing the area covered by the active area of the channels and the land width, we designed the following bipolar plates.

2.9. Bipolar Plate – Material Saving

One of our main goals for this project was to reduce the cost of the fuel cell as much as possible and one area where this was possible was to reduce the amount of material used in the manufacture of the bipolar plates. For example, we can see here in this square plate

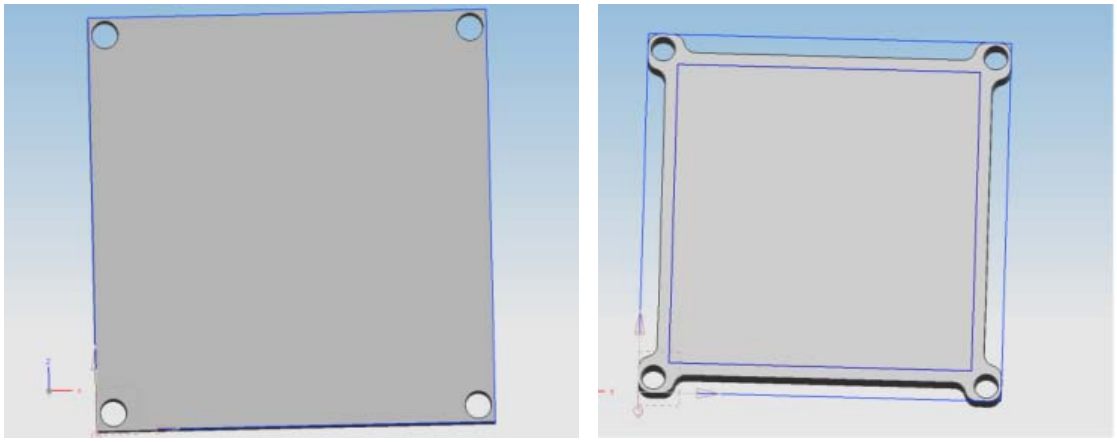


Fig 15: Material savings in a square bipolar plate

In the above case, we were able to obtain savings of about 16.5%

Therefore it was decided to remove all the extraneous area around the active area of the bipolar plate.

