EFFECT OF MORPHOLOGICAL AND WETTING CHARACTERISTICS OF THE GAS DIFFUSION LAYERS ON ELECTRODE FLOODING LEVEL IN A PEM FUEL CELL

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INTRODUCTION

Of the performance controlling components in the PEM fuel cell, the cathode is the most influential. Its poor performance contributes to more than two thirds of the total voltage loss in a PEM fuel cell during operation. The oxygen reduction rate at the cathode being the limiting kinetic step determines how much current can be generated. During operation, this rate, which depends on the transport rate of oxygen from the flow channels to the catalyst sites, is greatly reduced when liquid water accumulates in the cathode. Excessive liquid water accumulation results in reduced performance by blocking the gas pores needed for oxygen gas transport and covering the catalyst active surface required for reaction. Consequently, proper water management in the cathode is vital to ensuring successful performance of a PEM fuel cell.

Developing an effective water management strategy requires a better understanding of the mechanism and variables controlling the transport of liquid water in the cathode and the effect of liquid water accumulation on the performance of the cathode. Of significant interest are the liquid water saturation level in the electrodes during operation, the effects of the liquid water saturation level in the electrodes on the performance of the fuel cells, and the role of the operating conditions and the electrode physical properties on the liquid water transport rate in the electrode.

EXPERIMENTAL SETUP AND RESULTS

Taking advantage of the dead-ended flow channels and through-the-electrode gas flow characteristics of PEM fuel cells operated with interdigitated flow fields we configure our PEM fuel cell to measure the pressure drops due to fluid flow through the anode and cathode backing layers as shown in Figure 1. This setup gives us the capability to measure the effects of liquid water accumulation in the electrode backing layers on the gas pressure drop along the fluid flow path through the gas diffusion layers and the performance of the fuel cell as shown in Figure 2 [1-3].

![Figure 1. Electrode flooding measurement in a PEM fuel cell with interdigitated flow fields](image)

Figure 2 shows the cell voltage and the gas pressure drops across the anode and cathode backing layers as a function of the cell current density for a PEM fuel cell operating on hydrogen.
and air at constant gas flow rates, 50°C and ambient pressure. First, note that there was very little change in the pressure drop in the anode and that most of the changes are in the cathode. This confirms that liquid water accumulation occurs mostly in the cathode, as expected, because of the large amount of water generated in the cathode both by the electroosmotic drag of water and oxygen reduction reaction. Second, note that the sharp increase in gas pressure drop across the cathode-backing layer corresponds exactly with the sharp drop in the cell voltage. Liquid water in the backing layer reduces the gas pore volume available for gas transport resulting in higher pressure drop across the backing layer. This reduction in pore volume also results in lower gas diffusion rate to the catalyst sites and partial flooding of the catalyst active area leading to higher cathode overpotential and lower cell voltage as shown in Figure 2. Even though the effect of cathode flooding by liquid water accumulation in the backing layers on the performance of PEM fuel cell has been predicted by our two-phase fuel cell models [4-8] and those of others [9-12], the experimental results given in Figure 2 represent the first conclusive evidence that cathode flooding is one of the main root causes of poor performance in PEM fuel cells at high current densities.

Figure 2. I-V and pressure drop behavior of a PEM fuel cell with interdigitated flow fields

The setup described above has been used to look at the effects of operating variables such as air flow rate, cell temperature and current density on the liquid water flooding level and the fuel cell steady state and transient responses. Results for this study can be found in reference 4. In this study we will discuss the use of this setup to look at the influence of physical properties of the gas diffusion layers on the liquid flooding level and fuel cell performance. Results for gas diffusion layers with different wet-proof levels operating at different voltages and gas flow rates will be presented next. For this study two gas diffusion materials from SGL Carbon are used, 30CC and 30EC. Both gas diffusion materials have a microporous layer and are approximately 300 μm thick. The CC version has approximately 10% by weight of wet-proof material and the EC version has 30%.

Effect of Wet-Proof Level

Figure 3 shows the polarization curves and the pressure drop responses for the gas diffusion materials just mentioned. In this case study both the hydrogen and air flow rates were
held constant at 2.5 A/cm² and 3.0 A/cm² equivalent, respectively. Note that at low current densities where the effect of liquid water accumulation is minimal fuel cells from these two materials exhibit similar electrochemical (V vs. I) and flow (pressure drop) behavior. However, at current densities above 0.7 A/cm² both the electrochemical and flow behavior starts to deviate. The fuel cell made of gas diffusion layers with higher wet-proof level performs better showing higher voltages and lower pressure drops at the same current densities. We attribute this better performance to more effective liquid water removal and lower liquid water accumulation in the gas diffusion layers. That is, under the same shear rate (gas flow rate) more liquid water is dragged out of the gas diffusion layer when the material has more carbon surface wet-proof.

![Graph](image)

**Figure 3. The effects of wet-proof level on the electrochemical and flow response under constant air flow rate**

In the next case study, instead of holding the air flow rate constant we held the air flow rate to current density stoichiometric ratio constant at 2.5. This was done to avoid dehydrating the membrane at low current densities where the air stoichiometric flow rate is very high when a constant air flow rate is used and to simulate more realistic operating conditions. We expect liquid water to exist even at lower current densities when the air flow rate is low. The results for this case (see Figure 4) show responses that are similar to the case of constant air flow rate. Mainly, the fuel cell with higher wet-proof level performs better because of higher liquid water removal rate and lower liquid water accumulation. The main difference from the previous case is that at lower air flow rates there appears to be a small difference in both the electrochemical and flow behavior even at low current densities because of the existence of liquid water in the gas diffusion layers which did not show up in the previous case until the air flow rate to current density stoichiometric ratio decreases to a sufficiently low level.

To confirm the observation in the previous case studies, we conducted experiment in which both fuel cells were held constant at 0.6 A/cm² and the air flow rates were varied from 2 to 5 stoichiometry. The results are shown in Figure 5. As suspected once the air flow rate to current density ratio exceeds about 3.5 both fuel cells show similar electrochemical performance and pressure drop characteristic because there is sufficient air flow rate to remove most of the liquid water entrapped in the gas diffusion layers. A small difference in the electrochemical performance at high stoichiometric flow rates is attributed to possible dehydration of the membranes.

414 Electrochemical Society Proceedings Volume 2004-21
Based on these results, one could clearly see that proper water management in the cathode is vital to achieving high performance of PEM fuel cells. It is also clear that developing an effective water management strategy will require a better understanding of the mechanism and variables controlling the transport of liquid water and the effect of liquid water accumulation on the performance of the electrodes of PEM fuel cells. A diagnostic tool such as the one presented above is very useful. They can be used to identify components that have significant effects on the performance of a PEM fuel cell and determine operating conditions and design variables that control the transport and removal rates of liquid water from the gas diffusion layers and physical properties such morphological and wetting characteristics of gas diffusion layers that will result

**SUMMARY**

![Figure 4. Electrochemical and flow responses under constant air flow stoichiometry](image)

![Figure 5. Effect of air flow stoichiometry on electrochemical and flow responses](image)
in faster liquid water removal rates and lower liquid water accumulation in the electrodes of PEM fuel cells.

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