Development of 1 kW Class PEFC Stack System with Variable Gas Flow Channel

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Abstract

The 1 kW class PEFC stack system with a new function of variable gas flow channel has been developed to keep stable operation with high efficiency in a wide range of load. This stack system with the new function was turned out to suppress a flooding phenomenon by switching the connection of the channel from parallel to series flow to expel the remained water within the channels with increase of gas flow velocity at the low load less than 100 mA cm^{-2}. This system will be beneficial for the practical PEFC stack system as a power source capable to use for the wide range of load.

1 Introduction

Polymer electrolyte fuel cell (PEFC) is considered to be a promising candidate of clean power source for electric vehicles or stationary systems because of its high energy conversion efficiency. The stable and efficient operation of PEFC at various loads has been strongly required for the practical use. There needs, for example of electric vehicle, the minimum power for idling step and the maximum for accelerating step, respectively. Two main problems were observed in such a wide load operation. One is a flooding phenomenon caused by insufficient gas flow velocity enough to expel the remained water within gas flow channels, resulting in the remarkable voltage drop under the low power operation when the gas utilization is same as the case of high power.[1] The other is an increase of pressure loss through gas flow channels caused by the increase of amount of fed gas to meet its corresponding electrochemical reaction, resulting in the extra energy of auxiliary systems such as a gas feed pump and so on. We have proposed the variable gas flow channel of which function is to solve these problems by switching the connection of gas flow channels in series or parallel. The beneficial function will be discussed in more detail for the 1 kW class PEFC stack system.

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2 Experimental

The 1 kW PEFC stack composed of 20 single cells in series was designed with the function of variable gas flow channel. Each cell has gas flow plates and gas diffusion backings on both sides of membrane electrode assembly (MEA). The MEA was prepared by hot-pressing the catalyst layers on the both sides of polymer electrolyte membranes (Nafion 115). The catalyst material was Pt/C (platinum supported on carbon) for cathode and Pt-Ru/C (platinum-ruthenium supported on carbon) for anode. The value of platinum loading level for the cathodes and anodes was 0.8 mg cm^{-2} and 0.4 mg cm^{-2}, respectively. The apparent surface areas of these electrodes were 230 cm^2. Each cell was layered and then pressed with the metal plates set on either end of the stack. The representative structure of gas flow plates of the stack with variable gas flow channel is shown in Fig. 1. The two kinds of gas flow directions in series and parallel within the plates are shown with arrow in Fig. 2. These connections of gas flow channels were switched by the operation of valves set on the outside of stack.

The evaluation of stack was carried out selecting the connection of the channels for both sides of anodes and cathodes. Air and reformed gas or hydrogen were used as oxidant and fuel gas, respectively. The composition of reformed gas was 80% H_2, 20% CO_2, and 10 ppm CO. These gases were humidified at the temperature of 80 °C. The utilizations of oxidant and fuel gas were 40% and 80%, respectively. The coolant flow channel was equipped in every cell and the temperature of MEA was controlled by setting the temperature of 80 °C at the position of coolant outlet. The coolant was supplied to the channels

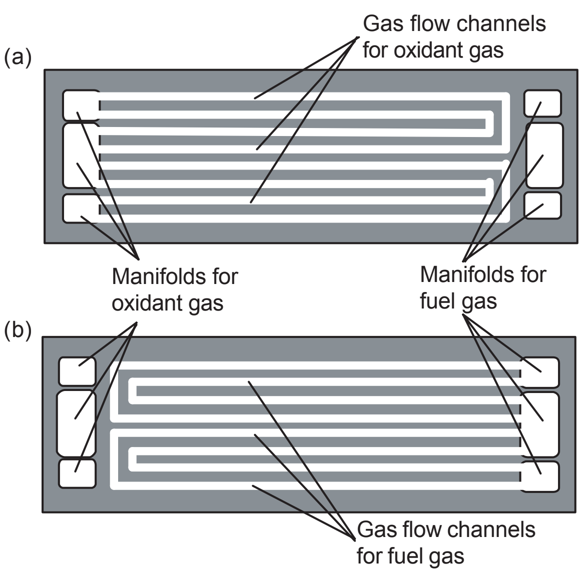

Fig. 1 The representative structure of gas flow plates for cathode (a) and anode (b) of the stack with variable gas flow channel.