3. Multiple Serpentine Flow field – (Megamet Industries design)

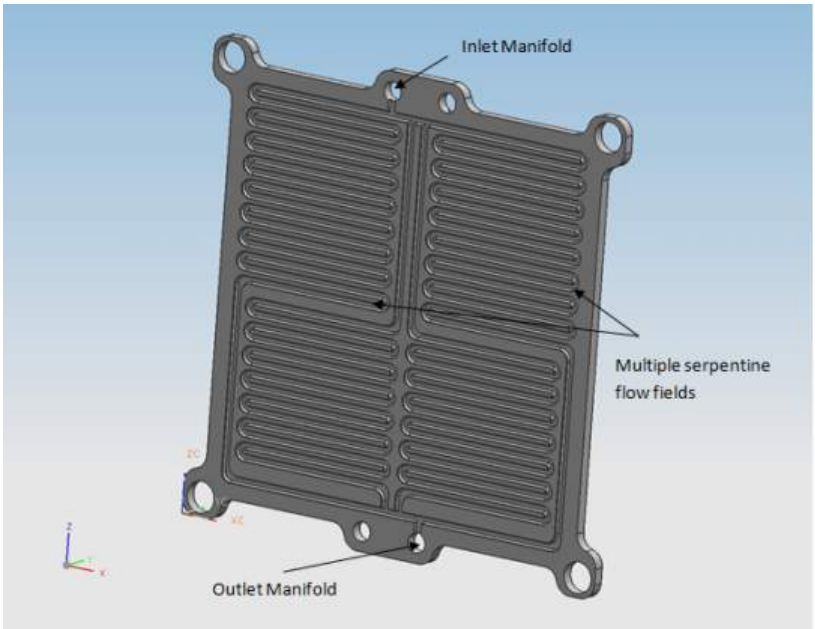


Fig 16: Bipolar plate with Multiple Serpentine Flow fields

This plate was successfully manufactured by the company Megamet Industries. But after testing this plate, severe leakage of the reactant gas was present. This plate was difficult to clamp together and seal properly due to the non-availability of the extraneous area around the active area for the purpose of gasketing and also the ears for the bolts were way too thin which caused it snap off when too much force was used to clamp the plates together. Another issue we faced was that having too thin channels and complex designs would prevent the easy passage of the reactant into the plate therefore impacting the performance of the fuel cell due to the starvation of the reactants. Therefore we left the extraneous area for the purpose of provide placing the gaskets and also to provide support to the ears.

4. Inter-digitated Flow field design

All the above designs incorporated continuous flow channels from the inlet manifold to the exit manifold. In this type of design, the reactant gases flow from the inlet manifold to the outlet manifold via molecular diffusion through the gas diffusion layer where it also undergoes the required electrochemical reaction and also generate power. One issue with this type of design is that molecular diffusion is a slow process which in turn would cause large concentration gradients of the reactants across the GDL's and BPPs.

An inter-digitated system consistes of dead ended channels on the active surface area. The channels are not continuous form the inlet manifolds to outlet manifolds. The reactant gases are made to diffuse under pressure through the MEA to reach the other channels connected to the outlet manifold thus developing a convection velocity in the MEA which would help in the removal of water formed. Therefore this type of design is effective in preventing flooding caused due to water formation and also provides better fuel cell performance at high current densities.

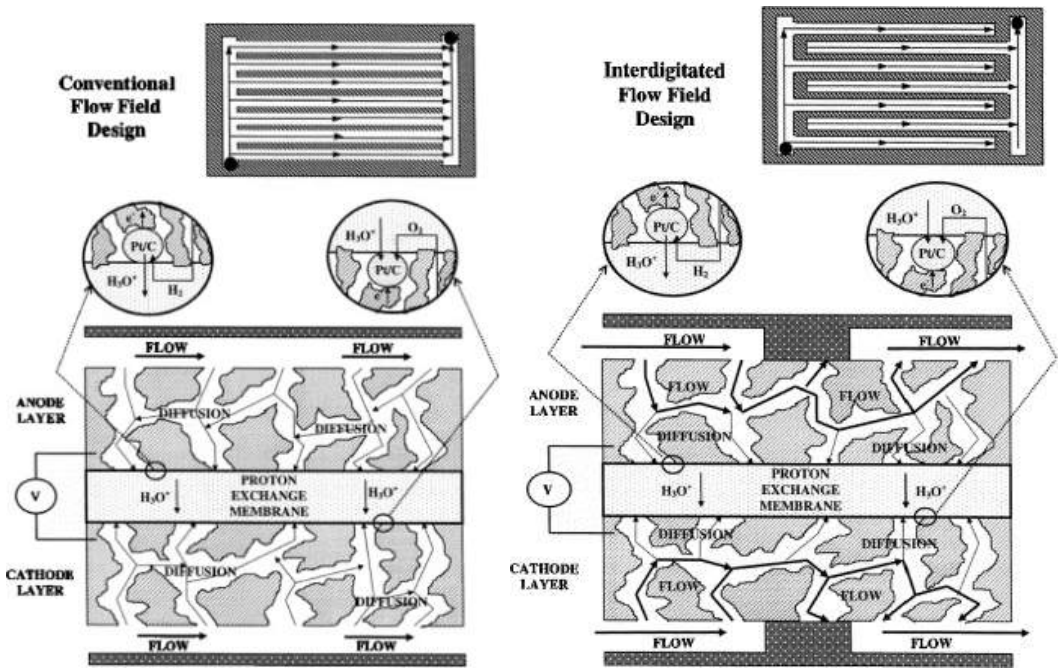


Fig 17: Mechanism of inter-digitated flow field design [10]

Fig 18: The machined bipolar plate with inter-digitated flow field design

This design performs better than the conventional continuous flow field design. Due to the problems faced by us when clamping the previously designed plates, it was decided to use clamp/end plates at either end of the BPP with the bolts passing through them instead of the BPP. Therefore for this purpose we designed a couple of clamp/end plates for use in our setup.

