

Design of low-humidification PEMFC by using cell simulator and its power generation verification test[☆]

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Abstract

As long as the perfluorinated proton exchange membrane (PEM) is used for the electrolyte, both the cell performance and life are highly dependent upon the water content in the electrolyte. On the other hand, pre-humidification of fuel and oxidant gases complicates the PEMFC system and prevents it from possible cost reduction measures. In this study, in order to maintain a membrane electrode assembly (MEA) with a satisfactory water content by only the water produced in catalyst layer through the electrode reaction without prior humidification of both the fuel and oxidant gases, a novel gas diffusion layer (GDL) was fabricated. This was achieved by coating a water management layer (WML) onto a traditional GDL in order to place the WML between the traditional GDL and the catalyst layer of the PEMFC. This study describes the significant balance of water with WML in the fuel cell using both simulation and experimental analysis.

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1. Introduction

Perfluorosulfonate ion-exchange resin is typically used for the electrolyte membrane of a proton exchange membrane fuel cell (PEMFC) [1–2]. In order to obtain a high cell voltage using this membrane, a high humidity must be maintained [3–7]. However, too high humidity causes flooding of electrode. Both flooding and dehydration are well-known factors that negatively affect the performance of PEMFC [8–10]. And both simplification and cost reduction to the PEMFC system as well as improvements to reduce the cell start-up time can be achieved by humidifying the electrolyte membrane with the water produced in the cathode catalyst layers through an electrode reaction and by operating at as low a humidity of fuel and oxidant feedstreams as possible [17]. To fulfill this goal, a water management layer (WML) was installed between the catalyst layer (CL) and gas

diffusion layer (GDL) of the PEMFC [11–16]. Optimization of the low humidity of the fuel and oxidant feedstreams is thereby achieved by controlling the movement of generated water to the outside of the cell.

In this study, as part of the above-mentioned investigation, the vapor permeation rate through the WML-coated GDL necessary to achieve low cell humidification was experimentally calculated with the reported cell simulator [18] and the vapor permeation rate through various porous media was evaluated. Then, power generation tests were conducted on a single cell in which a WML of selected material had been incorporated. As a result, the lowest possible humidification cell was attained.

2. Cell simulator

A flow chart of the cell simulator is shown in Fig. 1 [18]. The simulator allows for the phenomena inside the cell to be mathematically analyzed by coupling the electrode reactions, mass transfer and heat transfer including both evaporation and condensation.

Distributions of current density, temperature and gas composition are two-dimensionally calculated in a cell plane. And

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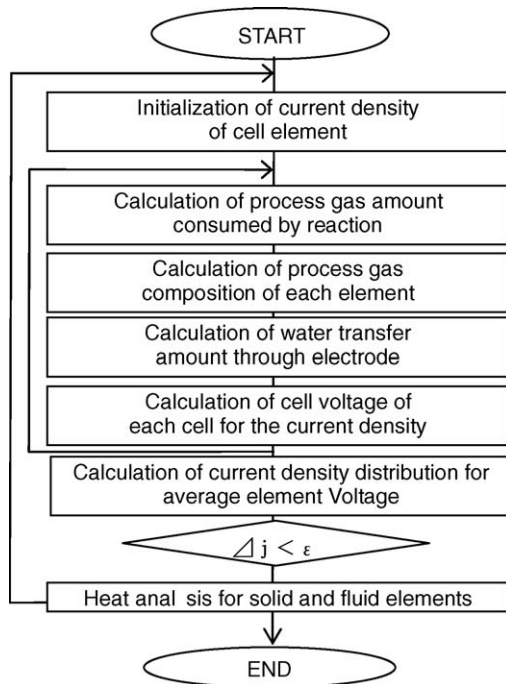


Fig. 1. Flow chart of cell simulator.

mass transfer of hydrogen, oxygen, proton, water and vapor in MEA are one-dimensionally calculated in a stacking direction of cell parts such as a membrane, catalyst layer and gas diffusion layers. By combining the two-dimensional calculation in a cell plane with the one-dimensional calculation in a cell stacking direction, phenomena in cell three-dimensionally simulated.

