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Construction of Water Electrolyzer for Single Slice O_2/H_2 Polymer Electrolyte Membrane Fuel Cell

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Abstract**—** In the first part of the research work, an electrolyzer (10.16 cm dia and 24.13 cm height) to produce hydrogen and oxygen was constructed for single slice O_2/H_2 fuel cell using cation exchange membrane. The electrolyzer performance was tested with 23% NaOH, 30% NaOH, 30% KOH and 35% KOH electrolyte solution with current input 4 amp and 2.84 V from the rectifier. Rates of volume of hydrogen produced were 0.159 cm^3/sec, 0.155 cm^3/sec, 0.169 cm^3/sec and 0.163 cm^3/sec respectively from 23% NaOH, 30% NaOH, 30% KOH and 35% KOH solution. Rates of volume of oxygen produced were 0.212 cm^3/sec, 0.201 cm^3/sec, 0.227 cm^3/sec and 0.219 cm^3/sec respectively from 23% NaOH, 30% NaOH, 30% KOH and 35% KOH solution (1.5 L). In spite of being tested the increased concentration of electrolyte solution, the gas rate does not change significantly. Therefore, inexpensive 23% NaOH electrolyte solution was chosen to use as the electrolyte in the electrolyzer. In the second part of the research work, graphite serpentine flow plates, fiberglass end plates, stainless steel screen electrodes, silicone rubbers were made to assemble the single slice O_2/H_2 polymer electrolyte membrane fuel cell (PEMFC).

Keywords**—** electrolyzer, electrolyte solution, fuel cell, rectifier

I. INTRODUCTION

A fuel cell is an electrochemical device that continuously converts the chemical energy into electric energy (and some heat) for as long as fuel and oxidant are supplied. In principle, a fuel cell operates like a battery. Unlike a battery, however, a fuel cell does not run down or require recharging, it operates quietly and efficiently, and when hydrogen is used as fuel, it generates only power and drinking water. Thus it is a so called zero emission engine [1].

The six basic types of fuel cell are classified by the electrolyte that they employ. Low temperature types include the alkaline fuel cell (AFC), direct methanol fuel cell (DMFC) and proton exchange membrane fuel cell (PEMFC). The three high temperature types are phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC) [1].

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The most representative kinds of fuel cells are the proton exchange membrane fuel cell (PEMFC) and the direct methanol fuel cell (DMFC), which use proton conducting membranes [2]. A fuel cell consists of a central voltage layer, sandwich between two catalyst layers. Various materials for these layers are used, but the basic process is the same. When a hydrogen atom contacts the negative anode catalyst layer, it splits into a proton and an electron. The proton passes straight through the central electrolyte layer, while the electron produces electricity as it passes through an external circuit. The circuit returns the electrons to the positive side of the electrolyte layer, where they bond again with the protons and join with an oxygen molecule, creating water in the positive cathode layer [3].

PEMFCs are also being developed for stationary applications. In the 250-kW range, *Ballard Generation System* is currently the only PEMFC-based developer. Most recently, the micro-CHP range has been claimed by a wide range of developers. Here, high power density not the most crucial issue. The overall goal is the most economic use of the fuel employed, usually natural gas, in order to generate electric power and heat [1].

II. MATERIALS AND METHODS

The electrolyzer was constructed with polyvinyl chloride (PVC) and the two electrodes were made up of stainless steel screen strips.

<u>Design Consideration of Water Electrolyzer</u>

First, the volume of electrolyzer was calculated based on 10.16 cm dia and 24.13 cm height of electrolyzer. So, the calculated volume of electrolyzer is 1.96L. Then the minimum required volume of electrolyte solution in the electrolyzer was considered. The level of electrolyte solution in the electrolyzer should be put between the range of 1.24L and 1.96L.

The volumetric flow rate of hydrogen produced from the electrolyzer was considered based on 150 mA/cm^2 of current density required for 27.82 cm^2 surface area of electrode. According to the calculation, the volumetric flow rate of hydrogen produced from the electrolyzer is 1.74 L/hr.

<u>Performance Test of the Electrolyzer</u>

Each of two 100 mesh stainless steel strips (14.605 cm × 1.905 cm) was used as electrodes and fit in the electrolyzer. Battery separator sheet was inserted between the two electrodes to insulate one electrode from the other. The electrolyzer was filled with 1.5 L of 23% NaOH solution. It is important that the water-electrolyte level was not to be fallen below the length of inside gas collection tube. Then the top cap with two gas collection tube (dia = 3.81 cm and length = 8.89 cm) was used to lid the electrolyzer filled with electrolyte solution. The volume of hydrogen and oxygen gas evolved from the electrolyzer was measured with time by using rectifier (4 amp and 2.84 V). Experiments were also conducted with 30% NaOH, 30% KOH, 35% KOH solution. An electrolyzer unit in operating condition is shown in Fig. 1.

