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Experimental study on mitigating the cathode flooding at low temperature by adding hydrogen to the cathode reactant gas in PEM fuel cell

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ABSTRACT

Severe flooding can be critical in a fuel cell vehicle operating at a high current density, and in a fuel cell vehicle at the initial stage of start up. It is often difficult to remove the condensed water from the cathode gas diffusion layer (GDL) of the fuel cell because of the surface tension between the water and the GDL. In this research, in order to remove the condensed water from the cathode GDL, a small amount of hydrogen was injected into the cathode reactant gases. The results showed that the hydrogen addition method successfully removed the liquid water from the cathode GDL. Water removal was verified for various hydrogen flow rates and hydrogen addition durations. Furthermore, the dew point temperature of the outlet gas at the cathode was observed to determine the amount of water removed from the cathode GDL. In addition, the water droplet in the cathode gas flow channel was visualized by using a transparent cell. Furthermore, degradation tests are also performed. Considering the degradation test, the hydrogen addition method is expected to be effective in mitigating cathode flooding.

1. Introduction

With depletion of natural resources and increase in environmental concerns, much effort has been directed at finding new and renewable energy sources for power generation, automobiles, construction etc. Among these new energy sources, polymer electrolyte membrane fuel cells (PEMFCs) are considered promising for automotive applications, due to their high energy density at low operating temperatures, fast response and low toxic emissions. For the extraction of the optimal power density from the PEMFC, research has focused on the issue of improved water management in the polymer electrolyte fuel cell because of its critical relation to fuel cell performance. Among the many problems that must be overcome to improve the performance of the PEMFC, water flooding in the gas diffusion layer (GDL) has become critical in the water management of the PEMFC. Many studies have investigated flooding mitigation methods for the high current density condition, as well as the behaviors of vapor and liquid water in the GDL to understand the water transport process in the GDL and to find methods of water removal. Shi et al. [1] investigated the effect of cell temperature on both liquid water saturation and capillary pressure distributions by using a one-dimensional steady state model. An elevated operating

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temperature has an undesirable influence on the removal of liquid water inside the GDL, and an over saturated environment can lead to more serious flooding in a GDL combined with a micro porous layer (MPL). Shimpalee et al. [2] studied the effect of GDL flooding on fuel cell performance by examining the pores of the GDL. Numerical and experimental results showed that as the effective diffusivity of gases in GDL reduced, the fuel cell performance decreased significantly. Recognizing the importance of detection of GDL flooding in its prevention, extensive research has been done on the detection of GDL flooding. Lee and Bae [3] experimented with a transparent fuel cell and observed a water slug in a channel. They demonstrated the properties of anode and cathode flooding: anode flooding can have more significant detrimental effects than cathode flooding because of back diffusion and low outlet flow rate. They also suggested the relation between flooding and voltage drop.

The strategies of water flooding mitigation can be classified into two major types. The first type improves the designs or the properties of materials for effective water management: for example, the properties of the GDL, such as the PTFE portion and the existence of micro porous layer (MPL), and the design of the gas flow channel [4–6]. The second type mitigates flooding by changing the operating condition of the fuel cell. Litster et al. [7] reported effective excess water removal in a fuel cell by employing an electro osmotic pump, which provided a sufficient pressure gradient within the wick and decoupled the oxidant delivery from liquid water effectively. Choi et al. [8] investigated the effect of reactant gas pulsation on the behavior of excess water in the GDL. The pulsation uniformly dispersed the species concentration in the GDL to remove water in the GDL.

In this study, the hydrogen addition method is introduced to mitigate flooding in the cathode GDL. A small amount of hydrogen is injected into the reactant air in the cathode, and the additional hydrogen reacts with the oxygen in the reactant air through a catalyst. The heat of the reaction evaporates the liquid water and lowers the water flooding level in the GDL in two ways. First, the vapor concentration near the catalyst layer will help the vapor diffuse into the gas flow channel; this phenomenon is called the heat pipe effect [9,10]. Second, the force of the vapor expansion due to the heat of reaction, expected to occur near the catalyst, forces the residual water in the GDL into the gas flow channel. Sun et al. [11] introduced the hydrogen addition method to increase the temperature of the fuel cell for cold startup. Gottesfeld and Pafford [12] studied oxygen addition method in the anode flow to solve the problem of carbon monoxide poisoning in fuel cells. Wang [13] researched internal air bleeding as an effective method for mitigating CO poisoning for a Pt/Ru in anode, and explained that the anode overpotential decreased with the increase of the cathode pressure and decrease of the membrane thickness because of the oxidation of CO by more O_2 diffusion from the cathode to the anode. Inaba et al. [14] investigated the effects of air bleeding on membrane degradation in fuel cells, and concluded that excess air bleeding deteriorated the anode catalyst, but that the rate of membrane degradation was negligibly low up to 2000 h. In this study, the hydrogen addition method is used to mitigate water flooding at temperatures lower than the optimal fuel cell operating temperature. Low temperatures near or below 30 °C are investigated to simulate the condition at the initial stage of start up. Water removal from the GDL at low temperatures is more difficult than at high temperatures, because of the high viscosity of water and low saturation vapor pressure [15,16]. Therefore, in this research, by injecting a small amount of hydrogen into the reactant air in the cathode GDL, the resulting water vapor concentration and vapor expansion can be used to remove the liquid water in the cathode GDL.

2. Experimental setup and procedure

2.1. Experimental setup

As shown in Fig. 1, the experimental setup consists of a fuel cell, mass flow controllers and a humidification system with controls for temperature and relative humidity, a coolant circulation unit, an electric load, and pressure and humidity sensors. A single cell with a coolant channel and a visualized single cell were used as fuel cells in this experiment. The single cell with a coolant channel had 5 serpentine flow fields and area of 25 cm^2, and coolant water was circulated through the single cell to maintain the cell temperature. The visualized single cell consisted of an end plate made with an epoxy glass for visualization of the cathode side, and a membrane electrode assembly (MEA) with active area of 25 cm^2, as shown in Fig. 2. Electronic load equipment was used to fix the delivered current to a desired value to obtain a maximum voltage ranging from 0 V to 150 V and a maximum current ranging from 0 A to 132 A. The coolant circulation unit maintained the temperature of the fuel cell, and the water pump in the cooling system handled the flow rate and temperature of the water through the PID controller. In the bubble type humidifier, the reactant gases were humidified by the heated water in the tank, and the humidity of reactant gases was controlled by the temperatures of the water tank and the gas supply line. The flow rates of the gases were controlled by the mass flow controller. Some sensors were used to identify the state of the cell, such as pressure transducers, thermocouples, and dew point hygrometers. In order to measure the amount of water vapor in the outlet gases, dew point hygrometers were used after the evaporation of the all the liquid water in the outlet gases by the line heater. All data from the electronic equipment and sensors were transmitted to a personal computer.

2.2. Experimental conditions

The hydrogen addition method must be applied under the same GDL flooding condition to verify its effectiveness. The amount of water in the GDL is strongly affected by the amount of water generated from the fuel cell reaction and the amount of water removed from the reactant gases. In order to simulate the flooding condition, the rates of water removal by evaporation and convection are minimized. The dew point temperature of the reactant gases is maintained at 30 °C by controlling the water temperature of the bubble type humidifier. On the other hand, the temperature of the fuel cell is also maintained at 25 °C by controlling the coolant temperature. Flooding becomes severe at higher current densities, so