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# Performance and flow characteristics of large-sized PEM fuel cell having branch channel

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ABSTRACT

In order to further commercialize fuel cell systems, the price of the systems needs to be reduced. In particular, problems concerning the high price of the stack, part of the fuel cell system, need to be resolved. The reduction of the number of stack layers can achieve shrinkage of the stack components, including the bipolar plate, MEA, and gasket, with a significant reduction in the price of the stack. Accordingly, to determine a way to reduce the number of stack layers, the bipolar plate needs to be large; this study thus presents a new channel pattern to restrain the increase of the differential pressure of the cathode that would be caused by a large-sized bipolar plate. Computational analysis shows that, in the case where a branching factor (*f*) of the branch channel is changed from 1 to 0.5 in its exit part, the performance of the channel is similar, but the pressure drop is reduced by 78.33% compared to a serpentine channel. Test results suggest that while the serpentine channel produces the electric power of 139.8 W due to the pressure drop, a blower consumes electric power of 9.12 W and, in case of the branch channel with the *f* value of 0.5 in its exit part, the blower consumes the electric power of 4.38 W, which is a 3.55% greater performance compared to the serpentine channel.


## Introduction

The performance of a polyelectrolyte (PEM) fuel cell is affected by the design of the bipolar plate, channel, and rib as well as the operating conditions. Especially, the design of the bipolar plate determines the pressure drop inside the plate, shows some difference in power consumption of the balance of plant (BOP) in the fuel cell system, and subsequently determines the power-generation efficiency of the system. Pattern optimization and computational analyses, however, have mostly been focused in the study of electrochemical reaction, but not in the study of the system's efficiency resulting from the performance and pressure drop of the bipolar plate [1–3]. The cathode, which plays the role of discharging the pathway of water produced and supplies air necessary for the reaction, affects the power consumption of the compressor and the efficiency of the fuel cell system according to channel patterns. Consequently, studies on the cathode patterns have been continuously conducted [4].

Shou-Shing Hsieh et al. [5] compared and tested the operating temperature, flux, limiting current density and pressure

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**Nomenclature**

| | |
|---|---|
| A | Area, $cm^2$ |
| C | Mass fraction |
| D | Diffusion coefficient, $cm^2/s$ |
| F | Faraday constant, 96,487 C/mol |
| H | Height, m |
| I | current, A |
| M | Molecular weight, kg/mol |
| N | Number of channels |
| W | Width, m |
| S | Entropy |
| T | Cell temperature, K |
| V | Cell voltage, V |
| h | Specific enthalpy, kJ/kg |
| k | Thermal conductivity, W/m·k |
| p | pressure, kPa |
| $\vec{u}$ | velocity vector, m/s |
| u | x-direction velocity, m/s |
| v | y-direction velocity, m/s |
| w | z-direction velocity, m/s |

*Greek letters*

| | |
|---|---|
| $\alpha$ | Transfer coefficient |
| $\beta$ | permeability, $m^2$ |
| $\varepsilon$ | porosity |
| $\mu$ | viscosity, kg/m·s |
| $\Phi$ | phase potential, V |
| $\rho$ | density, $kg/m^3$ |

*Subscripts*

| | |
|---|---|
| $H_2$ | hydrogen |
| $O_2$ | oxygen |
| $H_2O$ | water |
| m | mass |
| aw | anode water |
| cw | cathode water |
| x | x-direction |
| y | y-direction |
| z | z-direction |
| k | *k*th species of the mixture |
| eff | effective |
| cell | unit cell |
| cv | cell voltage |
| s | solid |
| e | electron |
| S | Source term |

drop inside a bipolar plate according to the change of operating hours and amount of water accumulated with regard to 4 types of bipolar plates: Mesh, Parallel, Serpentine, and Interdigitated. Seong Ho Han et al. [6,7] studied a channel pattern meeting the Concus-finn condition to positively restrain a flooding pattern, and conducted a study on the enhancement of reaction inside the channel of the bipolar plate using a wave form.

Given the shape of the leaf or blood vessel, R. Roshandel et al. [8] designed a bio-inspired bipolar plate and conducted a study to compare its performance to the parallel- and serpentine-patterned bipolar plate, while S.M. Senn et al. [9] presented a new form called the Double-staircase, applying the branching level of K value and studied its optimization.

Chengbin Zhang et al. [10] designed a network pattern, which was divided into two branches while reducing its cross-sectional area at a constant rate, and then conducted a study to compare the power consumption of the pump, the pressure drop inside the channel, and the COP to the serpentine pattern. In addition, Bladimir Ramos-Alvarado et al. [11] designed a bipolar plate, the pattern of which was divided into two branches and then recombined. They then presented a bipolar plate that had higher performance and lower pressure drop and showed a current density distribution homogeneous across the MEA area.

The existing studies have concentrated on a number of ways to improve the performance of the fuel cell, mostly in terms of the shape, size, and pattern of the channel. In order to further commercialize the fuel cell system, however, the price of the system needs to be reduced. In particular, any problems concerning the high price of the stack, part of the fuel cell system needs to be resolved. The reduction in the number of stack layers can result in the shrinkage of stack components, including the bipolar plate, MEA, and gasket, and consequently the significant reduction in the price of the stack. Accordingly, to reduce the number of stack layers, a large bipolar plate is needed. Therefore, this study presents a new channel pattern to restrain the increase of the differential pressure of the cathode that is caused by the large-sized bipolar plate.

This study presents the design of a new bipolar plate to obtain a lower pressure drop than that of the large-sized bipolar plate. The proposed bipolar plate is compared and verified through computational analysis and a channel is manufactured with the highest performance as a unit cell and verified by testing.

## Channel design

### *To design a channel suitable for a large-sized bipolar plate*

The reaction area of the bipolar plate needs to be large in order to minimize the loss of energy generated in the manifold and the energy of the coolant for cooling the bipolar plate. When the reaction area is small, it is necessary to stack many unit cells in order to manufacture a stack with the desired power, but when the reaction area is large, it is possible to reduce both the number of the stacked unit cells and the length of the manifold, thus minimizing the loss of energy caused by the pressure drop. Furthermore, the diminished length of the coolant manifold, which resulted from the enlarged reaction area, leads to the reduced deviation of flux supplied into the coolant channel; thus, not only is the flux by the cell supplied constantly, it also has the advantage of removing the relatively high heat flux accumulated at the central part of the stack [12]. The enlarged reaction area, however, results in an increased channel length and a weakness then develops whereby the pressure drop may increase inside the bipolar plate. As a result, it becomes difficult to acquire an