Our first prototype design had the anode side open for easy access to the air necessary for the reactions with the cathode plate designed appropriately to ensure that the air reaches the MEA, grooves on the inside of the plates to position the BPPs, 8 bolt holes to provide enough compressive force and also tapped inlet and outlet manifolds. We also added sleeves to the bolts so as to prevent any short circuit occurring in our setup.

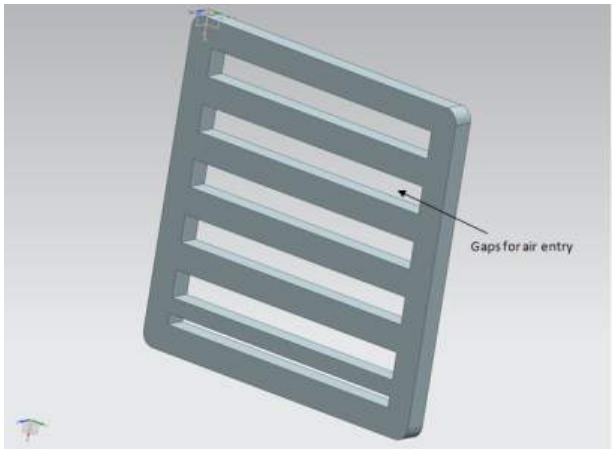


Fig 19: Open ended cathode plate

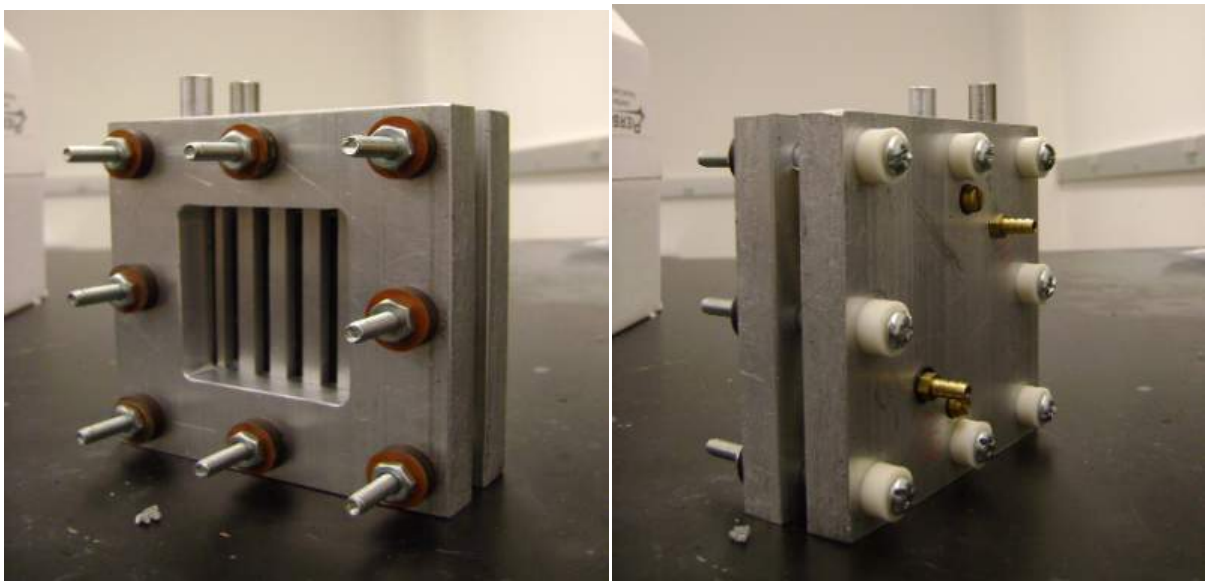


Fig 20: The fuel cell along with the open cathode side clamp/end plates and the anode side end plates with the inlet/outlet manifolds

After using the clamp plates, the sealing was significantly improved. But while clamping, we had to ensure that the clamping force was uniform across the plate i.e. at each of the bolt areas.

