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Effects of Nafion® content in the electrodes on the performance of a single proton exchange membrane fuel cell

M. KELLEGOZ*, I. OZKAN
Eskisehir Osmangazi University, Physics Department, 26480 Eskisehir, Turkey

The catalyst layers of proton exchange membrane (PEM) fuel cell consist of Nafion®, carbon particles and platinum particles. Nafion® is used to improve the catalyst layer performance. The increase of Nafion® content in the catalyst layer improves proton migration but reduces void spaces. Increasing platinum loading enhances the rate of the electrochemical reaction but increase the cost. In this paper, we have investigated the correlation of Nafion® content by a constant platinum loading of 1mg/cm^2 in the catalyst layer. This has been performed by using a single home-made PEM fuel cell. Optimum performance of PEMFC has been obtained for 0.25mg/cm^2 Nafion® content.

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Keywords: Proton exchange membrane fuel cell, Nafion®, Catalyst layer, Polarization curves

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 as 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 on the anode and cathode sides are

$$H_2 \rightarrow 2H^+ + 2e^- \quad (1)$$

and

$$2H^+ + 2e^- + \tfrac{1}{2}O_2 \rightarrow H_2O \quad (2)$$

respectively. The total reaction is given as

$$H_2 + \tfrac{1}{2}O_2 \rightarrow H_2O + electricity + heat \quad (3)$$

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 by changing the external R_L [9]. A typical polarization (performance) curve shown in Fig. 1 can be useful in the explanation of physical and chemical relationships, the fundamental operating principle of PEMFC. All regions are related to electro-chemical reactions [9,10].

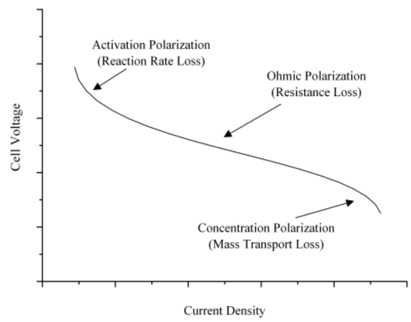

Fig. 1. Polarization curve of a typical PEMFC

In this paper, we have investigated the correlation of Nafion® content by a constant platinum loading of 1mg/cm^2 in the catalyst layer. This has been performed by using a single home-made PEM fuel cell. We have prepared catalyst layer using brush method.

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 these parts together with screws and nuts. Fig. 2 shows the schematic drawing of the produced PEMFC having H_2/O_2 feeding [20]. For the establishment of MEA, PEM provided by DuPont Inc., having 0.09 mm thickness and 16 cm^2 Nafion NE-1035 type, CC-S type carbon cloth having 0.38 mm thickness, 9 cm^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. have been used.

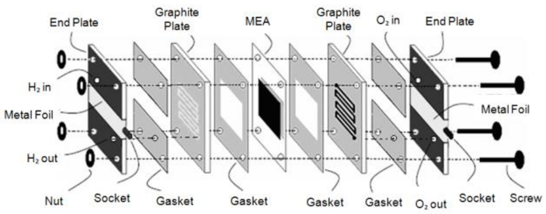

Fig. 2. PEMFC with H_2/O_2 feeding

PEM has been purified from surface contamination, organic contamination and metal ion contamination [11-13]. One of the surfaces of CC-S type electrodes which serve both as electrode and GDL are loaded with 1.0mg/cm^2-Pt. The catalyzing solution used in the loading of Pt has been prepared with brush method [14-18]. Pt-loaded GDLs are placed onto the surface of PEM, and MEA has been formed by keeping them under 250psi pressure at 130°C for 2min [2,4,15].

Operation of produced PEMFC is possible with the feeding of gas inlet/outlet channels with H_2/O_2 gases. Schematic drawing of the PEMFC with H_2/O_2 feeding is shown in Fig. 3. As it can be seen in Fig. 3, both fuel and oxidizer passes 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 humidification the conductivity feature of the PEM can be improved and the osmosis of H_2O which can be occurred on the cathode can be prevented. Feeding gasses have been heated by a water bath that heats the bubbler unit.

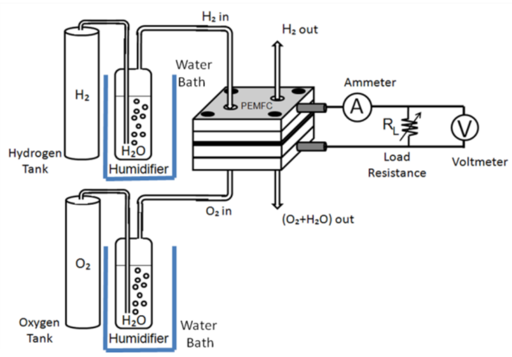

Fig. 3. Operated PEMFC with H_2/O_2 feeding

3. Results

The electrodes with the Nafion® contents of 0.10, 0.15, 0.20, 0.25 and 0.30mg/cm^2 have been prepared. All of these electrodes contained the same catalyst loading of 1mg/cm^2-Pt. The temperatures of the fuel gas and oxidant gas kept at 25°C. In all sets of the experiment the temperature of the PEMFCs has been kept constant at ambient temperature. During the experiments, backpressures of inlet/outlet sides of the PEMFCs were 1 atm. Polarization curves have been obtained for different R_L values. The test results have been carried out to investigate the effects of Nafion® contents on the performance of PEMFCs. The polarization curves of each type of Nafion® contents are given in Fig. 4.

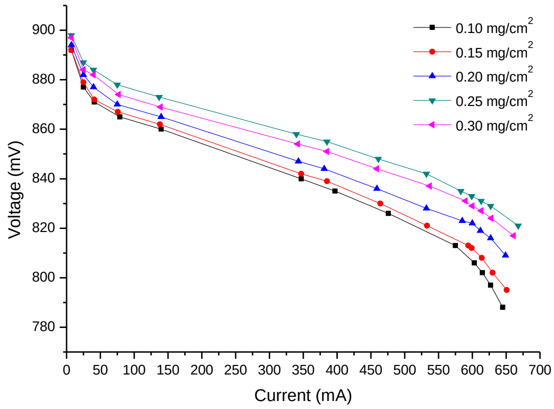

Fig. 4. Polarization curves of PEMFCs with H_2/O_2 feeding for various Nafion® contents

4. Discussion

Fig. 4 shows that the performance of PEMFCs with H_2/O_2 feeding increases with the increase of the Nafion® content. These curves indicate that performance has been improved with the increase of the Nafion® content from 0.10mg/cm^2 to 0.25mg/cm^2, and begin to decrease at 0.30mg/cm^2. The increase of the performance between 0.10mg/cm^2 to 0.25mg/cm^2 can be explained by the improvement of the proton migration as verified by Gode et al. [21]. After a critical Nafion® content of 0.25mg/cm^2, the polarization curve decreases. This can be explained by the reduction of the void space by increasing of Nafion® content as verified by Song et al. [22]. This causes the electro-chemical reaction rate to decrease.

5. Conclusions

In this work, we have investigated the correlation of Nafion® content by a constant platinum loading of 1mg/cm^2 in the catalyst layer. This has been performed by using a single home-made PEM fuel cell. We have prepared catalyst layer using brush method. It has been concluded that the performance of the PEMFC generally increases with the increase of the Nafion® content. The optimum performance has been obtained for the Nafion® content of 0.25mg/cm^2. Nafion® content and amount of void space have a dramatic effect on the performance of PEMFCs. This phenomenon is important for the future productions of more powerful PEMFCs which can be used in stationary/mobile power applications.

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*Corresponding author: murke@ogu.edu.tr