Fuel Cell Stack Prototype Used to Power a LED's System

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ABSTRACT

Petroleum supply will be in increasingly higher demand as heavily populated developing countries expand their economies and become more energy intensive. Air quality and global climate impact are other major concerns with this continuing dependence on fossil energy sources. Widespread use of hydrogen as an energy source in Mexico could help address concerns about energy security, global climate change, and air quality. Fuel cells is an important enabling technology for the hydrogen future and it has the potential to revolutionize the way we power our nation, offering cleaner and more efficient alternatives to supply energy than fossil fuels. In this work, a fuel cell stack prototype was designed and manufactured with three single assemblies to power a LED's system. The combination of anode/membrane/cathode is referred to as the membrane/electrode assembly, MEA. The three MEA's were prepared by placing the gas diffusion electrode (GDE, standard carbon cloth with 0.5 $mg_{Pt}\cdot cm^{-2}$), at both sides of the Nafion 115 membrane, followed by hot-pressing of 10 $kg\cdot cm^{-2}$ at 120 °C for 2 min. The effective area for each single MEA was 28 cm^2 being 84 cm^2 the total anodic and cathodic geometric area. The MEA's were tested with a commercial fuel cell system (Compucell GT, Electrochem) at 25 °C and atmospheric pressure. The performance achieved was a 2.7 V open circuit voltage, achieving a 7.4 W peak power, the optimum performance is at 2 V–2 A. The lamp was integrated by 16 LED's connected in parallel.

Keywords: Prototype, fuel cell stack, LED's system.

1. Introduction

The world now faces tremendous challenges associated with pollution, greenhouse gas emission, climate change and the need for a sustainable development. Providing reliable, environmentally friendly, and affordable energy has been a goal for many countries throughout the world. The rising consumption of energy and falling accessibility of natural resources are increasing the cost of electricity. Therefore, renewable energy has received more attention recently. Solar radiation is considered the most preferred renewable energy source for its availability and inexhaustibility [1]. However, due to the sporadic characteristics of natural resources, it has been a challenge to generate a highly reliable power with photovoltaic (PV) modules [2]. To overcome this limitation, previous studies were conducted using a fuel cell as another energy source and simulated results showed that a PV/fuel cell hybrid power system may be a feasible solution for standalone applications [3-5]. Since a multi-source hybrid power system increases energy availability in a significant way [6-7]. Fuel cells is an important enabling technology for the hydrogen future and it has the potential to revolutionize the way we power our nation, offering cleaner and more efficient energy supply alternatives than fossil fuels.

Production of hydrogen from renewable energy resources has the potential to bring a local energy solution. Water electrolysis is an attractive option to generate renewable hydrogen and oxygen with solar energy without any purification process and is one of the most important energy related electrochemical processes, because water is an inexhaustible natural resource and hydrogen a renewable non-polluted energy source [1-5]. Water electrolysis is a proven method for continuous production of hydrogen by converting electrical into chemical energy. Conversely, a fuel cell is an electrochemical cell which can continuously convert the chemical energy stored in a fuel into electrical energy. The launching of hydrogen and fuel cell technology in the market is now the starting block of renewable energy technology. There are no barriers to the introduction of hydrogen and fuel cells either from a technological perspective or from a safety point. Hydrogen has been produced and utilized in industry for over a hundred years [2], and can be produced by a number of different sources using a variety of techniques. When hydrogen is produced from coal, oil or natural gas, the by-products will be harmful to the environment if they are not handled in an environmentally reliable way. In this work, a stack fuel cell prototype was designed and manufactured with three single assemblies to power a LED's system. The three membrane-electrodes assemblies MEA's were prepared by placing the gas diffusion electrode (GDE, standard carbon cloth with 0.5 mg_{Pt} cm^{-2}), at both sides of the Nafion 115 membrane.

2. Experimental

The objective of the fuel cell stack design was to be simple, self-contained, and to achieve optimal performance with respect to size. The complete system includes the fuel cell stack and the LED's system. However, it is not included in the system design the hydrogen storage device, neither the hydrogen fuel pressure regulator nor the electronics system. A fuel cell consists of several components; these must be machined according to established design. Each

part of the fuel cell is very important and can help to optimize the operating conditions, providing a better performance.