Another issue that cropped up was the possibility of the open sided clamp plate not ensuring uniform compressive pressure on the anode plate which in turn would have affected the contact between the MEA and cathode plate and also caused uniform sealing problems. Therefore to ensure this does not happen, we designed a second clamp plate prototype that was a closed plate and also redesigned the cathode plate to include parallel grooves open to the MEA and atmosphere to ensure that air does reach the MEA.

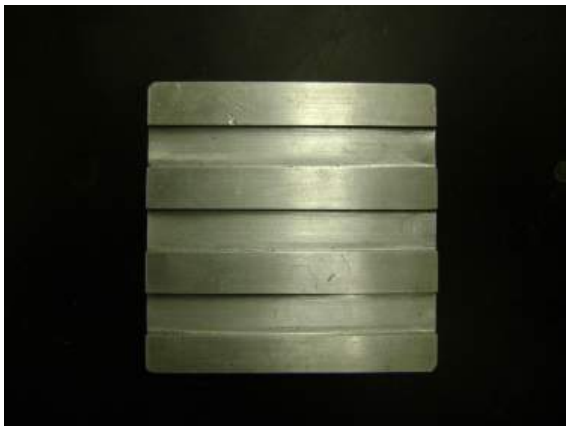
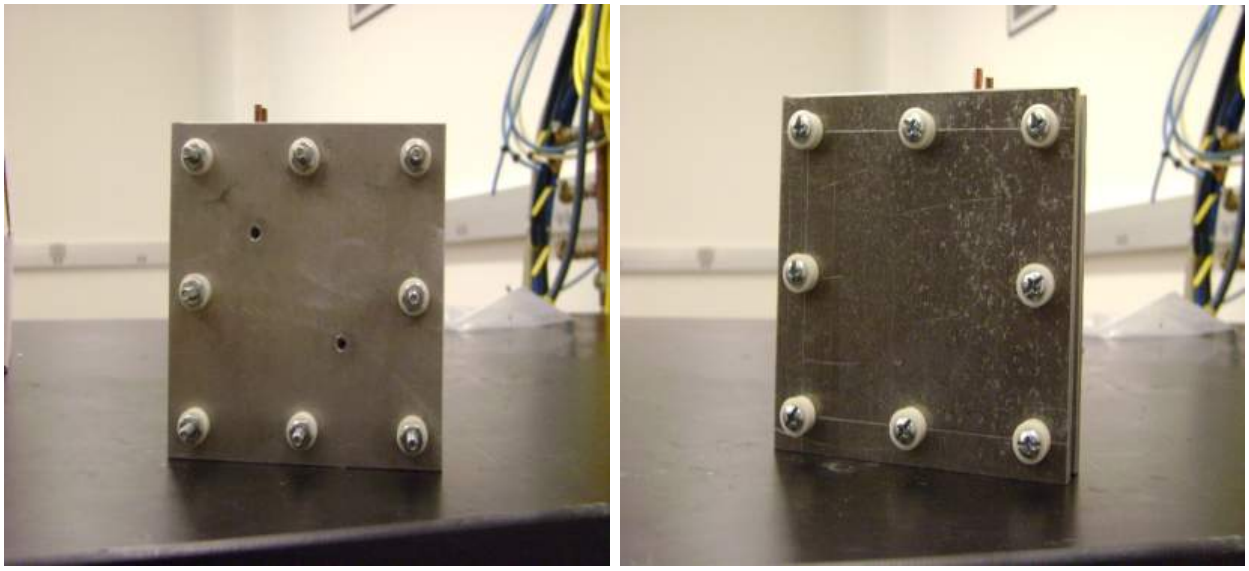


Fig 21: The cathode plate with open grooves

We also reduced the thickness of the clamp plates from prototype 1 as it was deemed unnecessary and which also added significantly to the weight of the entire fuel cell.