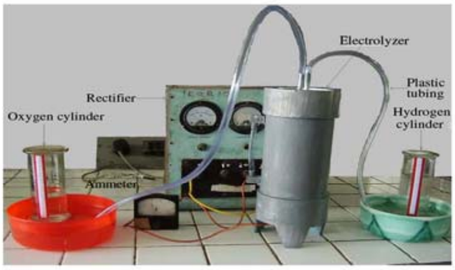


Fig. 1 An Electrolyzer Unit in Operating Condition

Required Membrane for Fuel Cell Applications

The proton conducting polymeric membrane (the ionomeric membrane) is the most distinctive element of the polymer electrolyte membrane fuel cell. In an ion exchange fuel cell, the membrane acts not only as an electrolyte but also as a physical barrier between the fuel and oxidant.

In this study, the required membrane was obtained from Nilar Win ,2006 [4] in which the membranes were made from commercial polystyrene. In the first method, the raw polystyrene beads were soaked in acetone and then sulfonated at 105±5°C with different time. In the second method, the raw polystyrene beads were soaked in methyl ethyl ketone and then sulfonated at 90±2°C with different time.

Preparation of Required Parts to Assemble Single Slice O_2/H_2 PEMFC

PEMFC consists of the MEA (membrane electrode assembly), graphite plates that serve as both electrodes flow field plates, electrode conductors, rubber gaskets, end plates and barbed hose connectors to accept tubing for gas flow, a few screws to hold it together and binding posts for electrical connections.

The main component of the fuel cell is the MEA which is sandwiched between the two graphite plates that act as electrodes and gas flow fields. The MEA is composed of a proton exchange membrane with a carbon paper diffuser loaded with platinum catalyst on either side.

(1) Design Consideration of Single Slice O_2/H_2 PEMFC

All fuel cells use hydrogen as a fuel and oxygen as an oxidant. The electrolyzer has been constructed to obtain hydrogen and oxygen gas required for single slice O_2/H_2 PEMFC. Volumetric flow rate of hydrogen and oxygen gas evolved from this electrolyzer using 23% NaOH electrolyte solution were 0.159 cm^3/sec and 0.212 cm^3/sec respectively.

According to continuity equation, the cross sectional area of gas flow line for hydrogen side is 0.136 cm^2. The cross sectional area of gas flow line for oxygen side is the same as that of hydrogen side. Therefore, inside diameter of gas port is 0.366 cm and depth is 0.24 cm.

(2) Preparation of Graphite Plates

Two graphite plates were prepared to flow oxygen gas and hydrogen gas. Each graphite flow field-conductor plate was slabbed into 0.476 cm thick. The slabbed plates were cut to the size of 8.57 cm×6.03 cm. Both sides of the plate surfaces were made to be smoothened with sandpaper.

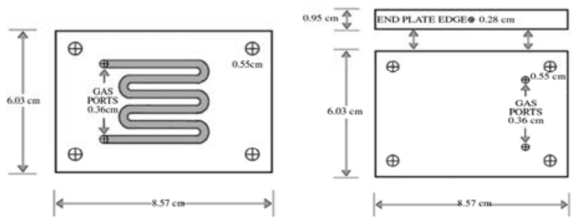
It is now ready to drill the holes and to rout the flow fields into the graphite plates. To drill the four fastener holes at the corner of the graphite plates, the 0.55 cm drill bit was used. The grooves were cut onto the graphite plates with the help of CNC machine as shown in Fig. 2(a). Each graphite plate consists of six horizontal grooves that are 0.32 cm wide, 0.24 cm depth and spaced about 0.32 cm from each other. The six parallel horizontal grooves were connected with the curves to complete the serpentine flow fields.

(3) Preparation of Fiberglass End Plates, Silicone Rubbers and Electrodes

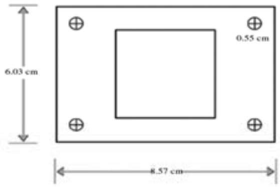
The two end plates were cut from a piece of 0.95 cm thick fiberglass sheet by means of CNC machine. Each fiberglass end plate was cut into 8.57 cm in length and 6.03 cm in width. At the corner of each fiberglass end plate the four holes (0.55 cm diameter) were drilled. The 0.28 cm holes for the binding post screw into the top sides of the each end plate were drilled. Then the 0.36 cm gas port holes were drilled on the edge of each end plate. The fiberglass end plate for hydrogen side and oxygen side is shown in Fig. 2 (b).

The 0.05 cm thick silicone rubber was used for gasket and spacer material. The silicone rubber sheet was cut by using a knife and scissors. It was use to make holes for the appropriate fastener holes and gas hole with a 0.55 cm punch. The silicone rubber for gasket is shown in Fig. 2 (c) and the silicone rubber for spacer material is shown in Fig. 2 (d).

