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Performance effects of proton exchange membrane fuel cell at various operating temperatures

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Performance effects of proton exchange membrane fuel cell (PEMFC) at various temperatures of the gases feeding the electrodes were investigated. Experiments have been carried out on two different homemade PEMFCs with hydrogen/oxygen and hydrogen/air feed. On each PEMFC with different feed that have an active area of 9 cm^2 Nafion™ NE-1035 as proton exchange membrane (PEM) and electrodes with platinum load of 0.9 mg/cm^2 were used. Temperature of humidified gases in 1 atm pressure that feed the PEMFCs kept at ambient temperature (25^oC) varies from ambient temperature to 95 ^oC by 10 ^oC step. During the experiment backpressures of each type of the PEMFCs held constant at 1 atm and the external load resistance (R_L) varies from 0 to 1000 KΩ. In high temperatures the diffusivity of gases increase and mass transport resistance decrease. However, the ion-conductivity of the PEM in ohmic region increases. As a result it was concluded that performance of the PEMFCs depends on the concentration of gases and on the discharge of water (H_2O) content formed by electro-chemical reactions.

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Keywords: Proton exchange membrane fuel cell, Operating condition, Performance, Polarization characteristic

1. Introduction

The energy systems of our world obtain their energy requirements mostly from fuel sources of fossil origin. Since these fuel sources of fossil origin have negative environmental effects and are depletable, studies directed to the utility and production of clean and renewable energy resources that can be substituted for fossil originated fuels and development of different energy systems are being demonstrated for a couple of decades [1]. PEMFCs, which are low temperature fuel cells, are electro-chemical devices that can convert chemical energy into electrical energy by a chain of reactions [2,3]. The usage of PEMFC as an energy converter system in fixed and mobile applications has attracted attention as reported in many papers [3,4-8]. In a PEMFC, when anode is fed with hydrogen gas (H_2), H_2 gas is separated into protons and electrons with the help of the platinum (Pt) load that serves the purpose of a catalyst found on the surface of the gas diffusion layer (GDL). When protons proceed to the cathode through the PEM used as an electrolyte, electrons reach the cathode over an external circuit. With the feeding of the cathode by oxygen gas (O_2), O_2 combine with the protons passing through PEM and electrons passing over the external circuit to produce water molecules [1]. The reactions in the anode and cathode are $H_2 \rightarrow 2H^+ + 2e^-$ and $2H^+ + 2e^- + (1\ 2)O_2 \rightarrow H_2O$, respectively. In this case, the total reaction is given with the equation of $H_2 + (1/2)O_2 \rightarrow H_2O + electricity$.

The voltage difference between the electrodes and the current passing over the external circuit depends on the speed of the electro-chemical reaction formed at the electrodes, and on the load resistance (R_L) between the electrodes. Polarization curve can be obtained with the measurements taken when external R_L is kept wide [9]. A typical polarization curve shown in Fig. 1 can be useful in the explanation of physical and chemical relationships, the subject of operating principle of PEMFC. All regions are related to electro-chemical reactions [9,10].

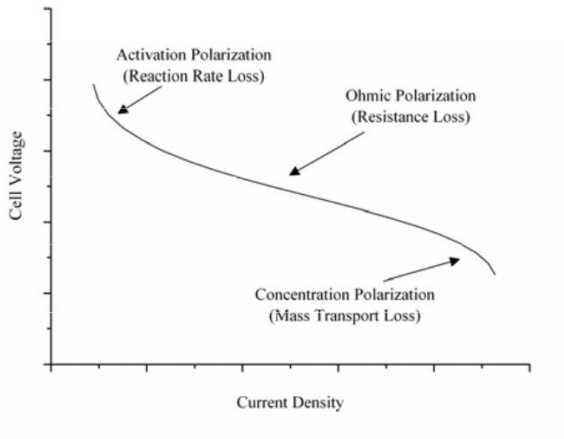


Fig. 1. Polarization curve of a typical PEMFC

In this paper, performance effects of PEMFC at various temperatures of the gases feeding the electrodes were investigated. Experiments have been carried out on two different homemade PEMFCs with H_2/O_2 and H_2/air feed. Temperature of humidified gases in 1 atm pressure that feed the PEMFCs kept at ambient temperature (25^oC) varies from ambient temperature to 95^oC by 10^oC step. During the experiment backpressure of the PEMFCs held constant at 1 atm and R_L varies from 0 to 1000 KΩ.

2. Experimental

PEMFCs consist of five main parts such as membrane-electrode assembly (MEA) in which electro-chemical reactions occur, plates in which gas flow channels are present, current collectors in which socket slots are placed, gaskets to avoid gas leakages, and holders that keep together with screws and nuts. Figs. 2 and 3 show the schematic drawings of two PEMFCs that have been produced by us; and have H_2/O_2 and H_2/air feeding, respectively [20]. For the establishment of MEA, PEM provided by DuPont Inc., having 0.09mm thickness and 16cm^2 Nafion NE-1035 type, CC-S type carbon cloth having 0.38mm thickness, 9cm^2 active surface area provided by Fuel Cell Scientific, LLC used as electrode and GDL, and perfluorosulphonic acid Nafion™ 5% w/w solution provided by DuPont Inc. were used.