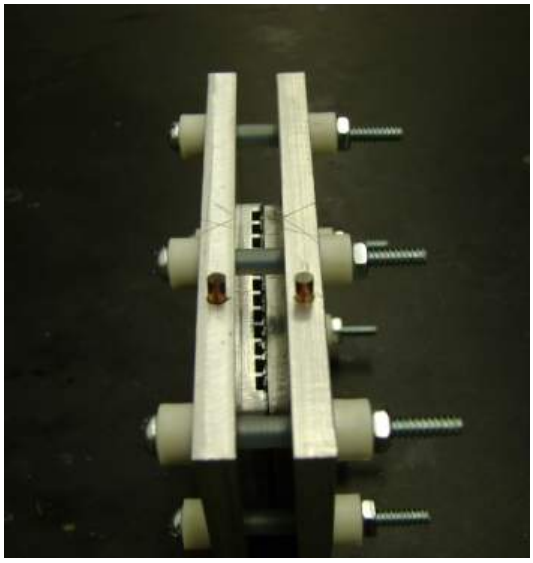


Fig 22: Clamp Plate (Prototype 2)

(a.) Anode side clamp plate with respective inlet and outlet manifolds

(b.) Closed Cathode side clamp plate

(c.) Top view of assembly

To ensure that the grooves did not cause bowing to occur in the MEA and also to increase area of contact with the MEA to collect more electrons, we welded a mesh onto the plate which would come in contact with MEA. This mesh ensured adequate air reached the MEA and also increased the capacity to collect electrons from the MEA.

