



Membrane performance comparison in a proton exchange membrane fuel cell (PEMFC) stack

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ABSTRACT

A 5-cell proton exchange membrane fuel cell (PEMFC) stack with different types of membrane electrode assemblies (MEAs) was tested to compare their performances and electrochemical characteristics. The experimental data were obtained with a stack of 5 cells and active area of 125 cm². The stack consisted of different Nafion[®] and hydrocarbon membranes with the same types of electrocatalyst. The membranes were installed in different cells and in the same stack. Polarization and voltage measurement data were obtained to compare their performances at different temperatures and anode humidity conditions. Also, impedance spectroscopy data were obtained in similar manner to compare the differences in their resistance.

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1. Introduction

The proton exchange membrane fuel cell (PEMFC) is regarded as a strong contender in the quest for alternative energy sources due to its high power density and wide operating range. The PEMFC is the strongest candidate among the various types of fuel cells due to its technological maturity for commercialization in the near future for transportation and stationary applications. A PEMFC stack consists of bipolar plates (BPs), membrane electrode assemblies (MEAs), gas diffusion layer (GDL), current collectors, end plates and sealants. These parts of the fuel cell stack govern its cost and performance.

Much effort has been made to improve the platinum catalysts used in fuel cell stacks [1,2]. Kwon et al. [1] explained that increasing the surface area of the platinum catalyst would improve the performance of a PEMFC. The improvement of the catalyst is required for commercialization of fuel cell systems. However, this improvement involves much time and cost. Mayrhofer et al. [2] introduced a new method of observing the degradation of the fuel cell catalyst which improves on the conventional TEM investigation procedure. This new procedure enables the observation of the corrosion processes. They demonstrated the impact of a potential cycling treatment on a carbon-supported platinum catalyst and proposed a new corrosion mechanism for fuel cell catalyst

degradation. Under harsh conditions, whole Pt particles detach from the support and dissolve into the electrolyte without re-deposition.

The PEMFC stack design, such as the geometries of the manifold and flow field, affects the fuel and oxidant distribution, liquid water removal and pressure drop in the fuel cell stack along the channel length. In our previous works [3,4], we elucidated the effect of the flow field design and operating conditions such as the anode and cathode humidity and stack temperature on the fuel cell performance. Ref. [3] explained how the pressure drop and contact resistance affect the performance of a fuel cell. The effects of the fuel and oxidant humidity on the PEMFC stack were explained in Ref. [4]. The cell voltage profiles as a function of cell number for various operating conditions were also examined in that work. The gas distributions and design of manifolds in a fuel cell stack were explained in Refs. [5,6]. Karimi et al. [5] emphasized the importance of the pressure loss ratio between the manifold and bipolar plate. They compared the various types of manifolds, namely the U-configuration and Z-configuration types. Their theoretical work showed that the U-configuration manifold yields a lower pressure drop than the Z-configuration manifold. They also explained that flow channels with a smaller cross-sectional area and longer length increase the pressure drop of the flow field and gas distribution. Jiao et al. [6] explained the correlation of the liquid water transport with the manifold. They analyzed the manifold design in terms of the liquid water removal, by keeping the unit cell and MEA side of the gas flow close to the outlet of the outflow manifold and the serpentine gas flow channel's "collect-

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ing-and-separating-effect” to facilitate water removal. They emphasized the importance of water removal to achieve stable performance.

The performance and cost of a PEMFC stack are strongly dependent on the membrane. Thus, the development of an electrolyte membrane is required for the commercialization of a fuel cell. One of the main factors affecting the performance, durability and cost of a fuel cell is the electrolyte membrane. Patel et al. [7] explained the preparation of a polymer membrane as an electrolyte material for a PEMFC in their experimental work. Various attempts have been made to increase the operating temperature [8–10]. Chen et al. [8] tried to improve the water content of a Nafion[®] membrane by adding TiO₂ powder. They added different types of TiO₂ powders to a Nafion[®] membrane and found an improvement in the water uptake in the membrane at temperatures above 100 °C. A modification of the acid–base polymer membrane was reported by Lee et al. [9]. They explained the various kinds of membrane that can be used as the electrolyte of a PEMFC in their review work. They modified a perfluorosulfonic acid membrane to increase its thermal stability and were able to obtain higher proton conductivity by recasting it with inorganic additives. Kim and Lim [10] also investigated different kinds of membrane materials, such as polybenzimidazol (PBI) to increase the operating temperature above 120 °C. On the other hand, many studies have been conducted for the purpose of investigating the degradation of fuel cell membranes. Tang et al. [11] investigated the durability and degradation behavior of Nafion membranes in detail under various mechanical, chemical and polarization conditions. Zhang et al. [12] used magnetic resonance imaging (MRI) to monitor the signal of the water contents across a Nafion membrane.