PEM has been purified from surface contamination, organic contamination and metal ion contamination [11-13]. One surface of CC-S type electrodes that were used as electrode and GDL are loaded with 0.9mg/cm^2-Pt. The catalyzing solution used in the loading of Pt was prepared with brush method [14-18]. Pt-loaded GDLs are placed onto the surface of PEM, and MEA was formed by keeping them under 1000 kgf/cm^2 pressure at 130^{0}C for 2 min [2,4,15].

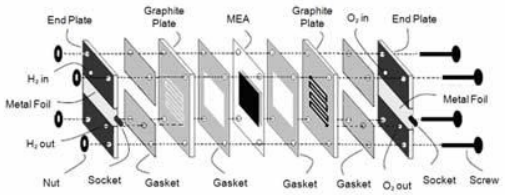


Fig. 2. PEMFC with H_2/O_2 feeding.

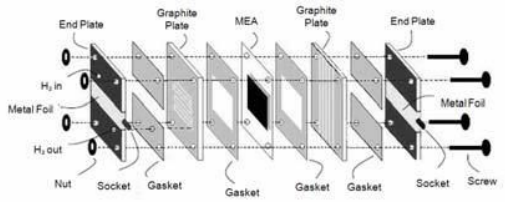


Fig. 3. PEMFC with H_2/air feeding.

Operation of produced PEMFCs is possible with the feeding of gas inlet/outlet channels with H_2/O_2 or H_2/air gases. Schematic drawing of operated PEMFC with H_2/O_2 and H_2/air feeding are shown in Figs. 4 and 5, respectively. As it can be seen in Figs. 4 and 5, either fuel or oxidizer is passed through a bubbler unit before being fed into PEMFC. The purpose of this bubbler unit is to humidify the feed gases [11,12,19,20]. As a result of humidify the conductivity feature of the PEM, and the osmosis of H_2O which can be occurred on the cathode will be prevented. Feeding gasses was heated by a water bath that heats the bubbler unit.

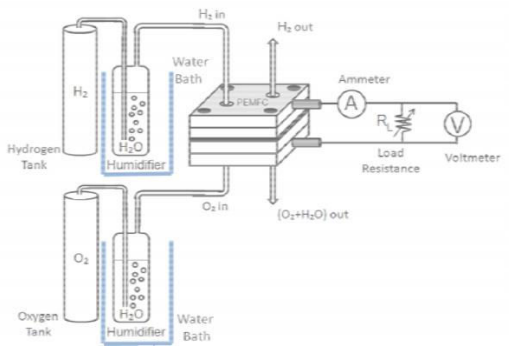


Fig. 4. Schematic drawing of operated PEMFC: (a) with H_2/O_2 feeding and (b) with H_2/air feeding.

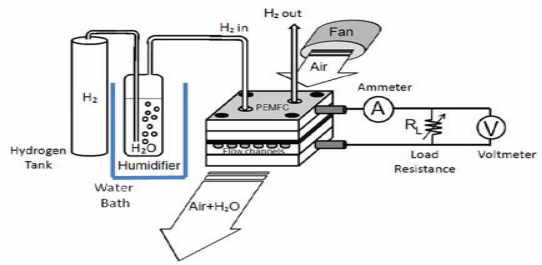


Fig. 5. Schematic drawing of operated PEMFC: (a) with H_2/O_2 feeding and (b) with H_2/air feeding.

3. Results

Three sets of experiment were carried out to investigate the effects of temperature on PEMFCs performance. First set of the experiment consisted of changing the feeding gases temperature from ambient temperature to 95^{o}C by 10^{o}C step. Second set of the experiment consisted of changing the fuel gas temperature from ambient temperature to 95^{o}C by 10^{o}C step. The temperature of the oxidant gas kept constant at 25^{o}C. Last set of the experiment consisted of changing the oxidant gas temperature from ambient temperature to 95^{o}C by 10^{o}C step. The temperature of the fuel gas kept at 25^{o}C. In all three set the temperature of the PEMFCs kept constant at ambient temperature. During the experiments, backpressures of inlet/outlet sides on both types of the PEMFCs were 1 atm. The polarization curves of each set of experiments are given in Figs. 6, 7, 8, 9, 10 and 11, respectively.

4. Discussion

Fig. 6 shows that the performance of PEMFC with H_2/O_2 feeding increases with the increases of the feeding gases from ambient temperature to 95^{o}C by 10^{o}C step. These curves indicate that performance was improved with the increase of the temperature from 25^{o}C to 85^{o}C, and

begin to decrease at 95 ^{o}C. The increase of the performance between 25 ^{o}C and 85 ^{o}C can be explained by the membrane conductivity and gas diffusivity at high temperatures. As the temperature increases, greater reaction rate of water form occurs. After a critical temperature (85^{o}C) the amount of produced water, decreases the active reaction area on the cathode side, so that the electro-chemical reaction rate decreases. Furthermore the resistance of the membrane increases. Therefore the membrane dried out and thereby, current and water production decreases.