2.1 Bipolar plates

The fuel cell used at the present study was designed and in-home built by our research group. Bipolar plates, BPs, being one of the most important components in PEMFC stacks, must perform a number of functions in order to achieve good stack performance and lifetime. BP 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. 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. The essential requirements for BPs, in respect to physicochemical characteristics, are: a uniform distribution of the reactant gases over the respective active electrode surface to minimize the overpotential concentration; high values of electronic conductivity for current collection; high mechanical strength for stack integrity; impermeability to reactant gases for safe operation; resistance to corrosion in severe cell environment for long lifetime; cheap materials, easy and automated fabrication for low cost. One of the main obstacles to large-scale commercialization of fuel cells is the gas flow fields and BPs, including the development of low-cost lightweight construction materials, optimal design and fabrication methods and their impact on PEMFC performance (i.e., energy efficiency and power density). As much as 50% increase in the output power density has been reported [7] just by appropriate distribution of gas flow fields alone. In spite of all the group efforts, the time-effective design and optimization of the gas flow fields and BPs remain one of the important issues for the cost reduction and performance improvement of PEM fuel cells. As to the geometrical configurations of the gas flow fields, a variety of different designs are known and the conventional designs typically comprise either pin, straight or serpentine designs of flow-field channels [1,7].

In this work, two flow field designs in AUTOCAD were done, horizontally, straight and parallel flow field and transverse, straight and parallel flow field. The flow fields design influences the fuel cell performance and can help to optimize the operating conditions on the reagent area, providing a better distribution of gas over the diffuser and exits the water in a more efficient way. It should be noted that the design of the flow fields is limited to the machinery that is type of specialized tools to work with sufficient accuracy. The current collector plate material was low porosity graphite, in order to avoid mixing of the gases and it is resistant to corrosion, high pressures and moderate temperatures. The machined current collector plates with flow fields was performed on a CNC milling machine CNC EMCO Concept MILL 55 mark, especially for graphite. At this stage monopolar and bipolar plates were fabricated.

2.2. Membrane electrode assemblies

The MEAs have an active area of 28 cm^2 providing a total active area of 84 cm^2 for the entire fuel cell stack. The MEAs were selected based on both the characteristics of performance and simplification of the system design. The electrolyte used was Nafion® N-115 type ionomer membrane. The catalyst loadings on the anode and cathode side were 0.2 mg Pt/cm^2. A carbon cloth type gas diffusion layer was used for both the anode and cathode sides of the MEAs. The MEAs were tested with a commercial fuel cell system (Compucell GT, Electrochem 890B) in a single cell rig with 5 cm^2 active geometrical area. The gas pressures (gp) at the anode and cathode sides were kept at 30 psi for H_2 and 34 psi for O_2, respectively. The fuel cell test station was operated with high purity H_2 and O_2 at 100 cm^3 min^{-1}. The temperature of the humidified reactant gases was kept 5 ºC above the temperature of the cell. The performance was measured under steady-state conditions at 25 ºC and atmospheric pressure.

2.3. Current collectors

The current collectors used are constructed out of 0.36 mm thick plates of high conductivity brass alloy machined with a guillotine. Also included with the current collectors are two tabs per collector, which are used for attaching power leads and voltage sensing leads for testing.

2.4. End plates

The endplates of the fuel cell stack consist of two 1 cm thick aluminum sheets with a 12-hole bolt pattern designed to accept M3 type fasteners. The end plate located on the anode side, or the fuel inlet side, of the stack contains two ports for hose fittings to supply each of the cells with hydrogen. Two ports were included instead of one because it allows the cell to be purged of water and air.

2.5. Gaskets/sealing

Due to the effusion characteristics of hydrogen, a significant amount of study and focus was required for the design of sealing the fuel cell stack. In order to prevent hydrogen from leaking from the gas inlet fittings to the mani-folding in the bipolar plates an “x-ring” was placed between the fittings, through the current collector, and to the first flow channel plate. An x-ring type seal was used as it provides more points of contact than an o-ring giving a better probability of a good seal. In order to prevent hydrogen from leaking from the perimeter of the flow channel plates, two separate gaskets were used. A 0.04 mm was placed around the perimeter of the flow channel plate on the anode side of each cell. A 0.02 mm Teflon gasket was used to provide sealing on the cathode side of the flow plates to prevent hydrogen crossover and to protect the Nafion of the MEAs from damage.

3. Results and discussion

Figure 1 shows the two flow field designs; horizontal, straight and parallel flow field, figure 1(a) is better than transverse, straight and parallel flow field, figure 1(b). Because of the fabricating horizontally channels is easier than transverse and efficiency is nearly the same.

