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An experimental investigation of electro-osmotic drag coefficients in a polymer electrolyte membrane fuel cell

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ARTICLE INFO

Article history:
Received 3 December 2007
Received in revised form
24 September 2008
Accepted 26 September 2008
Available online 14 November 2008

Keywords:
Electro-osmotic drag
Electro-osmotic drag coefficient
Water transport
Water balance
PEM fuel cell

ABSTRACT

Through the use of a water balance experiment, the electro-osmotic drag coefficients of Nafion 115 were obtained under several conditions (as a function of water content and thermodynamics conditions). For the cases when the anode was fully hydrated (corresponding to water content $\lambda \approx 14$ in the adjacent membrane) and the cathode suffered from drying when dry air was supplied ($\lambda \approx 2$), the electro-osmotic drag coefficients varied from 0.82 ($\pm$0.06) to 0.50 ($\pm$0.03) H_2O/H^+ when the current density varied from 0.4 to 1.0 A cm^{-2} (95% confidence level). When the current density increased, the electro-osmotic drag coefficient decreased. When the water content at the anode increased from $\lambda \approx 5$ to $\lambda \approx 14$, the cathode was supplied with dry air ($\lambda \approx 2$), and the fuel cell discharged constant current density at 0.6 A cm^{-2}, the electro-osmotic drag coefficient increased from 0.44 ($\pm$0.06) to 0.68 ($\pm$0.06) H_2O/H^+ (95% confidence level). Higher relative humidity gas leads to a higher electro-osmotic drag coefficient at constant current density.

1. Introduction

Obtaining reliable and reasonably priced sources of energy is essential for all nations. Recent spikes in energy prices have brought the critical role of energy to public awareness. Combined with the specter of climate change, which is one of the greatest environmental, social, and economic threats facing the planet, reliable energy sources are being sought. This has led to increasing interest in alternative power/fuel research such as fuel-cell technology, geothermal energy, solar energy, tidal and wind energy, and biomass power. Among them, a fuel cell is one of the few advanced energy technologies scalable over a wide range of applications. For fuel-cell applications to achieve widespread market penetration, however, key technical problems must be solved. To commercialize fuel-cell systems, the barriers that must be overcome include cost reduction, durability, fuel flexibility, reduction of complex integrated systems, and water/thermal management. To improve fuel-cell durability, proper water management is critical for high performance with polymer electrolyte membrane (PEM) fuel cells.

When insufficient humidified inlet gases are supplied, the water content in the membrane drops. This leads the membrane to start to dry, which increases the ionic resistance, and decreases the proton conductivity. Finally, the voltage drops and performance decreases. On the other hand, when excess humidified inlet gases are supplied, the water removal is not efficient. Water is built up at the cathode side, which leads to a "flooding" condition. The excess water blocks porous passages, reduces the electrochemical activity and the

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doi:10.1016/j.ijhydene.2008.09.077

transport rate of the reactant to the catalyst site. As a result of these actions, the excess water decreases the cell performance and reduces reactant diffusion. A sufficient amount of water for the system is a crucial item regarding the performance of the fuel cell.

1.1. *Water transport*

As seen in Fig. 1 [1], there are several water movements. First, water is supplied by an external humidification system to the anode and the cathode. Second, water is generated at the cathode because of the chemical reaction. Third, water is dragged from the anode to the cathode by protons moving through the electrolyte. Fourth, when there is a water concentration gradient because of both water generation at the cathode and supplied humidified inlet gases, water undergoes back diffusion from the cathode to the anode. Finally, water is removed by circulating hydrogen at the anode and the cathode outlet. All these processes may occur at the same time, which leads to a complex water balance for the fuel cell.

