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Short communication

Enhancement of PEM fuel cell performance by steaming or boiling the electrode

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Abstract

Treatment of electrodes or catalyst-coated membranes with steam or boiling water for as short as 10 min dramatically increased their performance when tested in proton exchange membrane (PEM) fuel cells afterwards. The treatment was found to be effective for numerous electrodes consisting of various types of carbon-supported Pt catalysts with different Pt loadings. It is proposed that the treatment increases the number of active sites or regions in the catalyst layer which leads to an enhanced catalyst utilization.

Keywords: Electrodes; Catalyst-coated membranes; PEM fuel cells; Catalyst layer; Pt/C

1. Introduction

A large amount of research has been directed towards improving the performance of proton exchange membrane fuel cells (PEMFCs) while keeping the Pt loading as low as possible. Smaller Pt particles supported on carbon have replaced unsupported larger Pt black to increase the catalyst surface area [1]. Impregnation of Nafion into the catalyst layer extends a two-dimensional reaction zone into a three-dimensional zone [2]. Furthermore, Nafion is directly mixed with the catalyst to achieve a more homogeneous distribution of the ionic conductor in the whole catalyst layer [3–6]. However, even mixing Nafion directly with the catalyst, a sizable portion of the catalyst layer still remains inactive due to poor access to the reactant, electrons, or protons.

It is clear that increasing the catalyst utilization is the key to achieving a good performance, especially for low Pt loading electrodes. We found that even after an electrode is made, the catalyst utilization can be increased by simply treating the electrode in either boiling water or steam. This short communication reports this finding.

2. Experimental

The catalyst mixture was prepared by directly mixing supported Pt/C with Nafion solution. The mixture was stirred thoroughly before it was applied onto a gas diffusion medium. Carbon paper-type material was used as the anode gas diffusion medium, while ELAT was used as the cathode gas diffusion medium. After catalyst application, the electrodes were dried in an oven at 135 °C for 30 min. These electrodes, with or without a further treatment as described below, were hot-bonded on Nafion 112 membranes at 130 °C.

The following treatment was only applied to the cathodes because they limit/determine the whole MEA performance when pure hydrogen is used as the fuel. The treatment used was either boiling in water or steaming in a household pressure cooker (PC-806M, Revere Electronics). When boiled in water, the electrodes floated on the surface of the water, so the catalyzed side was arranged to face the water. When steamed, either they floated in the liquid water phase or were supported by a stand so that only water vapor could be in contact.

A commercial catalyst-coated membrane (CCM) was also steam treated. This commercial CCM has a membrane of ca. 25 μm thick and a catalyst loading of 0.30–0.50 mg/cm^2 on each side. The gas diffusion medium was attached, but not bonded, to this catalyzed membrane during the testing.

MEAs or CCMs were tested using a home-made test station with a 10 cm^2 single cell. The cell consists of serpentine flow-fields on metal nitride-coated plates. Tests were performed at ambient pressure with a cell temperature of 35 °C using both hydrogen and air that were humidified at 45 °C by passing them through water bottles.

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3. Results and discussion

Fig. 1 shows the effect of steaming on electrode performance. The cathode catalyst layers were made of 20% Pt/C with a Pt loading of 0.11 mg/cm^2. Compared to the un-steamed electrode, the electrodes that were steamed for 10 and 40 min exhibited much higher performance in the whole voltage region. For example, at a cell voltage of 0.60 V, the un-steamed electrode had a current density of 0.28 A/cm^2, while the steamed electrodes both had a current density of 0.44 A/cm^2, a 57% increase. The two steamed electrodes performed similarly, indicating that steaming for 10 min was sufficient.

Effect of steaming on the performance of CCMs is shown in Fig. 2. Although the increase was not as dramatic as that in Fig. 1, an apparent increase was observed.

Performance was also increased by boiling the electrodes in water. Fig. 3 shows the results for electrodes with two different Pt loadings, 0.084 and 0.19 mg/cm^2, respectively. A 40% Pt/C was used to prepare the catalyst layer. Again, a large increase was observed for both Pt loading electrodes after a 10 min boiling.

