Hydrogen Fuel Cell with Stainless Steel Biopolar and Consideration of Copper Effect on the Performance of Biopolar Effect

Arezou. Ghadi, M.B.Limooei, M.Sharifian, Sh.Hoseini, R.Mehravar

***Abstract*—** Recently in our country due to industry growth, reduction of fossil fuels and the growth of pollution and effects of greenhouse gases, the fuel cell can be used as an alternative fuel for internal combustion engines. Because of its minimum noise and pollution, it can increase the power and it is portable easily. Therefore, this technology has been considered in the military and civilian centers. Bipolar plates are one of the most important components of fuel cell and their performance in the cell, have a direct effect on system efficiency and output. This paper investigates the performance of hydrogen fuel cell's steel stack (PEM). In addition, steel bipolar coating with copper and their comparison with each other and their common mode (graphite bipolar) were studied.

***Keywords*—** Bipolar, Coating, Copper and graphite, Fuel cell, Stainless steel.

I. Introduction

THE hydrogen fuel cell has very simple operation. In 1839, William Grovo, English physicist and journalist, with using examination discovered the working principles of fuel cell [1]. In one part, water is electrolyzed to hydrogen and oxygen by passing an electric current. On the other side, the source is replaced with an ampermeter and small current flows. In reality, electrolysis is diverged, hydrogen and oxygen are combined and the electric current is produced. In fact in a fuel cell, hydrogen fuel is burned in a simple reaction. However, instead of released heat energy, electrical energy is produced. Fig 2 shows a view of the fuel cell. The produced currents are very low. The main reasons for the low flow include:

- Little contact between gas, electrode and electrolyte
- Long distances between the electrodes and the electrolyte which resist in front of electric current

To overcome to this problem, flat electrodes with a thin layer of electrolyte were used. Structure of electrodes is porous, so, electrolyte from one side and gas from other side are able to penetrate. Which provide the greatest contact between electrode, electrolyte and gas. However, to see how the reaction between hydrogen and oxygen produces the electricity, we need to evaluate each electrode separately. In anode side of fuel cell, gas is ionized, electrons and H^+ ions or protons are produced.

This reaction produces energy.

In cathode side, oxygen reacts with electrons from electrode and H^+ ions from electrolyte and water is produced.

In anode, hydrogen reactions produce energy. But it does not mean the reaction progression with final rate. Because, reactions have a classic energy. If the molecule does not have enough energy, the reaction is slowly. (Other than high temperatures) for complete reaction, the activation energy is required which is done in three ways.

1. Using a catalyst
2. Increasing the temperature
3. Increasing the electrode surface

The first two items can be used in chemical reactions, but the third one is just for fuel cell and is very important.

The main structures of polymer fuel cells include:

- Electrolyte
- The structure of the electrode and catalyst

a. *Electrolyte and its performance*

Recently, the various polymers are used as polymer electrolyte in the cells. The most common are Flore, solfunate polymers are such as polyethylene and Flore. The most common of these polymers is per floro sulfonic acid polymer membrane (PFSA), which has been found from 60s AD, and development with nafyun brand by Diopunet Company. It is a standard electrolyte and other polymeric electrolytes act like it.

b. *Structure and design of the electrode's membrane*

Membrane electrode includes a membrane with catalyst layer which is spread on the membrane surface. In some cases, the gas diffusion layer (GDL) is added to this category.

Catalytic layers in two sides of membrane where the electrochemical reaction such as oxidation of hydrogen, proton (H^+ ions) production and oxygen restoring is done are called anode and cathode electrodes, respectively. Membrane

Arezou. Ghadi Department of Chemical Engineering, Islamic Azad University of Ayatolla Amoli Branch (corresponding author to provide phone: +98 1212517000 ; fax: +98 1212517043; e-mail: arezooghadi@yahoo.com).
M.B. limooei, Department of Chemical Engineering, Islamic Azad University of Ayatolla Amoli Branch (e-mail: m.b.limooei@iauamol.ac.ir).
M.Sharifian, Department of Chemical Engineering, Iran University of Science and Technology, Tehran, Iran.
Sh.Hoseini, Department of Chemical Engineering, Iran University of Science and Technology, Tehran, Iran.
R.Mehravar, Department of Chemical Engineering, Iran University of Science and Technology, Tehran, Iran.

performance in polymeric fuel cell is H^+ ion transportation from anode electrode to cathode electrode and separation of oxidation and reduction reactions.