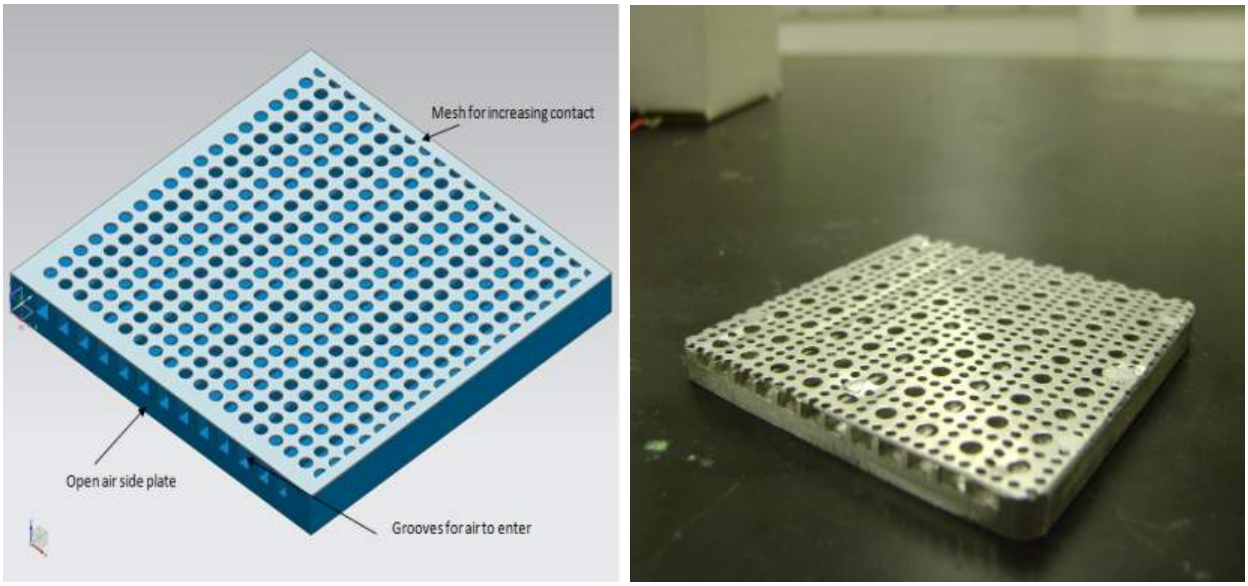


Fig 23: The meshed cathode air plate

Incorporating the above design changes, we were able to notice comparatively better performance than before with other types of flow fields. We were able to obtain around 0.47 W when tested on the fuel cell test station. Also the sealing of the plates was found to be significantly better than before but was still not matching our requirements. Therefore a better way to seal the plates was needed to be found.

4.1. Hybrid Inter-digitated flow field design

This is an entirely new design. This incorporates the use of an exhaust channel totally separate from the flow field channels of the bipolar plate and also a separate groove for the gasket. This design follows the same theory as that of the inter-digitated design. The main purpose of this design was to improve the sealing of the bipolar plates having a theoretically similar inter-digitated flow field design.

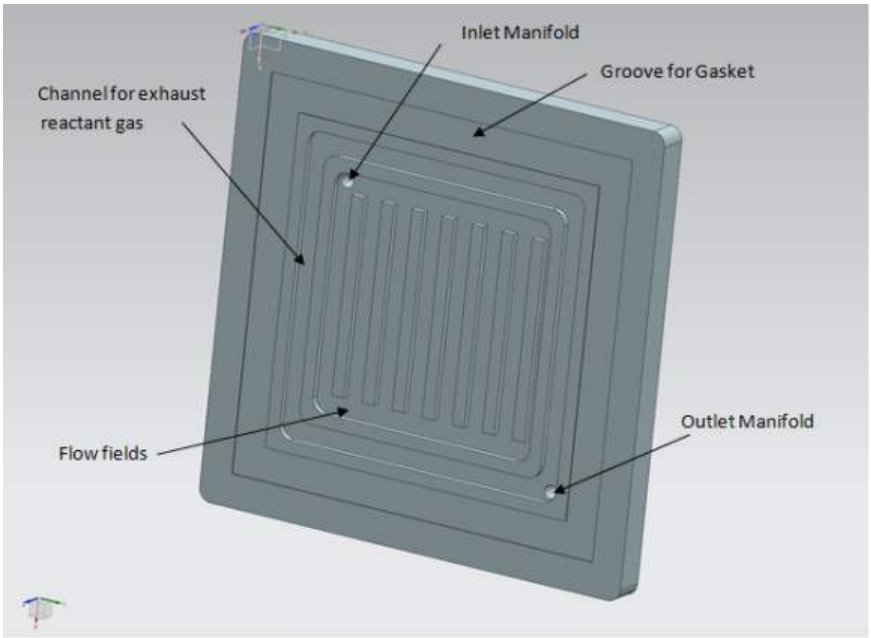


Fig 24: Hybrid Inter-digitated flow field design

As we can see from the above figure, the plate has a conventional straight/parallel flow field design except without the outlet manifold. The reactant gas flows through the flow fields and into the MEA by molecular diffusion and then flows out into the exhaust groove to the outlet manifold. This type of design increases the active area available for diffusion when compared to the inter-digitated design and also provides a better sealing than the previous designs due to the polished surface and the dedicated groove for the gasket around the active area of the BPP. The groove for the gasket is lesser in depth than the thickness of the gasket to ensure that on compression, the gasket due to its elasticity would flow outwards and fill all the gaps that might be present and ensure proper sealing that we need. Using the redesigned clamp plates and anode plate did provide us with comparative better sealing than before but it still wasn't enough. The reactant gas; in this case was hydrogen is extremely small on a molecular level and would just require a small gap to escape. Therefore to ensure proper fit and sealing between all

the components namely the bipolar plates and the clamp plates, we polished all the surfaces that would come into contact with each other using sandpaper having grit size of 600, 800, 1000, 1500, 2000 and 2500. We polished the surfaces with the mentioned grit sizes to obtain a mirror surface which ensured that each adjoining surface had a proper fit. With the help of the gasket groove and by improving the surface finish of the plates we were able to obtain a comparatively superior sealing than which was obtained before.

