Fabrication and Performance Analysis of Pem Fuel Cells with Different Bipolar Plate Materials

S. Om Prakash[1] R. Sunil Kumar[2] N. Manikandan[3]
[1,2,3]Assistant Professor
[1,2,3]Department of Mechanical Engineering
[1,2,3]United Institute of Technology, Coimbatore, India

Abstract— Proton exchange membrane fuel cell (PEMFC) system is an advanced power system for the future that is sustainable, clean and environmental friendly. The flow channels present in bipolar plates of a PEMFC are responsible for the effective distribution of the reactant gases. Uneven distribution of the reactants in a PEMFC can cause variations in current density, temperature, and water content over the area of a PEMFC. The materials and machining methods for PEMFC bipolar plates are of ultimate importance as they constitute more than 60% of the weight and 30% of the total cost in a fuel cell stack. This work investigates how the performance of the PEMFC varies with different bipolar plate materials. Here graphite is used as bipolar plate with flow channels machined in them. The experiments were carried out in a single cell PEMFC. The results are to be compared with Stainless steel, Aluminum and brass bipolar plates.
Key words: PEMFC, Bipolar Plates, Porous Carbon Foam

I. Introduction

Polymer electrolyte membrane fuel cells (PEMFC) are the most widely researched power generation technologies all over the globe. The fuel cell technologies are gaining attention due to their ability to produce clean and efficient power. The main advantages of a PEMFC are its low-temperature operation, high power density, fast start-up, system robustness, and low emissions which attracts majority of the motor manufacturers to pursue research and development. PEM fuel cells have emerged as a viable energy source for use in the automotive industry and eventually may replace the internal combustion engine. With its ability to attain high power densities and perform with elevated efficiencies, the PEM fuel cell is at the forefront of technology advancement for automotive application. Several key benefits such as reduction in harmful air pollutants and greenhouse gases arise from the use of fuel cells with hydrogen as the reactant fuel.

II. Bipolar plates

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 flowfield and use of lightweight materials. Different combinations of materials, flow channel layouts and fabrication techniques have been developed for these plates to achieve its functions efficiently, with the aim of obtaining high performance and economic advantages.

A. Functions of a Bipolar Plate:

Bipolar plates (BPs) being one of the most important components in PEMFC stacks must perform a number of functions simultaneously in order to achieve good stack performance and lifetime. BPs supply the reactant gases through the flow channels to the electrodes and serve the purpose of electronically connecting one cell to another in the electrochemical cell stack. These plates also provide structural support for the thin and mechanically weak MEAs and means to facilitate water management within the cell. In the absence of dedicated cooling plates, the BPs also facilitates heat management. The plate topologies and materials facilitate these functions. Topologies can include straight, serpentine, or interdigitated flow fields, internal manifolding, internal humidification, and integrated cooling. Therefore, optimal design must be sought for the BPs because the above functions have conflicting requirements on the BP design.

B. Requirements of a Bipolar Plate:

The essential requirements for BPs, in respect to physicochemical characteristics, are

- Good electrical conductivity,
- High thermal conductivity,
- High chemical and corrosion resistance,
- Mechanical stability toward compression forces,
- Low permeability for hydrogen,
- Low-cost material being processable with mass production techniques,
- Low weight and volume, and recyclable materials.

C. Bipolar Plate Materials:

According to Heinzel et al [1], the materials under scrutiny are divided into metallic and graphitic. For mobile applications of the fuel cells, where the weight is the main criteria, metallic plates are used. Thin metal sheets show sufficient mechanical strength and can be easily mass produced. Two sheets of thin and structured metal plates can be combined into a bipolar plate with flow fields on both sides and cooling channels in between. For improving lifetime, a corrosion-protective coating is typically required. For stationary applications like residential power supply system's where the lifetime expectations are usually much higher about 40000 to 80000 hours graphite would be advantageous. The main advantage of graphite materials are their corrosion resistance property. However, there brittleness in nature increases the plate thickness and difficulty in machining.