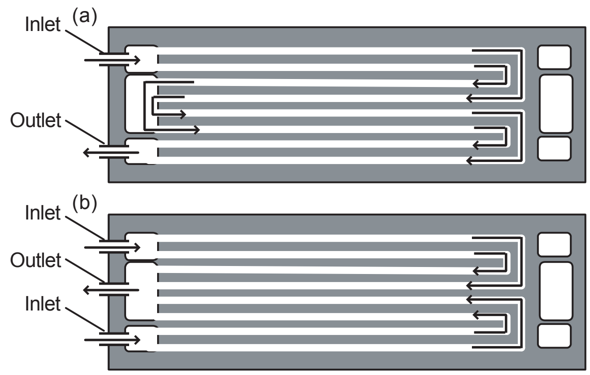

Fig. 2 Representative illustrations for the gas flow direction of series flow (a) and parallel flow (b) within gas flow plate.

with the same direction as the air flow in the selection of the parallel flow condition. The difference of temperature between inlet and outlet of the coolant was also controlled so as to maintain to be less than 2 °C. The change in average cell voltage of the stack on short-term was measured at 50 mA cm^{-2} with series and parallel flow under the condition of air and pure hydrogen. The pure hydrogen was only used for this measurement in order to avoid an affect of voltage drop due to CO poisoning. The distribution of operation voltage of single cells within the stack was measured at constant current density of 50 mA cm^{-2} using four types of combination flows in series and parallel. The evaluation of voltage-stability test after switching the connection of the channels for only air was conducted at 300 mA cm^{-2}. The evaluation of stability performances on continuous operation of the stack with suitable connection of the channels was conducted at constant current density of 50 and 300 mA cm^{-2}.

3 Results and Discussion

Polarization curves for 1 kW PEFC stack with gas flow channel in series and parallel flow are shown in Fig. 3. The obvious drop in average cell voltage is observed at lower current density than 50 mA cm^{-2} in the case of parallel flow. This voltage drop is considered by the occurrence of shortage of reactant

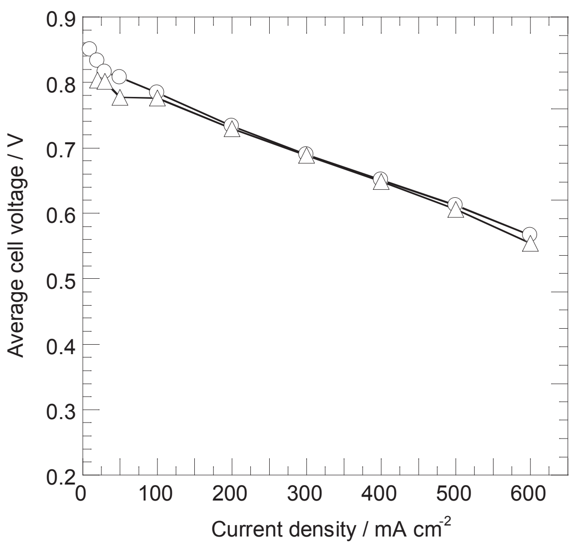

Fig. 3　Polarization curves for 1 kW stack with series flow (○) and parallel flow (△) under the condition of air and reformed gas at 80 °C.

gas caused by the flooding phenomenon within the gas flow channel. The change in pressure loss of air and reformed gas flow channels in series and parallel for the stack under various current densities is shown in Fig. 4. There observes the big difference in pressure loss between series flow and parallel