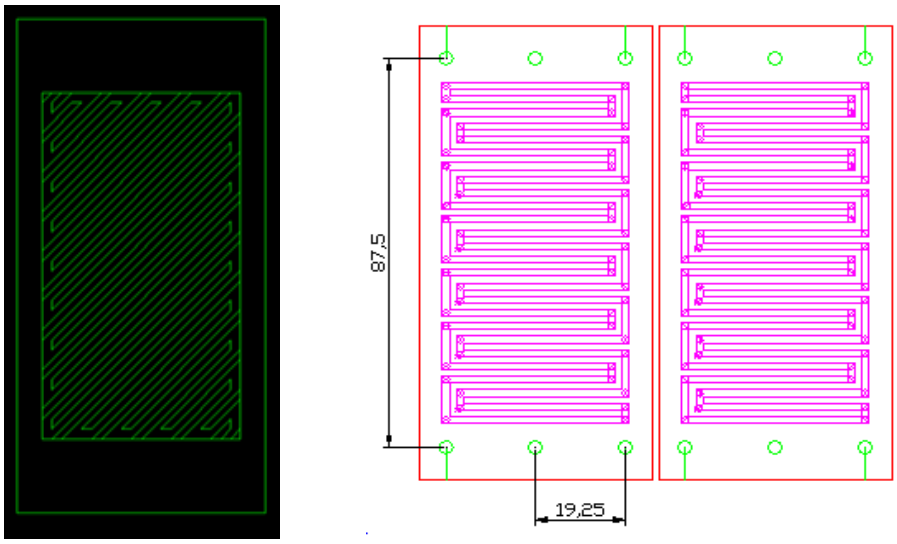

Figure 1 Variation of configuration in straight or parallel flow field design

When the reactant flow channels are formed on the anode and cathode plates, the plates are normally referred to as fluid flow-field mono-polar plates. When the flow channels are formed on both side of the same plate, one side serves as the anode plate and the other side as the cathode plate to the adjacent cell, and the plate is called bipolar (separator) plate.

The primary compartments of the PEM fuel cell have are shown in figure 2. Advantages of fuel cells in comparison with other type of equipments which produce energy are: higher efficiency, no existence of mobile parts and as a result lack of sonic pollution, no emissions of environmental polluting gases such as SOx, NOx, CO2, CO, among others. On the opposite side, the main disadvantage of fuel cells is their high cost, but it is expected that this problem will be solved by applying the new technologies and mass production of these fuel cells.