D. Metallic BP Materials:

Metals offer some undeniable advantages over carbon as Bipolar Plates (BP) materials. They possess higher thermo and electro conductivities, lack of porosity, gas impermeability (as a result, metal plates can be very thin), and high strength, including flexural strength, which allows production of thinner plates. However, all advantages of metals as BP material are much depreciated by their principal disadvantage which is their low corrosion resistance. Aluminium-magnesium alloys, Titanium, special alloyed steel such as 316L are being used as common metallic bipolar plate materials.

Titanium is a fairly promising material for BP applications, since it is highly corrosion-resistant, possesses good mechanic properties (strength and hardness), and titanium ions are not too poisonous for catalysts and ion exchange membranes but it is fairly expensive. Machining of titanium, like power metallurgy, is much more expensive than steel sheet stamping. Titanium is heavier than aluminum and its alloys.

Thus the main disadvantage of the metallic BP materials are their corrosion resistance, as the fuel cell medium is quite aggressive, metal plates should be protected with corrosion resistance coatings.

In their research about protective coatings for metallic bipolar plates P.J. Sebastian et al [4] inferred that Al and stainless steel bipolar plates with corrosion resistant coatings such as Ni-P, PTFE (polytetrafluroethylene), polyaniline (PANI) and polypyrrole (PPY) showed considerable improvement in their characters. The authors proved that The Ni-P, PANI and PPY coated Al and SS metallic bipolar plates exhibited corrosion resistance in simulated PEMFC environment. However the corrosion resistance for longer periods and ageing characteristics were not evaluated by them.

III. Graphitic Bipolar Plate Materials

Graphite was already known for its application in phosphoric acid fuel cell to be a suitable material. Pure graphite-based bipolar plates offer the advantages of excellent chemical resistance and good thermal and electrical conductivity combined with a lower density than metal plates. However, machining the flow fields into pure graphite plates is a complicated and time-consuming step that leads to high prices. Moreover, graphite plates are brittle and porous; they have to be coated to be made impermeable to the fuel and oxygen. Hence, graphite-based bipolar plates are nonviable candidates as low-cost PEMFC components.

Different types of bipolar plates are being developed which makes use of carbon materials like, electro graphite, flexible graphite, carbon–carbon composites, graphite–polymer, etc. As stated by Heinzel et al [1] Graphite composite materials with polymer binders are more suited to achieve the desired properties and to improve manufacturing technologies for bipolar plates including the flow fields and cooling channels. These composite materials are made of commercially available polymers as binders and a high loading of conductive carbon compounds (e.g., natural or synthetic graphite powder, carbon blacks, and carbon nanotubes), which increases the conductivity. The polymers are either thermoplastics such as polyvinylidenefluoride, polyethylene, polypropylene, liquid crystal polymers, and polyphethylene sulfide, or thermosets, such as vinyl ester, phenolic resins, and epoxy resins.

H.S. Lee et al [5], in their study on alternative materials for bipolar plates fabricated graphite composite by compression molding. Graphite particles mixed with epoxy resin were used as the main substance to provide electric conductivity. To achieve desired electric properties, specimens made with different mixing ratio, processing pressure and temperature were tested. To increase mechanical strength, one or two layers of woven carbon fabric were added to the original graphite and resin composite Flow channels were fabricated by compression molding. The results obtained by the authors indicate that by increasing the mixing ratio of graphite particles, processing pressure and temperature, electric conductivity of the composite was improved.

Theodore M. Besmann et al [6], proposed a carbon/carbon-composite bipolar plate material with very promising fabrication, material, and performance characteristics. Carbon/carbon composite bipolar plates for proton-exchange-membrane fuel cells have been fabricated by slurry molding a chopped-fiber preform followed by sealing with chemically vapor-infiltrated carbon. The resulting component proved to be hermetic with respect to through thickness leakage, high electronic conductivity as a result of the deposited graphitic carbon, and low density due to retained porosity and corrosion resistant.