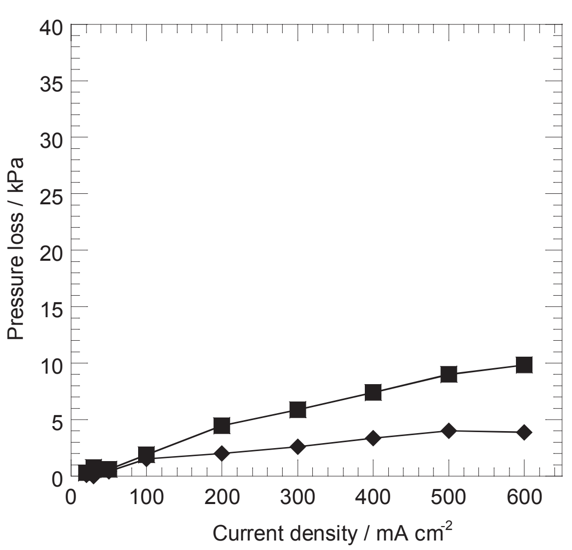

Fig. 4　Change in pressure loss of air and reformed gas in gas flow channel for 1 kW stack with in series flow (●, ■) and parallel flow (▲, ◆) under various current densities at 80 °C.
(a) Air; (b) Reformed gas.

flow for both of air and reformed gas especially at the higher current density over 100 mA cm^{-2}. That is, the former flow shows the larger pressure loss than that of the latter flow. It is obviously due to the longer length of gas-flow-pass for the former one. Considering the above mentioned undesirable phenomena observed in lower and higher current density, it is natural that the stack with fixed connection of either series flow or parallel flow should not be proper for the operation in wide range of current density. Therefore, a new function of variable gas flow channels was added to the PEFC stack system to be capable for the application in the wide range of load, especially for electric vehicle or stationary power sources.

The combined functions of prototype 1 kW PEFC stack with variable gas flow channel were evaluated by selecting optimum condition of series flow less than or equal to the current density of 100 mA cm^{-2} and parallel flow beyond 100 mA cm^{-2} to show the improvement of the combined flow direction system. The representative polarization curve and air pressure loss of gas flow channels are shown in Fig. 5. The function of variable gas flow channel is turned out to provide stable average cell voltage and low pressure loss for air and reformed gas at wide range of operating current density from 10 to 600 mA cm^{-2}. The selection of series flow at the lower current density below 100 mA cm^{-2} is considered to expel the remained water from its channel to outlet by increasing of gas flow velocity, resulting in the stable cell voltage. The switching of the connection from series to parallel is also considered to reduce the pressure loss of feed gas, resulting in the reduction of energy loss for auxiliary systems at high load operation. The change in average cell voltage for the stack with series at the lower current density during the continuous operation is shown in Fig. 6 for the clear difference of the effect of variable gas flow channel. The average cell voltage with series flow is confirmed to be stable compared with the case of parallel flow in which the repetitious voltage change with a momentary drop was observed by the

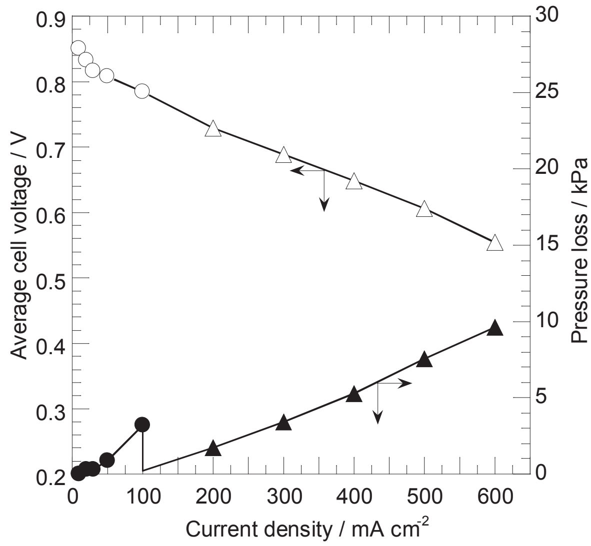

Fig. 5 Representative polarization curve and change in pressure loss of cathode gas flow channel for the prototype 1 kW stack with optimum selection of the variable gas flow channel with series flow (○, ●) and parallel flow (△ , ▲) at 80 ^{o}C under the condition of air and reformed gas.