Since steaming or boiling enhances the electrode performance in the whole voltage region, the enhancement is believed to be due to an increase in Pt utilization. In order to make a catalyst layer active in three-dimensions, Nafion

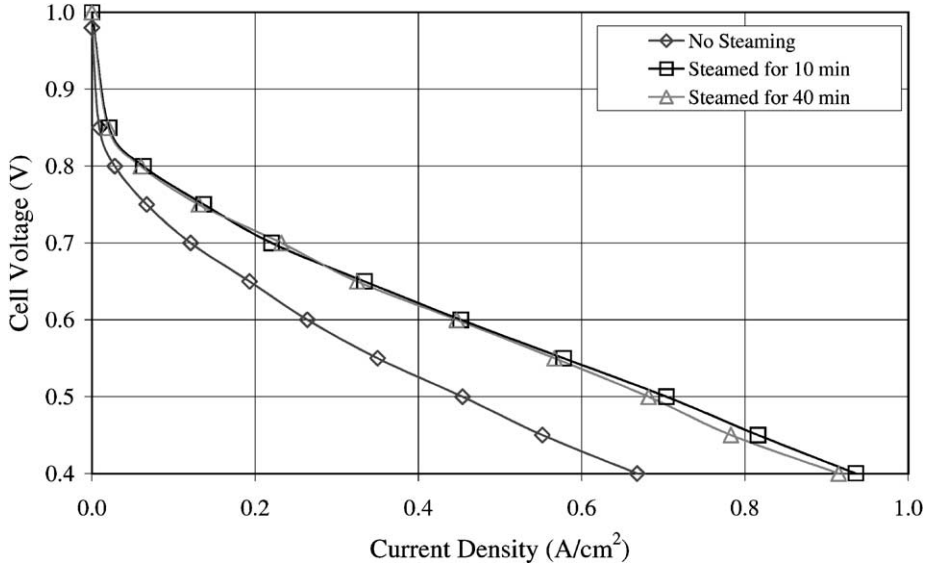

Fig. 1. *V–I* curves of electrodes that were steamed for 0 (◇), 10 (□) and 40 min (△), respectively. Pt = 0.11 mg/cm^2, 20% Pt/C.

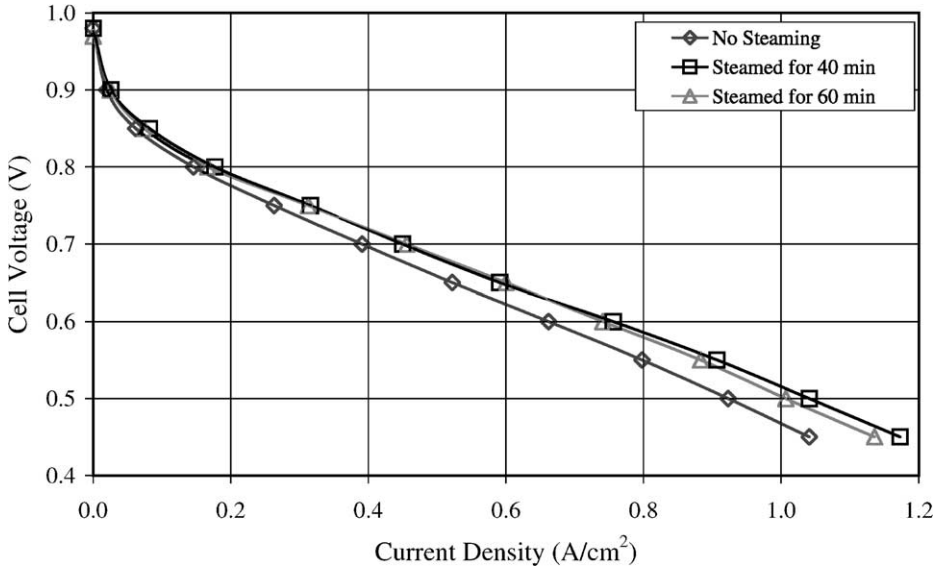

Fig. 2. *V–I* curves of CCMs that were steamed for 0 (◇), 40 (□) and 60 min (△), respectively. These commercial CCMs have a 25 μm thick membrane and a catalyst loading of 0.30–0.50 mg/cm^2 on each side.