Jenn-Kun Kuo and Shiuh-Ming Chang [7] used a Nylon-6 / S316L stainless steel alloy fiber composite material to mold conductive plastic bipolar plates for a PEM fuel cell. The plates were fabricated via an injection molding process, which yields better production rates than coating or treating metal plates with a suitable surface material The resulting bipolar plates were found to be inexpensive, have favorable corrosive, hardness, and gas tightness properties, are lightweight and small, and are easy to manufacture.

A replacement for the conventional graphite bipolar plate was reported by R.B. Mathur et al [8], which is twice as strong as the conventional monolithic graphite plate. These plates have been produced by compression molding technique using natural graphite, synthetic graphite, carbon fiber and carbon black as reinforcing constituents and phenolic resin as a binder matrix.

IV. Methodology and Experimental Procedures

According to the literature survey it is clear that the corrosion rate of the graphite, 15 µm per year, is among the best. The SS 316L, titanium and tungsten ranked among the second best, <100 µm per year. The corrosion rate of aluminum was about 250 µm per year. The materials selected in this study are SS 316L, aluminum, Brass and graphite. Four sets of bipolar plates are made with these four materials and performance analyses are carried out to predict the impact of materials on the general performance of a single cell PEMFC.

The flow channels can be machined with CNC machining or EDM. Here Brass, Al and graphite are machined using CNC machining and with the difficulty involved in machining 1×1mm flow channels in SS plate using CNC machining, EDM is chosen to machine them.

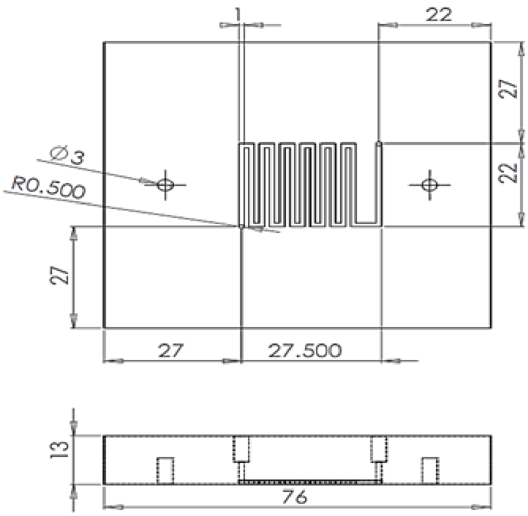

Fig. 1: Detailed drawing of bipolar plate

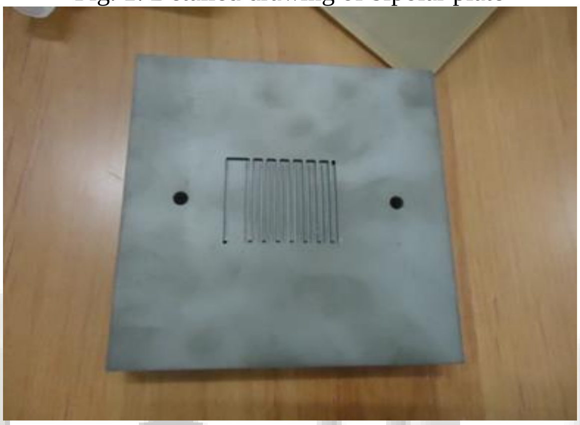

Fig. 2: Graphite bipolar plate

V. EXPERIMENTAL OBSERVATION

Presently available experimental techniques are excellent tools for investigating the transport phenomena in PEMFC. The performance analysis is done using fuel cell test station 850e (fig 3). The test station is run using a pc with fuel cell software installed in it. The experiments were carried out using a single cell PEMFC integrated with the test station. The bipolar plates used are graphite plates (fig 2) with flow channels of 5 cm2 surface area on the anode and cathode side respectively. The operating gases are hydrogen and oxygen supplied to the PEMFC through the test station at a flow rate 0.05 lpm set using the fuel cell software.