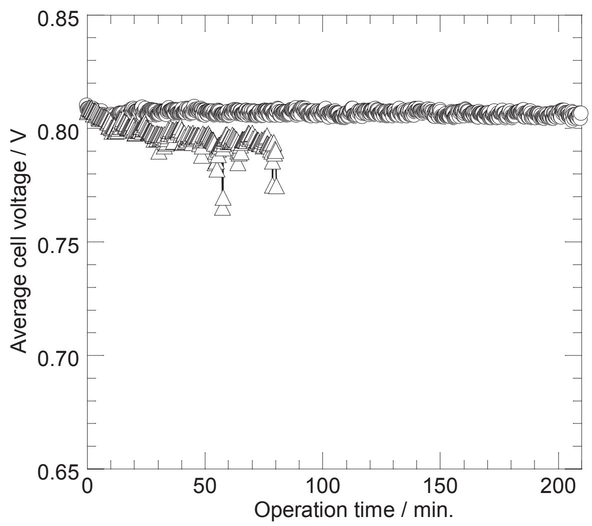

Fig. 6 Change in average cell voltage of 1 kW stack on short-term operation at 50 mA cm^{-2} and 80 ^{o}C under the condition of air and hydrogen with series flow (○) and parallel flow(△).

flooding phenomenon caused of remained water.

The voltage distribution of each cells composed for 1 kW PEFC stack was investigated to clear the effect of different combination of series flow and parallel flow for each of cathode and anode. The representative distribution of cell voltage is shown in Fig. 7. Uneven distribution of cell voltage is observed in the combination of parallel flow for each electrode. This means that the large cell voltage drop is occurred by the flooding phenomenon even in the anode as well as cathode.

Inevitable backward flow is considered to be appeared after switching the gas flow channel because of the change of the stream of gas flow as indicated by the change of the direction of arrow in Fig.2. The representative behavior of average cell voltage of the stack after switching the connection of channels for cathode is shown in Fig. 8. The operation time was counted from the switching. The sudden drop of average cell voltage is observed subsequent to the gradual increase towards the stable voltage in the case of the change from parallel to series as expected. The reverse behavior is also observed in the case of the change from series to parallel. These phenomena are derived from the temporary variation of gas utilization towards higher value, in other words, shortage of oxygen gas by the increment

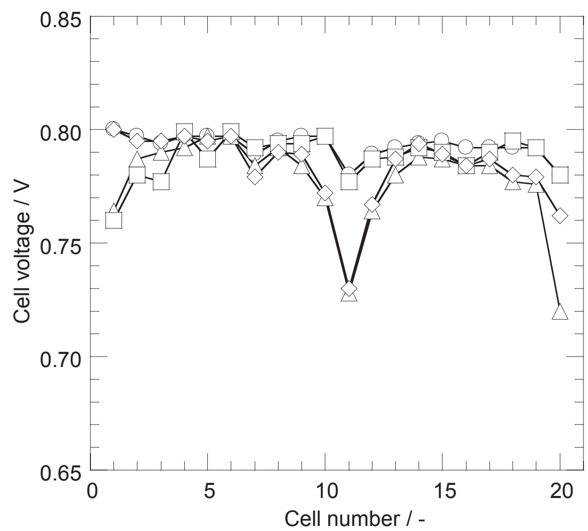

Fig. 7 Cell voltage distributions for prototype 1 kW stack operated at 50 mA cm^{-2} and 80 ^{o}C under the condition of air and reformed gas.
○ Series flow for both air and reformed gas; △ Parallel flow for both air and reformed gas; □ Parallel flow for air and series flow for reformed gas; and ◇ Series flow for air and parallel flow for reformed gas.