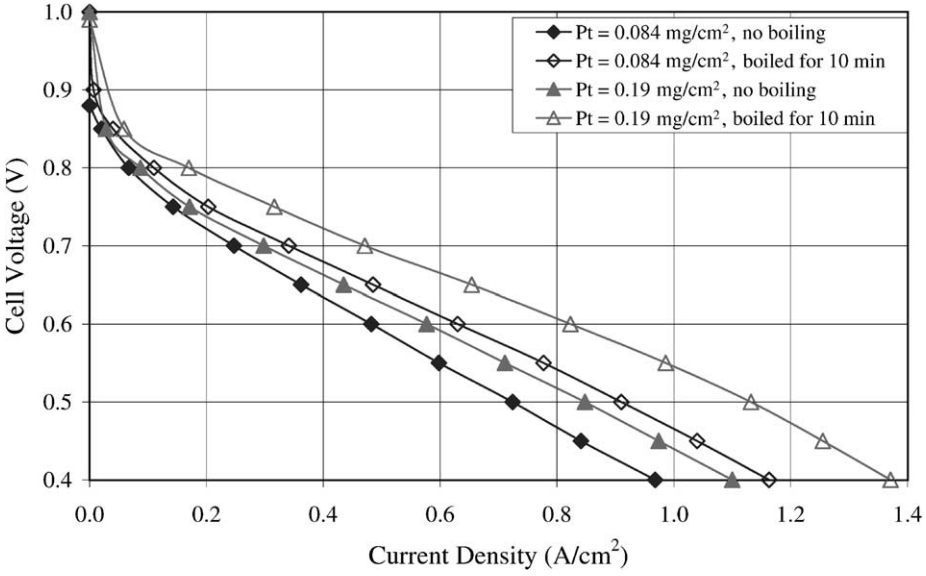

Fig. 3. *V–I* curves of electrodes that were boiled for 0 (◆, ▲) and 10 min (◇, △), respectively. Pt = 0.084 (◆, ◇), or 0.19 mg/cm^2 (▲, △), 40% Pt/C.

(or other ionic conductors) is put into the catalyst layer. The electrodes are then dried in order to remove the solvents before they are used. However, Nafion needs to be hydrated to achieve sufficient proton conductivity. When the electrodes are steamed or boiled in water, the Nafion in the entire catalyst layer could achieve a complete hydration. Although the following hot-bonding step dehydrates the catalyst layer, most of the Nafion seems to maintain an easier-hydration-characteristic obtained from the treatment. So, when the electrodes are tested, not only Nafion in the catalyst layer gets hydrated faster, but also Nafion in more regions of the catalyst layer is hydrated. This leads to more regions of the catalyst layer to become active, resulting in an enhancement in the performance.

Steaming or boiling may also open some otherwise ''dead'' regions in the catalyst layer. There is normally Pt/C, Nafion and PTFE in the catalyst layer. Some regions could be blocked or enclosed in such a way that the gaseous reactant can not have access, so these regions are literally ''dead'' regions. When treated in hot water or steam, some of these regions are opened, so they become accessible and active.

Depending on the structure and composition of the catalyst layer, treatment by hot water or steam will achieve different degrees of enhancement. If the original catalyst layer is made in such a way that the catalyst sites are easily accessible to the reactant, as well as easily hydrated, the treatment will only have a slight effect. Otherwise, a large enhancement will be observed.

4. Conclusions

Steaming or boiling an electrode can dramatically increase its performance in PEM fuel cells. Electrodes made of 20 and 40% Pt/C at various Pt loadings, all showed a large enhancement. CCMs also achieved higher performance after such a treatment. The higher performance is believed to be due to an increased catalyst utilization that results from an increase in the number of active sites within the catalyst layer initiated by the treatment.

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