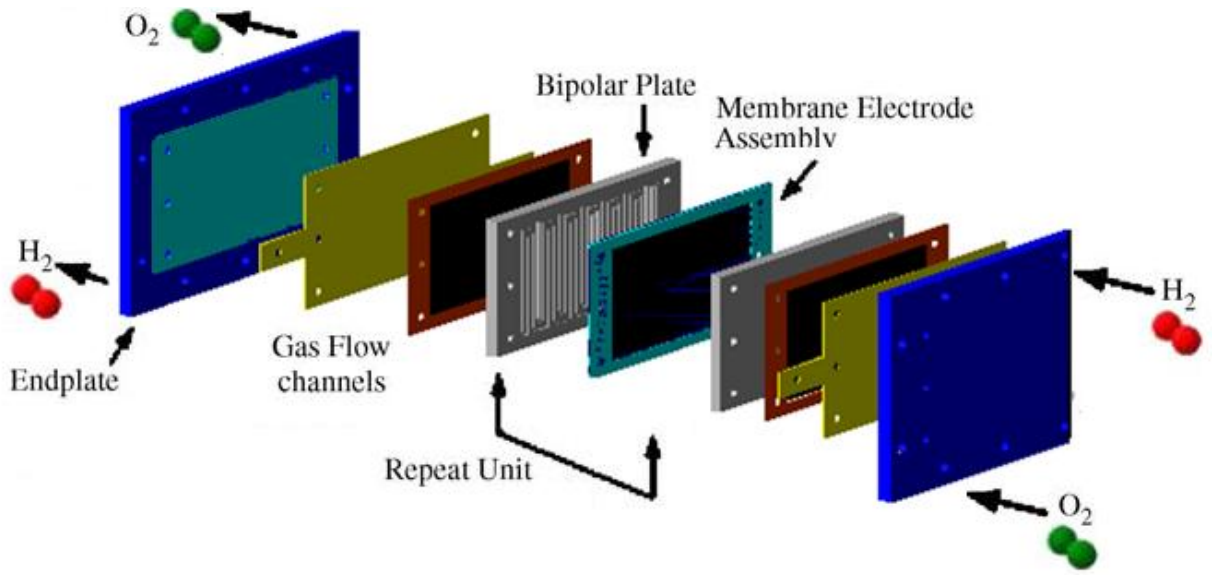

Figure 2. Stack components of fuel cell

The hydrogen feeded fuel cell stack designed in this project contains three individual cells, each having a 28 cm^2 active area. The three cells are stacked in a series configuration with current collectors placed on the anode and cathode sides. An image of the CAD model used for fuel cell stack design is show in figure 3. The components considered in the volume size restriction are the endplates, current collectors, bipolar plates, all sealing materials, and the membrane electrode assemblies (MEA). The components not included in this volume are the fasteners, hose fittings, and the current collector tabs. The dimensions of these components are 114.5 mm x 63 mm x 45 mm when the stack is fully assembled and compressed. Images of the fuel cell stack are shown in figure 4.

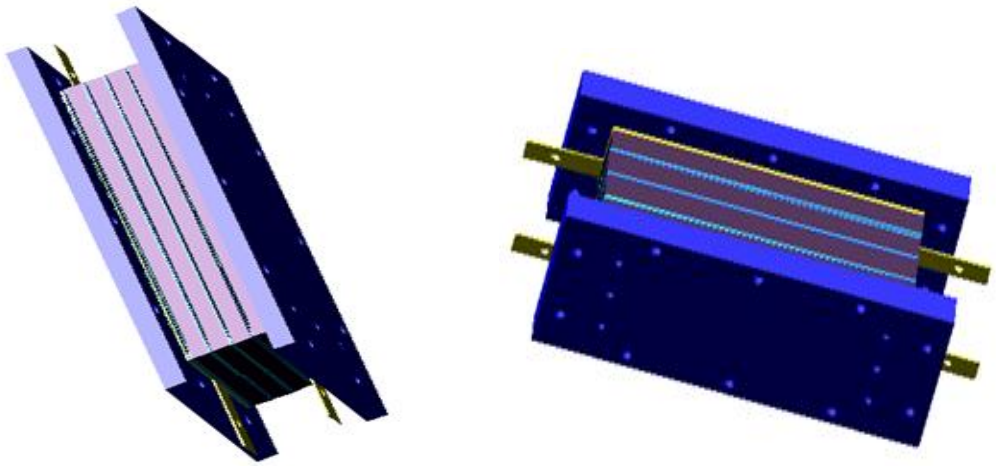

Figure 3. CAD model used for fuel cell stack design.

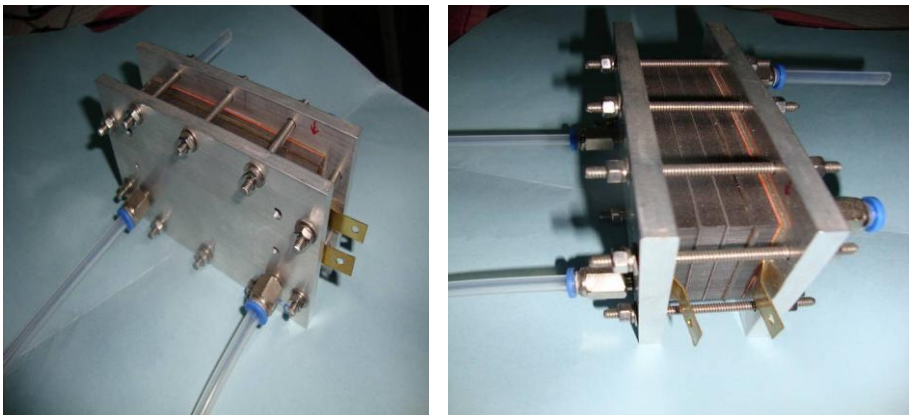

Figure 4. Images of PEM Fuel Cell Stack.

In the fuel cell the chemical energy of the stored in hydrogen is converted to electrical energy. Figure 5 shows the performance (cell voltage-current-power) of the stack containing MEAs with 0.2 mg Pt/cm^2 on anode and cathode catalyst. The fuel cell was tested with a commercial fuel cell system (Compucell GT, Electrochem), without pressure and flow rate of 100 cm^3 min^{-1} of both gases at cell temperature of 25 °C.