The data presented in this work were obtained using a PEMFC stack of 5 cells with an active area of 125 cm² and different types of membranes. The different MEAs with different types of membranes installed in different cells of a same stack will enable the comparison of membrane performance in same operating conditions.

2. Experimental

A 5-cell stack with different MEAs was used in this experimental work. A PEMFC fuel cell stack of 5 cells with an active area of 125 cm² was used to compare their MEA performance under certain conditions. The MEAs used in this work were a combination of Nafion 112 and hydrocarbon membranes with a thickness of 50 μm and catalyst loadings of Pt/Ru and Pt of 4.5 and 6.0 mg/cm² for the anode and cathode, respectively. The GDLs were 10BC (a

SGL Carbon product) with a nominal thickness of 400 μm. An Arbin fuel cell test machine was used to perform the experimental work. Digital mass flow controllers made by MKS were used to control the flow rates of the fuel and oxidant. The mass flow controller was calibrated with a bubble flow meter. The gases were humidified in humidifier bottles. Two bubbler-type humidifiers were used to control the anode and cathode humidification. The dry gas enters into the humidifier and contact to water as the form of bubbles in the humidifier. The humidities of both the anode fuel and cathode oxidant were controlled by changing the humidifier bottle temperature. The stack temperature was adjusted with cooling water controlled by an external heating/cooling system. The stoichiometries of the hydrogen fuel and oxidant gas were 1.25 and 2.0, respectively, in this experimental work. The fuel and oxidant gas were 99.999% pure hydrogen and industrial air, respectively. The stack temperature was determined by measuring the outlet temperature of the cooling water flowing from the stack used in this work. A schematic diagram of the experimental setup is illustrated in Fig. 1. The hydrogen and air flow rates were controlled and recorded by mass flow controllers. The steady state performances for various loads, polarization curves, were attained by changing the current and waiting until the voltage converged to a stable value at each current density step. A schematic diagram of the stack is illustrated in Fig. 2. The gases and cooling water were distributed to each cell via a manifold. The manifold of the stack was a U-type one, in which the gases and coolant enter into one side and flow out in the same side. A 5-cell stack was used to verify the performance of the hydrocarbon-based MEAs. Two Nafion[®] and three hydrocarbon MEAs were used in this experimental work. The Nafion[®] MEAs were located at the first and the last cells of the stack. The hydrocarbon MEAs were located at the second, the third and the fourth cells.

The experiments were performed at various stack temperatures. The effect of the anode humidity was also examined. The stack was operated and the performance was compared at three different temperatures, 65, 75 and 85 °C. Also, the effect of the fuel humidity was examined by comparing the results obtained at 100% relative humidity and under dry conditions for the anode at the stack temperature of 65 °C.

An electrochemical impedance spectroscopy (EIS) was performed at currents of 25 A and 45 A, corresponding to current densities of 200 and 360 mA/cm², respectively, with a Solatron[™] 1280Z frequency analyzer unit made by Advanced Measurement Technology, Inc., AMETEK, Inc. To ensure steady state conditions, the operating fuel cell was allowed to equilibrate for at least 30 min before performing the impedance scans. For the AC impedance measurements, an oxygen electrode was used as the

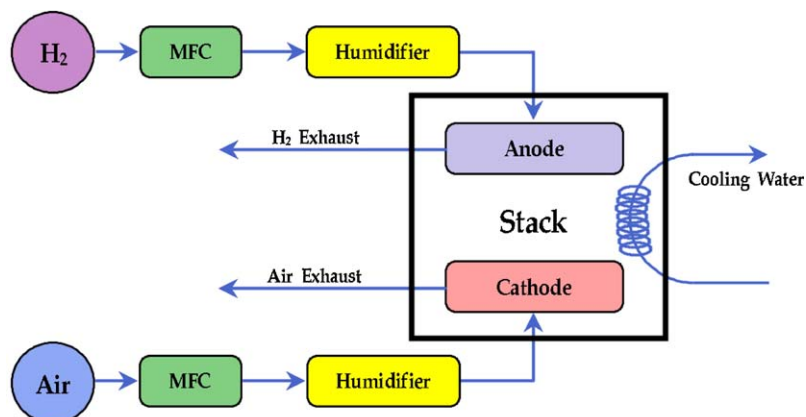


Fig. 1. Schematic diagram of the experimental setup used for fuel cell operation.

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