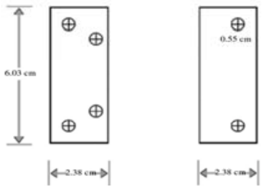
100 mesh stainless steel screen was used as the electrodes. It was cut into two pieces of 3.49 cm and 6.98 cm and drilled the holes (0.28 cm in diameter). The electrode piece was sandwiched between two stiff pieces of aluminum and then lined up the bend line on the edge of the sandwich. It was clamped with C clamps and bent the 90˚ angle. The dimension for electrode is shown in Fig. 2 (e).



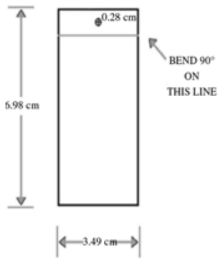
(a) Graphite Serpentine Flow Plate (b) Fiberglass End Plate



(c) Silicone Rubber for Gasket



(d) Silicone Rubber for Spacer Material



(e) Stainless Steel Screen Electrode

Fig. 2 Required Parts for Single Slice O_2/H_2 PEMFC

III. Results and Discussions

Results and Discussions on the Performance Test of the Electrolyzer

The volumetric flow rate of hydrogen gas evolved from the electrolyzer using 23% NaOH, 30% NaOH, 30% KOH and 35% KOH solution is shown in Figure 3. The volumetric flow rate of oxygen gas evolved from the electrolyzer using 23% NaOH, 30% NaOH, 30% KOH and 35% KOH solution is shown in Fig. 4.

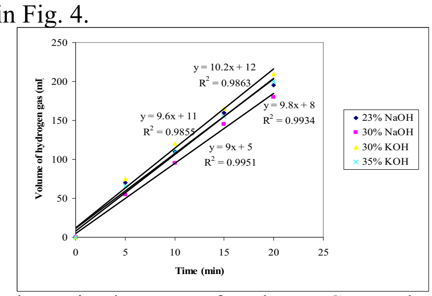


Fig. 3 Volumetric Flow Rate of Hydrogen Gas Evolved from the Electrolyzer

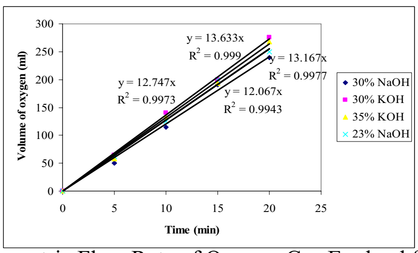


Fig. 4 Volumetric Flow Rate of Oxygen Gas Evolved from the Electrolyzer

The performance of constructed electrolyzer was tested with 23 % NaOH, 30% NaOH, 30 % KOH and 35% KOH electrolyte solution with current input 4 amp and 2.84 V from the rectifier. The volumetric flow rate of hydrogen gas evolved was 0.159 cm^3/sec, 0.155 cm^3/sec, 0.169 cm^3/sec and 0.163 cm^3/sec respectively from 23% NaOH, 30% NaOH, 30% KOH and 35% KOH solution. The volumetric flow rate of oxygen gas produced was 0.212 cm^3/sec, 0.201 cm^3/sec, 0.227 cm^3/sec and 0.219 cm^3/sec respectively from 23% NaOH, 30% NaOH, 30% KOH and 35% KOH solution (1.5 L). In spite of being tested the increased concentration of electrolyte solution, the gas rate does not change significantly. Although more gas production rate was obtained with 30 % KOH electrolyte solution, inexpensive 23% NaOH solution was chosen to use as the electrolyte in the electrolyzer.

IV. Conclusion

To construct the water electrolyzer the volume of electrolyzer, the amount of electrolyte solution required to use in electrolyzer and production rate of hydrogen were calculated. The volume of electrolyzer was 1.96 L. The level of electrolyte solution in the electrolyzer must be put between the range of 1.24 L and 1.96 L. The performance of constructed electrolyzer was tested by varying the concentration of NaOH and KOH solution. Although 30% KOH electrolyte solution gives the best result to obtain higher gas production rate among 23% NaOH, 30% NaOH and 35% KOH, the inexpensive 23% NaOH electrolyte solution was chosen to use as the electrolyte in the electrolyzer. The constructed water electrolyzer was capable of producing hydrogen and oxygen to apply in the single slice O_2/H_2 polymer electrolyte membrane fuel cell. To build a single slice O_2/H_2 polymer electrolyte membrane fuel cell, graphite plates, fiberglass end plates, electrodes and membranes were made. The ion exchange membrane required to make an MEA (membrane electrode assembly) was prepared according to Nilar Win 2006 [4].

Acknowledgment

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