II. BIOPOLAR PLATES AND THEIR DUTIES

Review Stage Bipolar plates are one of the most important components of fuel cell and their functions in the cell, have a direct effect on the system's efficiency and output. In summary, the main functions of bipolar plates are as follows:

• Uniform distribution of fuel and oxygen inside the cell
• facilitate of water management within the cell
• Conduction of generated electrical currents inside the cell
• Transfer of generated heat inside the cell to environment and in overall the cell's heat management
• Separation of oxygen and fuel inside the cell
• Connection of single cells in order to achieve higher voltage
• Creation of pass for oxygen, fuel and cooling fluid

There are grooves on the surface of bipolar plates which can be caused to the fuel (hydrogen) and oxygen flow within them (Fig. 1). In this way, gas flows on the membrane surface uniformly. Provided grooves on the bipolar plates should distribute hydrogen and oxygen uniformly with suitable concentration and pressure on all active parts of membrane.

Fig .1 Spiral and Parallel Channels (Bipolar Stainless Steel)

Non-uniform pressure distribution on the membrane causes an imbalanced water and local heat production and increases the excess water and decreases the efficiency in a fuel cell. Connection of single cells is another duty of bipolar plates. Maximum expected theoretical voltage of a single polymer fuel cell is 1.23 V. Because of different reduction in the ohmic, activation, and concentration, this amount in the normal functional condition and average current density (0.5 1A/cm^2) reaches to 0.5 V [17]. This voltage is not sufficient for starting of electrical appliances and cars and etc., therefore, to increase the voltage, series connection of single cells are needed. The number of connected cells is dependent to needed voltage. Cells connect to each other by bipolar plates. For this purpose, there are grooves in two sides of the plates. In one side, oxygen and in the other side hydrogen flows.

In fact, one side of this page is the anode for one cell and the other side is the cathode for other cell. The combination continues until to reach the end of plates in two sides of the fuel cell.

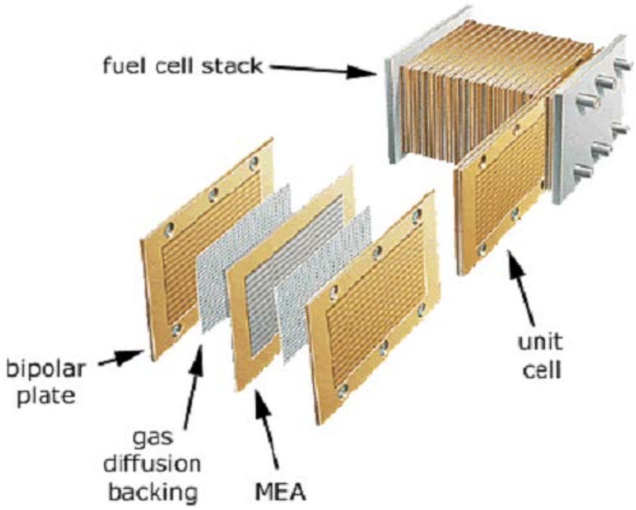

Fig. 2 Cell Mass (Stack)

electrical conductivity is the other functions of bipolar plates. Such as series connections of batteries, electrical current in cells are connected in series to each other. So, produced current in a cell, is transferred too adjacent cell by these plates. At the end of the cell, the current is transferred to the copper plates by two terminal plates. Therefore, bipolar plates should be selected from very low electrical resistance materials. Because high voltage drop will occur so, a lot of heat is produced inside the cell [8].

Water management is another function of bipolar plates. As we know, water is the product of polymeric cell's inside reactions that because of low functional temperature of this cell (around 70 ^{0}c), produced water is usually in liquid form. So, if the water is not sent to out of the cell, effectively leads to flooding phenomenon (especially at the cathode side) and come cell efficiency will be reduced.

a. Bipolar plates' material

The main criteria for selecting material for bipolar plates include:

Easy and inexpensive way to build
Low electrical resistance
High thermal conductivity
Adequate resistance against corrosion and performance of the cell
Low Price
Low density
High mechanical strength

The material that is used for bipolar must provide the following conditions:

Its electrical conductivity should be larger than 10Scm^{-1}.

If cooling fluid is used for wasting of produced heat in the cell, thermal conductivity should be larger than $20WCm^{-1}k^{-1}$, and if the heat is transferred to the air only by the edges of bipolar plates, thermal conductivity should be larger than $100Wm^{-1}k^{-1}$.

The gases permeability should be less than 10^{-7} mbar $LS^{-1}cm^{-1}$.

Material must have sufficiently high mechanical resistance and its bending strength should be greater than 25Mpa.

It should have high corrosion resistance against acid, oxygen, temperature and humidity.

Historically, machined graphite is a material that provide above conditions and physical requirements but other materials are being developed for use in this field. These materials are metal (steel, aluminum and other alloys) and graphite (composite, foil), which are briefly reviewed in this section [7].

b. Graphite

Graphite has good electrical conductivity and its corrosion resistance is the best. Graphite's density is little ($2g/cm^3$) and its mechanical strength is low [14]. It limits bipolar plates' thickness to a minimum of 6-5 mm. Thus, making the gas flow channels on graphite bipolar plates is only limited to machining. Making channels with a complex design on these pages by using the machining process is expensive and time consuming and it is not suitable for high production of fuel cells. However, the graphite as the basis for the development and performance comparison to other materials is considered.

c. Stainless Steel

Stainless steel is a cheap alloy with relatively low electrical conductivity, acceptable volumetric heat (70-80 ΩCm and 16 WCm^{-1}), the least permeability and good mechanical properties [12]. Due to the high density of these metals using of their thin sheet is possible.

