An Analysis on Operation Conditions of PEMFC to Minimize External Humidification of Gases

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The proton exchange membrane fuel cell (PEMFC) is one of the most suitable power generation devices for future automobile applications because of high energy efficiency, low level of noise, and almost no pollution. However, the stable and reliable power generation of PEMFC is strongly depended on the proton conductivity of the membrane which is also governed by the hydration condition. Therefore the water management in the membrane is one of the most important operating conditions. The water is produced as result of electro-chemical reaction of the reactant gases. The part of this water is used to humidify reactant gases at the anode and cathode when these gases are not saturated. Thus, the relative humidity of the incoming gases greatly affects the hydration state of the membrane. To keep the proper amount of the water in the membrane, external humidifiers have been used to humidify the incoming gases, but these external systems also consume power generated and add more weight on the system. Also with external humidifiers the anode and cathode can be flooded because of an excess amount of the water.

In this work an analytical study is conducted to investigate the operation conditions in terms of pressure ratio and stoichiometry of gas. Temperature is implicitly included into the pressure ratio which is the ratio of the partial water vapor pressure to the total pressure. A mathematical model is developed for the water transport in the MEA. It is assumed that the system is in a steady state and the PEMFC has a uniform temperature. Also the temperatures of the incoming gases are the same as that of the PEMFC. The gas at the anode outlet is assumed to be saturated. Hydrogen and air are used as reactant gases for the analysis. Four different cases shown in Table 1 are considered based on the relative humidity of incoming gases. The relative humidity of the gas in the cathode channel is calculated to judge the operation conditions. When this relative humidity is much lower than the saturation, the membrane may be dehydrated.

The Case 1 is corresponding to an operation condition without external humidifiers. In this case the product water is only source to maintain the hydration state of the membrane. The results show that for only low pressure ratios the relative humidity of air in the cathode channel becomes near the saturation condition. The increase in the stoichiometries of hydrogen and air decreases the relative humidity of gases. When hydrogen is humidified at the anode inlet such as the Case 2, the pressure ratio can be increased up to 0.5. Also, the relative humidity of air in the cathode is independent of the stoichiometry of hydrogen in the anode.

In the Case 3, the saturated air is used at the cathode inlet while dry hydrogen enters at the anode inlet. The results show that up to pressure ratio of 0.9 the relative humidity of air leaving the cathode is near the saturation for the air stoichiometry of 3 as shown in Fig. 1. When the stoichiometry of hydrogen is increased, more water will be consumed at the anode so that the relative humidity of air decreases. The Case 3 is the most promising one among the cases. Also, Fig. 2 shows the variations of the optimum stoichiometries for the Case 2 and 3 with the pressure ratios to keep the saturated gas at the cathode outlet. For the Case 4, all incoming gases are saturated so that the MEA is also saturated and may be flooded when the excess water is not carried out by air in the cathode

The analytical results show that humidifying the gas at the cathode inlet instead of the anode inlet is more effective for the broad range of pressure ratios. Without external humidifiers, PEMFC can be operated for low pressure ratios. Humidifying gases at both inlets leads flooding of MEA due to the excess amount of water. For the Case 2 and 3, optimum relationships between the pressure ratio and stoichiometry are given to maintain the saturation condition at the cathode outlet.

Table 1. Summary of Conditions of Reactant Gases

Location	Anode Inlet	Cathode Inlet	Anode Outlet
Case 1	Dry gas	Dry gas	Saturated gas
Case 2	Saturated gas	Dry gas	Saturated gas
Case 3	Dry gas	saturated gas	Saturated gas
Case 4	Saturated gas	Saturated gas	Saturated gas

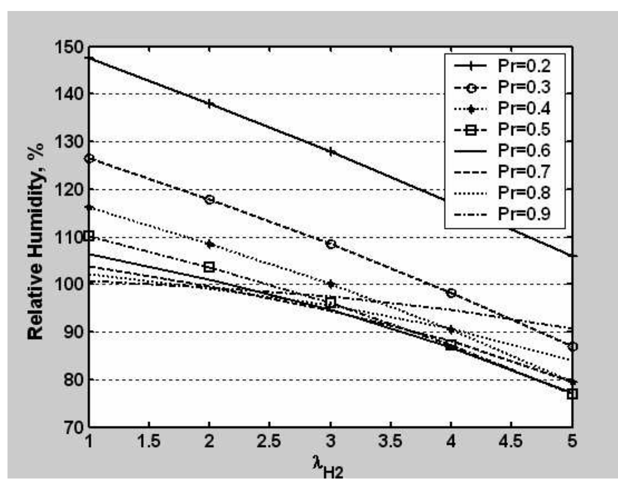

Fig. 1. The relative humidity of the air at the outlet of the cathode for the air stoichiometry of 3 in the Case 3.

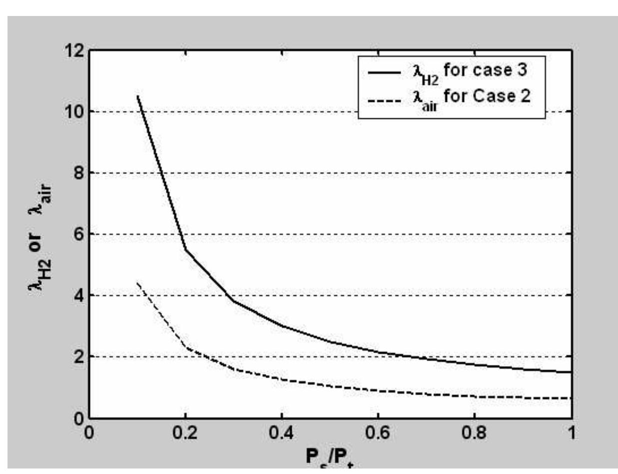

Fig. 2. The optimum stoichiometries for the Case 2 and 3.