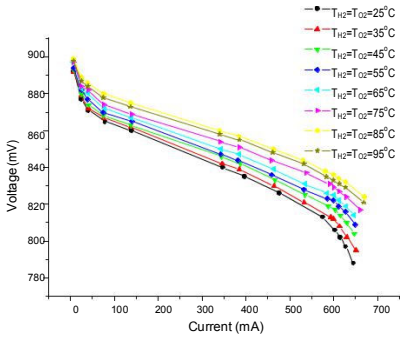


Fig. 6. Polarization curve of PEMFC with H_2/O_2 feeding by increasing the feeding gases temperatures.

Fig. 7 shows the performance of PEMFC with H_2/air feeding. There is no apparent change in the performance of the PEMFC except the decrease of the current compared to Fig. 6. This could be explained by the concentration of oxygen in air. Low oxygen concentration caused to decrease of the reaction rate on the cathode side.

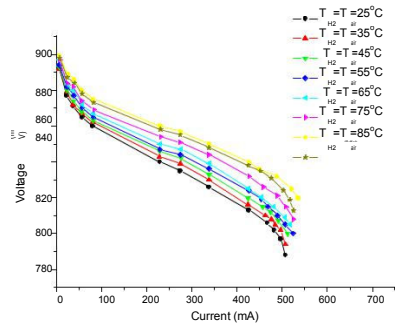


Fig. 7. Polarization curve of PEMFC with H_2/air feeding by increasing the feeding gases temperatures.

Figs. 8 and 9 show the performance of PEMFC with H_2/O_2 feeding with the increases of the fuel gases from ambient temperature to 95 ^{o}C by 10 ^{o}C step. These curves indicate that the performance does not vary significantly by changing the R_L at the ohmic polarization area. The curves come closer because of the high osmosis and water form rate. This could be explained by the hydration of the catalyst layer.

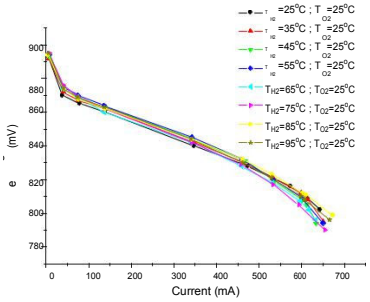


Fig. 8. Polarization curve of PEMFC with H_2/O_2 feeding by increasing the fuel gas temperature

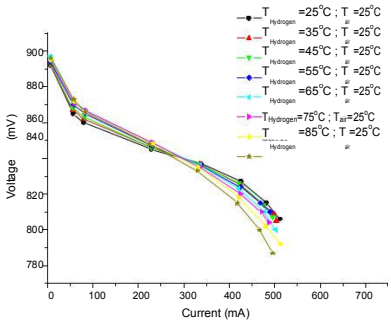


Fig. 9. Polarization curve of PEMFC with H_2/air feeding by increasing the fuel gas temperature.

Figs. 10 and 11 show the performance of PEMFC with H_2/O_2 feeding with the increases of the oxidant gas from ambient temperature to 95^{o}C by 10^{o}C step. These curves illustrates that does not vary significantly by changing the R_L at the ohmic polarization area. The curves at high ant low current could be explained by the decrease of the active reaction area of the GDL. Therefore the reaction rate decreases at high current and increases at low current.

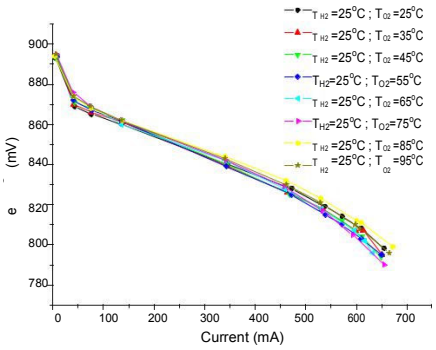


Fig. 10. Polarization curve of PEMFC with H_2/air feeding by increasing the oxidant gas temperature.

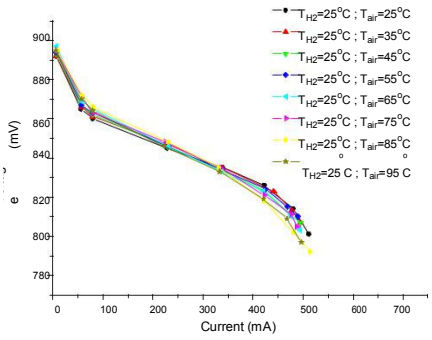


Fig. 11. Polarization curve of PEMFC with H_2/air feeding by increasing the oxidant gas temperature.

5. Conclusions

In this work, three sets of experiments with various operating temperature of feeding gases have been performed. As a result it was concluded that the performance of the PEMFC generally increases with the increase of the operating temperature. The optimum condition is operation at 85°C. In high temperatures the diffusivity of gases increases and mass transport resistance decreases. However, the ion-conductivity of the PEM in ohmic region increases. The PEMFCs depends on the concentration of gases and on the discharge of H_2O content formed by electro-chemical reactions.

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