So, production of cells with high potential to volume ratio is possible. Due to chemical instability and formation of oxides at the cell's surface, uncoated steel is considered less.

Steel is protected against corrosion by formation of a passive layer of oxide such as Cr_2O_3 on the metal surface.

In this part we succeeded to coat of copper on the steel. The coating process was carried out with spray coating method. The coating has been done because of unique characteristics of copper that can help to increase the cell's efficiency. Spray coating, is a coating method in nanotechnology range.

III. EXPERIMENTS

In this part, bipolar was provided from different metal such as uncoated stainless steel 316 and coated stainless steel with copper and graphite. These bipolars' dimensions are 11 × 10 × 8 cm. Active page is membrane (5 × 5), so, channeling was done on the middle (5 × 5) of bipolar plates with the thickness and depth of 1 mm.

Channels in anode (hydrogen) were selected as spiral and as can be seen in Fig 3, entrance hydrogen must pass along all channels to reach the exit. Because of this, spiral channeling selected in anode side. So, with respect to the relatively long pass of hydrogen, resistant time of this gas in contact with the catalyst increases and the more reactions are performed on active surface of catalyst and finally increases the efficiency.

Canalling in cathode side (oxygen) was done in parallel (Fig 3). The reason is proper conduction of produced water and permanent presence of oxygen in membrane. Single cells were fabricated in the same conditions, there is the same type of membrane and on the equal and separate terms were tested inside a fabricated box.

Copper plates are placed in behind the bipolar to gather the current. To prepare compressed hydrogen a 50-liter capsule is used. For providing of oxygen, air is used that is guided by an air pump to inside the stacks. It is worth noting that to achieve the maximum power in each cell, input feed before entering the cell are heated and humidified to enter the cell in its performing temperatures.

Fig. 3 parallel and spiral graphite channels.

As noted above, testing was done separately and was continued until the produced voltage reaches to a steady state condition.

IV. RESULTS

TABLE I
COMPARISION OF BIOPOLARS PERFORMANCE

Time (hr)	Stable power (w)	Maximum power (w)	Efficiency %	Weight (gr)	Biopolar
24	4.2	4.5	42	620	Stainless Steel
20	3.9	4	39	300	Graphite
23	4.4	4.8	44	620	Covered Steel

It should be note that the open circuit voltage obtained in the case that the output of anode and cathode connected to the voltmeter without any current. This voltage is approximately 1 volt, and in practice is not very reliable. For current giving from circuit, we should connect it to the resistance. It should be noted that the efficiency of these cells is about 50 percent. Using polarization curves to show the efficiency and voltage at different amperes is useful.

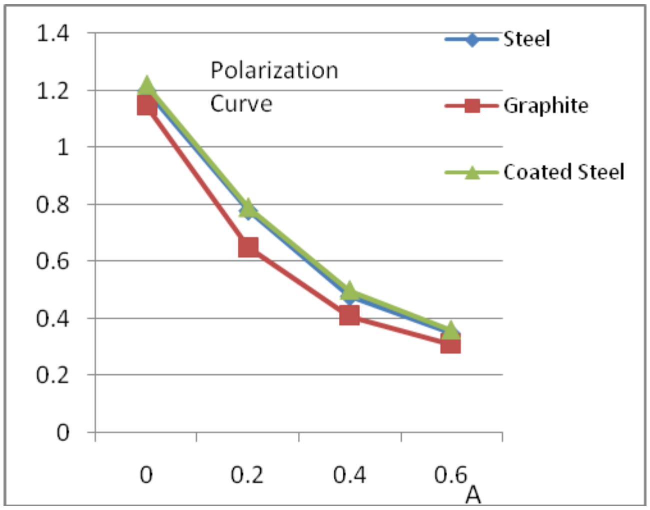

Fig. 4 polarization curve as a criterion to show cells' function

V. DISCUSSION AND CONCLUSION

a. *BIPOLAR STAINLESS STEEL*

This bipolar has high strength. With respect to its strength, making it is difficult. It has highest efficiency and power among bipolars but the time to reach to steady state is relatively high. Moreover, this metal can be used as a stack instead of flex glass.

b. Coated bipolar steel

Physical properties of this bipolar are similar to steel. However, the efficiency and the maximum power are improved. Moreover, covering in Iran is relatively expensive.

c. Graphite bipolar

It is the most widely used type bipolar in the world because of its good performance, easy making, and good electrical conductivity. Its total price is relatively high but it has an acceptable efficiency and power production.

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