In this cell simulator, the WML is coated onto a traditional GDL so that it can be inserted between the anode and cathode's catalyst layer and GDL, and the movement of the generated water to the outside of the cell is controlled. Thus, the goal was to maintain the polymer membrane and the catalyst layer in a humid state. In this analysis model, the vapor permeation rate, dn/dt ($\text{mol s}^{-1} \text{m}^{-2}$), through the GDL or the WML-coated GDL can be expressed in the following equation [20]:

$$\frac{dn}{dt} = \frac{1}{1 - \omega} n D \frac{\partial \omega}{\partial y} \quad (1)$$

Here ω is the mole fraction of water vapor in humidified air, D the diffusion coefficient of water vapor through GDL or WML-coated GDL ($\text{m}^2 \text{s}^{-1}$), n the mole density of water vapor (mol m^{-3}), y the stacking direction of cell parts, and t is the time (s).

3. Design of low humidification cell with simulator

The cell simulator described in Section 2 was used to evaluate the optimum vapor permeation rates through the GDL or WML-coated GDL for a cell with a reaction area of $3 \text{ cm} \times 15 \text{ cm}$. The purpose of this configuration is to maintain the catalyst layers, which are located on both sides of the polymer mem-

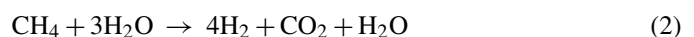
Table 1
Analytical conditions for cell stack

| | |
|---------------------------------|--|
| Active area | 0.03 m × 0.15 m |
| Operating pressure | Ambient |
| Cell temperature (°C) | 80 |
| Flow field | |
| Fuel | Straight |
| Oxidant | Straight |
| Gas flow direction | Co-flow |
| Gas composition | |
| Fuel | H ₂ + CO ₂ (20%) |
| Oxidant | Air |
| Current density | 0.4 A cm ⁻² |
| Utilization (%) | |
| Fuel | 70 |
| Oxidant | 40 |
| Humidification temperature (°C) | |
| Fuel | 60 |
| Oxidant | 40 |

brane, at a high humidity using only the reaction-generated water.

3.1. Analytical conditions

The analytical conditions for the cell stack are shown in Table 1. For this analysis, a stack with an active area of $3 \text{ cm} \times 15 \text{ cm}$ was assumed, and only a single cell with insulated boundary conditions on both sides was used as the model, in order to represent one of the stacked multi-cells. As shown in the table, the operation pressure was atmospheric pressure and the cell temperature was 80 °C. The gas composition of the fuel was that obtained by methane reforming, and is shown in the following equation:



The utilization of fuel was 70%. The oxidant was air that is humidified at a relatively low temperature, 40 °C, with a utilization of 40%. The current density was fixed at 0.4 A cm^{-2} . The water diffusion coefficient through the membrane was fixed as $D/\partial y = 2.0 \times 10^{-2} \text{ m s}^{-1}$ divided by a membrane thickness, which was experimentally obtained in a water permeation test of the same kind of membrane as used in power generation test [17].

3.2. Analysis results

Fig. 2(a) and (b) shows the relationship between the relative humidity and $D/\partial y$ of Eq. (1). The relative humidity is plotted for fuel, oxidant, the anode catalyst layer, and the cathode catalyst layer at both the oxidant inlet and outlet, which were all obtained from the simulation analysis. As shown in the figure, a vapor permeation rate of the GDL or WML-coated GDL at the oxidant inlet and outlet should be set to $D/\partial y = 9 \times 10^{-4}$ and $2.5 \times 10^{-3} \text{ m s}^{-1}$, respectively, in order to maintain a relative humidity of around 90% at both catalyst layers.

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