1.2. *Water production rate*

Water is produced on the cathode side as a result of the electrochemical reaction, which is the rate of 1 mole for every two electrons. The rate of water production is defined as follows:

$$j_{H_2O\_prod} = \frac{i}{2F}\left[\frac{mol}{s\ cm^2}\right] \quad (1)$$

where j is the molar flux of water, i is the current density [A cm^{-2}], and F is Faraday's constant (96,485 coulombs electro-mol^{-1}). When a proton moves from the anode to the cathode, water is 'dragged.' This is as called an electro-osmotic drag, and the flux of the dragged water is represented as follows:

$$j_{H_2O\_drag} = \xi(\lambda)\frac{i}{F}\left[\frac{mol}{s\ cm^2}\right] \quad (2)$$

where ξ is the electro-osmotic drag coefficient defined as the number of water molecules per proton, and λ $[N(H_2O)/N(SO_3H)]$ is the water content in the Nafion. After substituting Faraday's constant and the molar mass of water (18.02 g mol^{-1}) into the Eq. (1), water production becomes the following:

$$m_{H_2O\_prod} = 9.34 \times 10^{-5} \times i \quad (3)$$

Since water is generated at the cathode, there must be a concentration gradient between the anode and the cathode. When the concentration at the cathode is greater than the anode's, back diffusion occurs from the cathode and anode. The water back-diffusion flux can be determined by the

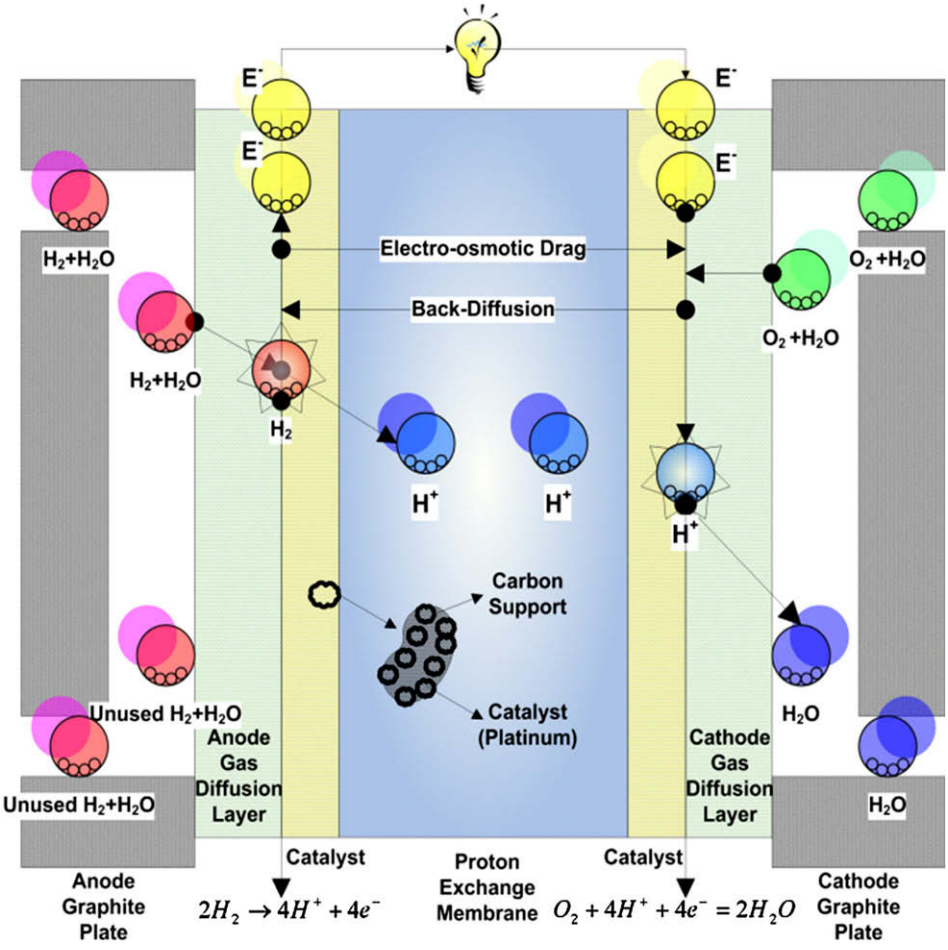

Fig. 1 – The basic principle of operation of a PEM fuel cell [1].