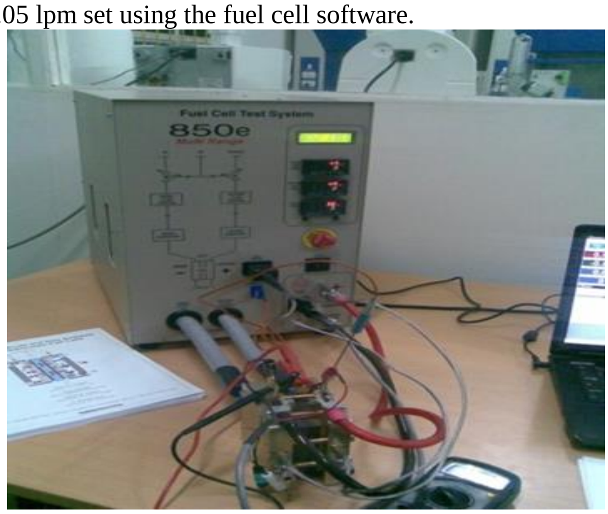

Fig. 3: Test Station 850e

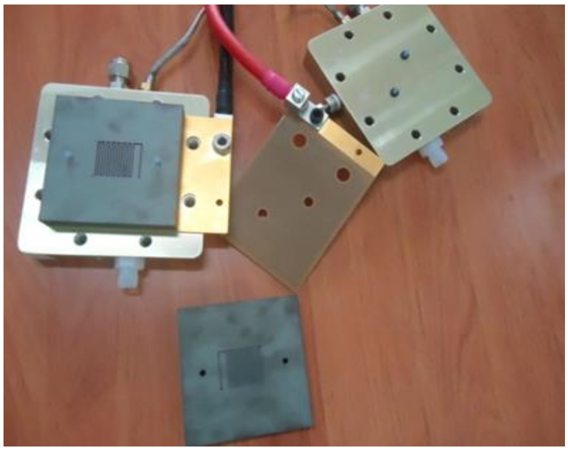

Fig. 4: single cell PEMFC assembly

A. Effect of Humidification Temperature:

Humidification temperature variation studies are carried out on the anode and cathode sides by keeping the cell temperature constant in order to prove the performance drop due to water formation. Initially the hydrogen gas humidification temperature is varied (400C, 500C, 600C, 700C) by keeping the oxygen gas humidification temperature and the cell temperature constant at 500C. The scan current experiment in conducted and the corresponding voltage and power are noted. The graph (graph 1) is plot using the voltage, current density and power density values. The graph shows no significant variation in power density by hydrogen gas humidification temperature variation as the water formation in the cathode side where the temperature is maintained constant. The experiment is repeated by varying the oxygen gas humidification temperature by keeping the oxygen gas humidification temperature and the cell temperature constant and the graph is plot accordingly. The graph (graph 2) clearly shows that with the increase in oxygen gas humidification temperature the performance drops as the excess water vapour present in the gas condenses and forms water.

B. Effect of Cell Temperature:

Further the cell temperature variation studies are carried out on the same PEMFC by keeping the humidification temperatures of inlet hydrogen and oxygen as constant. Here the cell temperature is kept at 300C, 450C, 600C, 800C respectively by keeping the humidification temperatures of oxygen and hydrogen at 500C. The graph (graph 3) clearly shows that the performance increases with increase in cell temperature as the water molecules present in the inlet gases evaporate at higher temperatures.