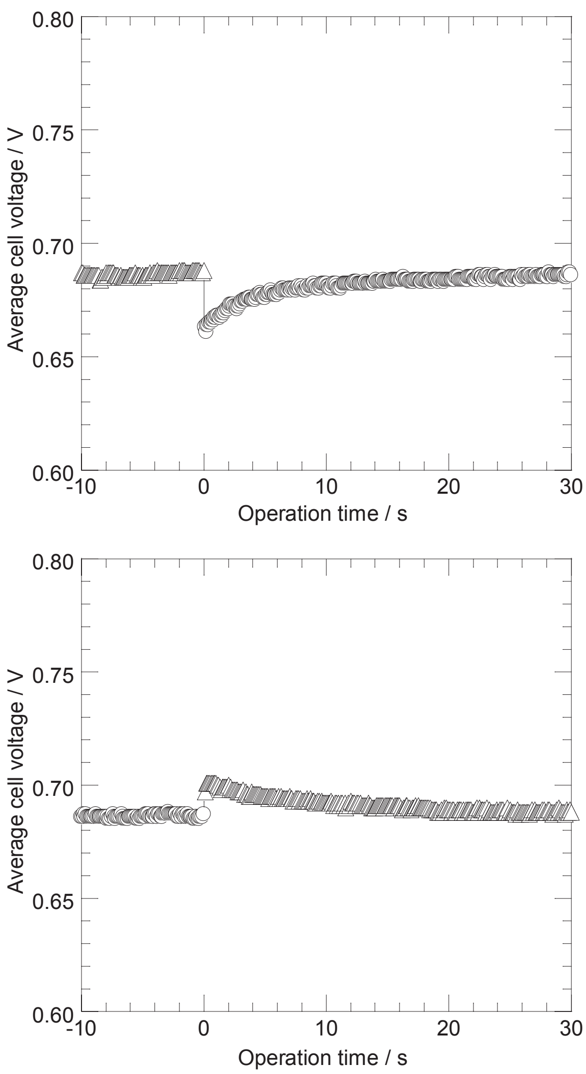

Fig. 8 Representative change in average cell voltage for prototype 1 kW stack after switching connection of gas flow channels for air operated at 300 mA cm^{-2} and 80 ^{o}C under the condition of air and reformed gas.
(a) Switching of channels for air from parallel flow (△) to series flow (○); (b) Switching of channels for air from series flow (○) to parallel flow (△).

of pressure loss in the former case and lower value, excess of the gas by reduction of pressure loss in the latter case at the condition of constant current density operation (See Fig. 4 (a)). However, these phenomena are limited to be observed only up to 15 seconds.

Finally, the representative change in average cell voltages on continuous operation of the prototype 1 kW PEFC stack with variable gas flow channels is shown in Fig. 9. The average cell voltages are turned out to be stabled in both series and parallel flow over 100 h at low and high current density.

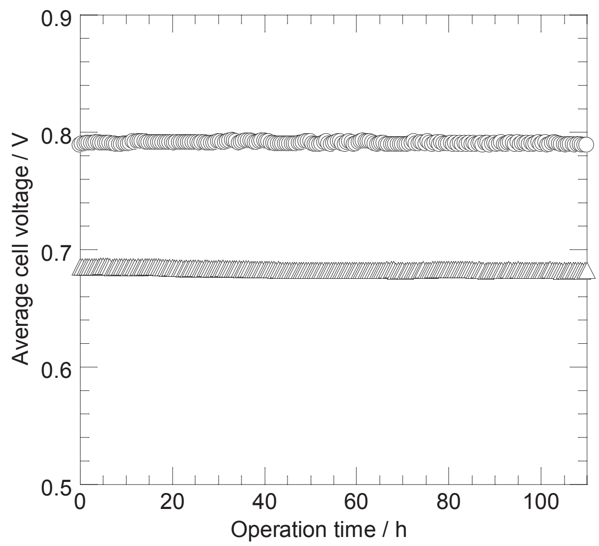

Fig. 9 Change in average cell voltage for prototype 1 kW stack operated at 80 ^{o}C under the condition of air and reformed gas.
○ Series flow at 50 mA cm^{-2};
△ Parallel flow at 300 mA cm^{-2}.

4 Conclusion

The 1 kW class PEFC stack system with a new function of variable gas flow channel has been successfully developed to keep stable operation with high efficiency in the wide range of load. The PEFC stack system with the new function was turned out to be able to suppress a flooding phenomenon by switching the connection of the channel from parallel flow to series flow to expel the remained water within the channels with the increase of the velocity of gas flow at the low load of low current density less than 100 mA cm^{-2}. This new system will be beneficial for the practical PEFC stack system with the wide range of load use, especially for electric vehicles or stationary power sources.

Acknowledgememt

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Reference

1) P. Rodatz, F. Buchi, C. Onder and L. Guzzella, *J. Power Sources*, **128**, 208 (2004).