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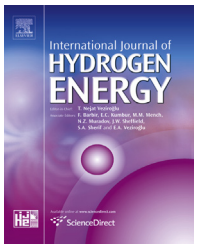

Simulation and experimental analysis on the performance of PEM fuel cell by the wave-like surface design at the cathode channel

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ABSTRACT

A polymer electrolyte membrane fuel cell shows different levels of performance depending on the designs of the flow fields. The designs of the flow fields vary the diffusion flux, which is the flow in a channel moving through gas diffusion layers to catalyst layers. Therefore, flow fields that can suppress concentration loss in the area of high-current density have been suggested. The bottom of the cathode channel was fabricated in a wave shape to increase the velocity gradient of the flow from the gas diffusion layers. As a result, concentration loss induced by unstable mass transfer was delayed and the fuel cell's performance was improved by 5.76% in the experiment using a 25 cm^2 unit-cell and by approximately 5.17% in the numerical analysis using a 84 cm^2 unit-cell.

1. Introduction

Studies to improve the performance of the polymer electrolyte membrane fuel cell (PEMFC) are being conducted across various fields including catalyst development. A number of researches on channel designs are being conducted to find more effective fuel and oxygen supply methods, especially in the flow fields.

Among experimental researches, Yan et al. [1] compared the performance between interdigitated flow fields and parallel flow fields with or without the use of a baffle and concluded that the performances improved with the use of a baffle. In addition, Rahimi et al. [2] inserted wire coils inside cathode channel increase the momentum and proved that the inserted wire coil channels increased the power density by up to 41% from that of the reference channel by numerical analysis and experiment.

Numerical analysis is vital role in the study of fuel cells because it can measure momentum, heat transfers and mass transfers of fuel cells, which cannot be measured in experiments.

First, Shimpalee et al. [3] compared current densities, temperatures, and the water content distributions of membranes of serpentine flow fields for the same reaction surface according to the numbers, the lengths and the designs of channels using numerical analysis. Wang et al. [4] showed the

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Nomenclature

c	concentration, mol m^{-3}
D	diffusivity, m^2/s
E	standard equilibrium potential, V
F	Faraday constant, C mol^{-1}
H	channel height, m
h	channel amplitude, m
J	diffusion flux, mol m^{-2} s^{-1}
j	current density, A/cm^2
K	permeability, m^2
L	channel pitch, m
V	voltage, V
U	velocity, m^2/s
ER	expansion ratio
AD	adhesive distance

Greek symbols

δ	thickness, m
ε	porosity

Superscripts

0	bulk
*	catalyst layer

Subscripts

P	product
R	reactant

improved performances of the interdigitated flow fields and the serpentine flow fields by forced convection. When the reaction surface in the channels was increased but the performance of the parallel flow fields was reduced due to low oxygen supply. Roshandel et al. [5] applied biological fluid flow patterns of leaves to parallel flow fields based on the facts derived through numerical analyses. That is, the performances of flow fields varied depending on the design, size and pattern of the flow field. The results showed that the power density was improved by 56% compared to the parallel flow field and by 26% compared to the serpentine flow field. Han et al. [6,7] used a non-dimensional variable to predict flooding in the cathode and suggested a channel that used the Concus–Finn phenomenon to effectively remove flooding.

Based on the installation of a flow resistance device, Wu and Ku [8] installed resistors widthwise to disturb the flow in the channels according to variations of five main variables using the Taguchi method. Furthermore, Perng and Wu [9] installed square blocks inside the channels and changed the gaps between GDL and the channels. By experiment and computational numerical analysis, they discovered that the performance of fuel cell was improved compared to the channels without the blocks. Also the fuel cell with open type blocks installed in the middle of the channels demonstrated the best performance. Based on these results, the heat transfer inside the channels according to the sizes and the locations of the blocks were obtained by computational numerical analysis, and time-variant Nusselt number distributions were analyzed [10]. In addition, the parameters studies including tapered ratio and gap ratio on the channel were also studied by computational numerical analyses [11]. Kuo et al. [12] claimed that a wave-like flow channel improved the power density of the fuel cell up to 39.5%. The numerical results reveal that the wave-like surface enhances the transport of the reactant gases through the porous layer, improves the convective heat transfer effect, increases the gas flow velocity. However, past studies mainly analyzed the wave effectiveness in the gas flow channel, these studies were limited they failed to suggest optimization conditions of the wave form.

This study suggests the design factors, such as the amplitudes and the pitches of waves, to effectively improve the catalysis reaction performance in the catalyst layer and verifies the effectiveness of this method by evaluating the performance of the PEM fuel cell. This study provides the design factors and conditions that are necessary for improving the performance of the PEM fuel cell as information for determining the optimized design of the cathode channel of the PEM fuel cell.

The purpose of this study is to suggest contemporary alternatives to reduce the concentration loss. For this reason, we were examined according to the variations of the heights and the distances of the wave-form and the changes of variations induced by the suppression of concentration loss. We fabricated the optimized channel, which was verified by simulation and an experiment, as a unit cell of the PEM fuel cell to compare the performance of the optimized channel with those of other channels.

2. Associated theories

2.1. Polarization curve

Fuel cell creates 1.23 V of equilibrium potential between hydrogen and oxygen. However, the actual open circuit voltage is around 1 V due to temperature, pressure, and the concentration of the reactant. Generated potential decreases as generated current increases. Eq. (1) demonstrates the three voltage losses. At first, activation loss depends on the activation levels of the electrochemical reactions. The ohmic loss is the resistance loss induced by the unique resistances of the components of fuel cell. And the concentration loss occurs when reaction rates of hydrogen and oxygen are faster than their supply rates.

$$V = E_{\text{thermo}} - \eta_{\text{act}} - \eta_{\text{ohmic}} - \eta_{\text{conc}} \quad (1)$$

Among these, mass transfers of hydrogen and oxygen occur during concentration loss through the gas diffusion layers in the channels. The gas diffusion layers have low permeability and minimal convection effects [13].

In Fig. 1, c_R^*, c_p^* represent the catalyst layer reactant and product concentrations respectively and c_R^0, c_P^0 represent the bulk reactant and product concentration, respectively. δ represents the thickness of the gas diffusion layers. The fuel cell begins producing current at time $t = 0$. Starting from constant