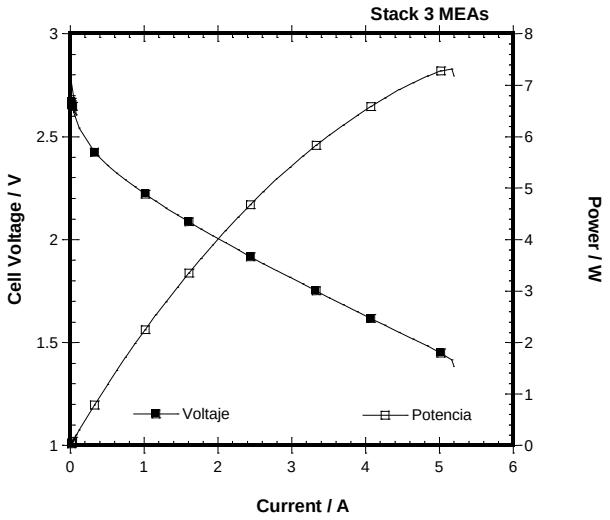

Figure 5. H_2/O_2 fuel cell stack performance curves at 25 °C.

The open-circuit potential is 2.8 V lower than the reversible potential of 3.69 V. This behavior is attributed to the crossover of hydrogen from the anode to the cathode sides and also to a mixed potential that results from the galvanic currents in the oxygen electrode, which is caused by platinum oxidation. At low overvoltage low current arises due to the slow kinetic rate of the oxygen reduction. In the intermediate current the transfer of the conductive

protons from the anode to the cathode is predominant. The global power output under hydrogen and oxygen saturation conditions from figure 6 is 2 A and 4 W evaluated at 2.0 V. Figure 6 shows the picture of the integrated fuel cell connected to the LED's system.

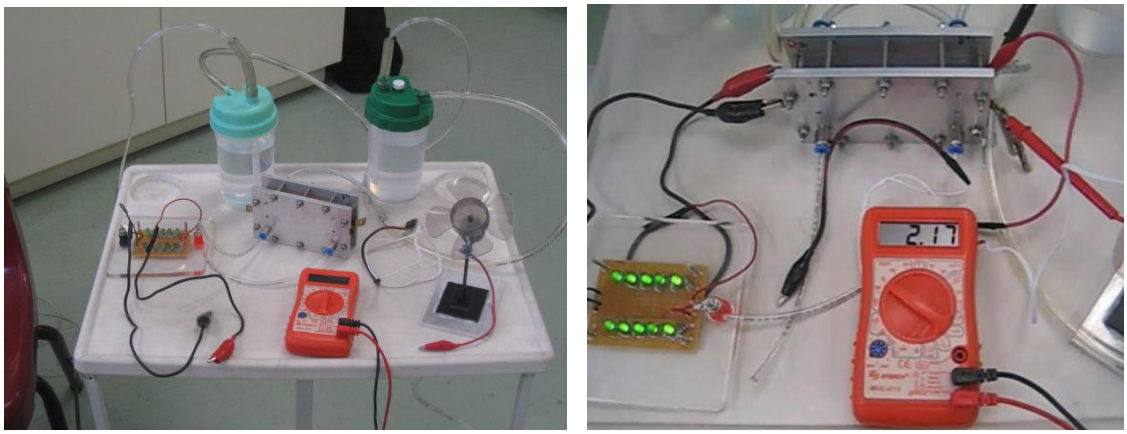

Figure 6. Images of the fuel cell system in operation.

4. Conclusions

A PEM fuel cell system was designed, constructed, and experimentally tested, which has a continuous power output of 4 W and a peak power output of 7 W. This fuel cell was coupled to a LED's systems.

The next stage of this project is to scale up the fuel cell to power a 50 W LED's system. The results of testing and analysis reveal that significant improvements can be made to future designs to greatly improve performance and efficiency. The polarization curve of the fuel cell indicates significant concentration losses at higher power densities which also reduce the efficiency of the fuel cell. The fuel cell is also the greatest contributor to power loss in the entire system. Therefore, the most significant improvements can be made from a more efficient design of the cathode flow channel geometry and the use of a more efficient and a more properly sized cell stack?. Further, a controller power could be used to increase the efficiency of the power electronics. This would reduce the amount of fuel consumed when the fuel cell system is at idle and when operating at low power output.

5. Akcnowledgements

This work was partially supported by the Instituto de Ciencia y Tecnología del Distrito Federal-México (ICYTDF) in the Project "Desarrollo de celdas de combustible tipo PEM para la iluminación de bajo consumo energético" under grant number PIEMP 11-31 and in the Multidisciplinary Project IPN-SIP 1338.

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