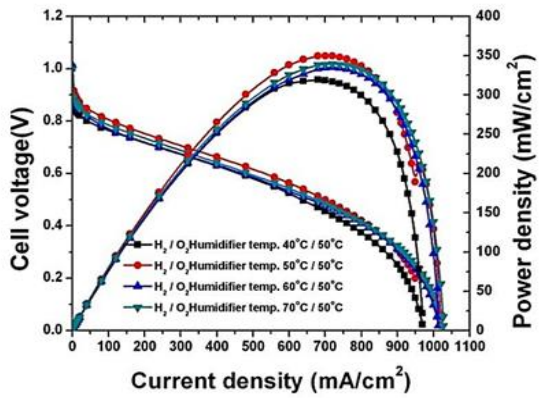

Fig. 5: Graph 1 Humidification temperature variation-anode

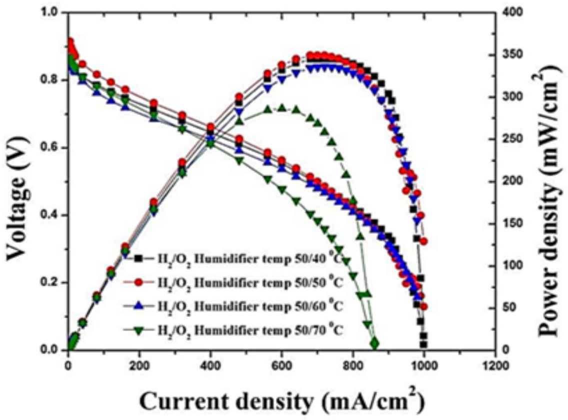

Fig. 6: Graph 2 Humidification temperature variation-cathodes

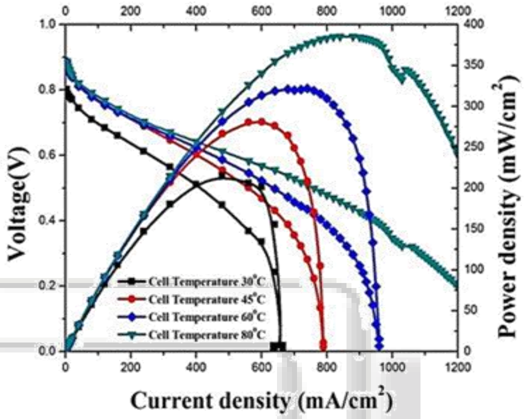

Fig. 7: Graph 3 Cell temperature variations

VI. CONCLUSIONS

Experiments studies on graphite bipolar plate revealed that there is a performance drop due to water formation on the cathode side of PEMFC. Graphite has excellent corrosion resistance when compared to metals but inability to remove water formation on the flow channels results in considerable performance drop when the cell runs for a longer period of time. The results show that the cell performs better with increased temperature. The experiments are to be continued with the metallic bipolar plates and the results are to be compared in order to find the optimum choice of material for bipolar plate.

REFERENCES

[1] Bipolar Plates, A Heinzel, F Mahlendorf, and C Jansen, University of Duisburg–Essen, Duisburg, Germany & 2009 Elsevier B.V.
[2] Materials for Bipolar Plates for Proton-conducting Membrane Fuel Cells Yu. A. Dobrovol'skii A. E. Ukshea, A. V. Levchenkoa,I. V. Arkhangel'skii, S. G. Ionovb, V. V. Avdeevb and S. M. Aldoshina. ISSN 1070-3632, Russian Journal of General Chemistry, 2007.
[3] Shuo-Jen Lee, Ching-Han Huang and Yu-Pang Chen, Investigation of PVD coating on corrosion resistance of metallic bipolar plates in PEM fuel cell, Department of Mechanical Engineering, Yuan Ze University, Chung-Li, Taiwan, ROC.
[4] Sebastian P.J. et al, Development Of PEM Fuel Cell Materials And Components, UNAM, Temixco 62580, Morelos, Mexico, Journal of Power Sources 168 (2007) 418–425.
[5] Lee.H.S.et al, Evaluation of graphite composite bipolar plate for PEM (proton exchange membrane) fuel cell: Electrical, mechanical, and molding properties, Journal of Materials Processing Technology 187–188 (2007) 425–428.
[6] Theodore Besmann. M et al, Carbon/Carbon Composite Bipolar Plate for PEM Fuel Cells, Metals and Ceramics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830-6063, USA Society of Automotive Engineers,
[7] Jenn-Kun Kuo and Shiuh-Ming Chang, Compound material for injection molded PEM fuel cell bipolar plates, ICSET 2008.
[8] Mathur. R.B.et al, Effect of different carbon fillers on the properties of graphite composite bipolar plate, Carbon Technology Unit, Engineering Materials Division, National Physical Laboratory, Dr. K.S. Krishnan Marg, New Delhi 110012, India, journal of materials processing technology 203 (2008) 184–192.
[9] Water transport in polymer electrolyte membrane fuel cells- Kui Jiao, Xianguo Li. Progress in Energy and Combustion Science (2010) 1e71.