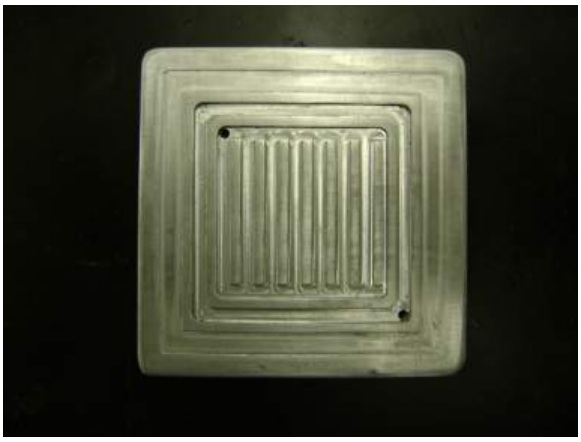


Fig 25: Machined bipolar plate with Hybrid Inter-digitated flow field

5. Conclusions

The Bipolar plate is one of the essential components in a PEM fuel cell and it performs many essential functions in a PEM fuel cell stack operation like supplying reactants to the MEAs, current collection, providing structural support to the MEA, water management & thermal management. In essence, the success of the PEM fuel cell boils down to the appropriate design of the bipolar plate. The design of the bipolar plate entails the design of the flow fields on both surfaces of the plate with optimum design parameters. A variety of flow field configurations have been proposed here including pin-type, straight/parallel channels, serpentine and multiple serpentine channels, inter-digitated design and also a hybrid inter-digitated design. Each of these designs has their own pros and cons and they can be used for different applications. Also, the design of the plate is not enough for the successful operation of the fuel cell. We should also have very good sealing between the plates and the MEA. If not, the cell is prone to reactant leakage which reduces the efficiency of the cell and also leads to a hazardous environment. We have shown that improving the surface finish of the plates and using gaskets in their separate grooves around the active area greatly improves the sealing of the bipolar plates. Therefore improvements in the bipolar plates and the sealing between them can help us achieve our goals for improved cost and performance for fuel cells and help in the commercialization of the PEM fuel cell.

7. References

1. http://orgs.kettering.edu/altfuel/fcback.htm
2. http://en.wikipedia.org/wiki/Fuel_cell#Proton_exchange_membrane_fuel_cells
3. Xianguo Li and Imran Sabir, Review of Bipolar plates in PEM fuel cells: Flow Field designs, International Journal of Hydrogen Energy **30** (2005), Pages 359-371
4. http://www.Ballard.com (Last retrieved on April, 2011).
5. University of southern California (2007)
6. www.earthsafefuels.com (Last retrieved on April, 2011)
7. Vladimir Gurau *,* Michael J. Bluemle , Emory S. De Castro , Yu-Min Tsou , Thomas A. Zawodzinski Jr., J. Adin Mann Jr. , Characterization of transport properties in gas diffusion layers for proton exchange membrane fuel cells 2. Absolute permeability, Journal of Power Sources **165** (2007), pp. 793-802
8. Yutaka Tabe*,* Sang-Kyun Park, Kazushige Kikuta, Takemi Chikahisa, Yukio Hishinuma, Effect of cathode separator structure on performance characteristics of free-breathing PEMFCs, Journal of Power Sources **162** (2006), pp. 58-65
9. Atul kumar, Ramana G. Reddy, 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** (2003), pp. 11–18
10. A. Kazim, H.T. Liu and P. Forges, Modeling of performance of PEM fuel cell with conventional and interdigitated flow fields, Journal Appl Electrochem **29** (1999), pp.1409–1416