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Short communication

Operating characteristics of 40 W-class PEMFC stacks using reformed gas under low humidifying conditions

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Abstract

The small PEMFC stack to be integrated with miniaturized fuel reformer is usually operated under very poor operating conditions such as low relative humidity and reformed gas conditions including trace amounts of CO. Hence, for the stable operation of the stack under such real conditions, the effect of reactants feeding method and stack operating conditions such as stack temperature and gas humidity were experimentally investigated and the optimal operating strategy was suggested.

The external-manifolds configuration was not efficient compared to the internal-manifolds due to their poor water management. The fuel introduction to the stack by opposite directions between air and hydrogen enhanced the stack stability, particularly under low humidified conditions, by enhancing water exchange between the two fuel streams. Even 10 ppm of CO in the reformed gas deteriorated the stack performance seriously under low stack temperature or low relative humidity conditions. Hence, for the stable operation of the small PEMFC stack, particularly under practical operating conditions, air-bleeding method seems to be a promising strategy.

Keywords: Polymer electrolyte fuel cells; Portable fuel cells; PEMFC stacks; CO tolerance; Low humidified conditions

1. Introduction

Small proton exchange membrane fuel cells (PEMFCs) have been receiving much attention as an attractive candidate for portable power sources. Several PEMFC systems for electronic devices [1–2], portable powers [3–4] and military applications [5] have been already reported. However, they still have many technical challenges for high power density and durability under practical operating conditions to enter the real fuel cell market.

In the present study, we developed 40 W-class air-cooling PEMFC stack to be integrated with a miniaturized methanol reformer. To minimize the PEMFC system volume, the present stack was designed to be operated under severe operating conditions including low humidified fuels and reformed gas containing a few ppm of CO as a hydrogen source. Hence, our study mainly focused on investigating the reactants feeding strategies to enhance the stack performance under low humidifying conditions. As reactants feeding methods, two stacks employing internal- and external-manifolds were prepared and compared on their performance behaviors. In addition, the reactants feeding options such as same direction and opposite direction between hydrogen and air in the stack have been examined to improve the water utilization and uniformity of gas humidity in the stack. Another research interest in the present study is to examine the CO tolerance of the stack under severe operating conditions for portable power applications. Although many efforts have been made on the CO effect of PEMFC stack, they are mainly focused on the residential power applications [6–8]. Therefore, those were mainly performed at mild operating conditions such as high stack temperature and fully humidified conditions. It was expected that the CO will seriously deteriorate the stack performance at the present stack operating conditions such as low stack temperature and low humidifying conditions. Hence, present study mainly examined the effect of trace levels of CO

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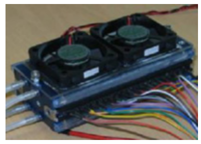
Table 1
40 W-class PEMFC stacks prepared in the present study

Designation	E-1	I-1	I-2
Picture			
Cell no.	20	17	19
Manifold type	External	Internal	Internal
Stack dimension	44 × 27 × 102 (122 cm^3)	62 × 28 × 93 (162 cm^3)	62 × 28 × 101 (175 cm^3)

on the stack performance under various operating conditions and proposed the optimum operating conditions for the stable stack performance. In addition, air bleeding in the anode was also tried as an option of CO tolerant stack.

2. Experimental

2.1. Fabrication of PEMFC stacks

Three PEMFC stacks which have about 30–50 W of nominal power have been designed and prepared as summarized in Table 1. The stacks contained 17–20 cells, each with an active area of 10 cm^2. The commercial MEA with 0.4 mg cm^{-2} Pt loading and 0.45 mg cm^{-2} Pt–Ru loading on cathode and anode, respectively, was employed for the stacks. Bipolar plates were made of graphite compound with machined serpentine flow fields. The current collectors and endplates are made of gold-coated copper and aluminium, respectively. The stack temperature was controlled by the cooling fan placed on the stack. E-1 stack employed external manifold configuration which was made of polycarbonate plate and attached to the side of the stack by silicon adhesives. I-1 and I-2 stacks used internal manifold configuration, while they have different cell numbers.

2.2. Experimental set-up

The stack performance was tested in the PEMFC test station manufactured by Fuel Cell Technologies, Inc. Pure hydrogen and simulated reformed gas (H_2 68%, N_2 10%, CH_4 4%, CO_2 18%, CO 10 ppm) cylinders which were prepared by the domestic gas company were used as anode reactants. The relative humidity (RH) of feed gas stream was controlled by humidifier in the test station. All reactants are fed into the stack at ambient pressure. Before testing the stack performance, all stacks were fully activated under the following conditions, 60 °C of stack temperature, 100% of RH and 3 A of electronic load, for 12 h in the test station.

3. Results and discussion

3.1. Optimization of reactants feeding methods in the stack

In designing the small PEM fuel cell stacks, we considered both options of reactants feeding method including external- and internal-manifolds. External-manifolds are very attractive in the small stack design because it can make more compact size and more even flow distribution compared to internal-manifolds. However, in general, internal-manifolds are often used in the PEM fuel cell stack design because of better sealing and more versatility in gas flow configuration [9]. Two small PEMFC stacks employing external- and internal-manifolds, respectively are prepared as shown in Table 1 (E-1 and I-2), and compared their performances and operation behaviors. The E-1 stack with external-manifolds configuration showed relatively small volume compared to the I-2 stack with internal-manifolds although the E-1 stack contains one more cell than the I-2 stack. However, the E-1 stack revealed lower performance compared to the I-2 stack. The I-2 showed superior performance to the E-1 at all load ranges as shown in Fig. 1. The comparison of the stack performance based on a single cell level showed the I-2 stack is higher than the E-1 stack by 450 mA cm^{-2} at 0.6 V. The main reason of the low performance of the E-1 stack was poor water management of the stack in the external-manifolds. Because the external-manifolds are exposed to the outside of

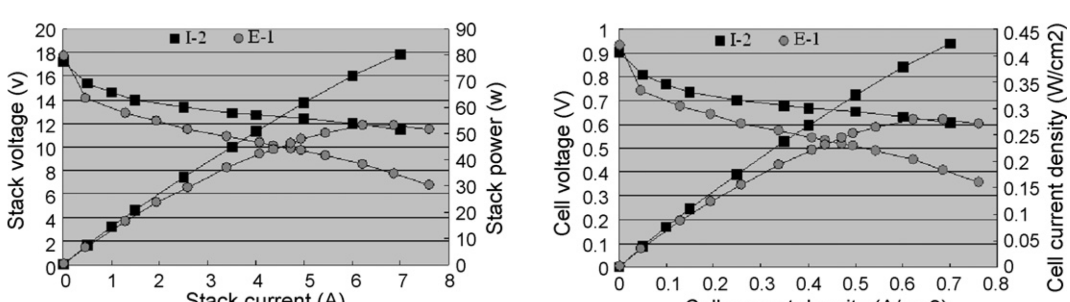


Fig. 1. *I–V* characteristics of E-1 and I-2 stacks (fuel utilization: air/H_2 = 2.5/1.4).

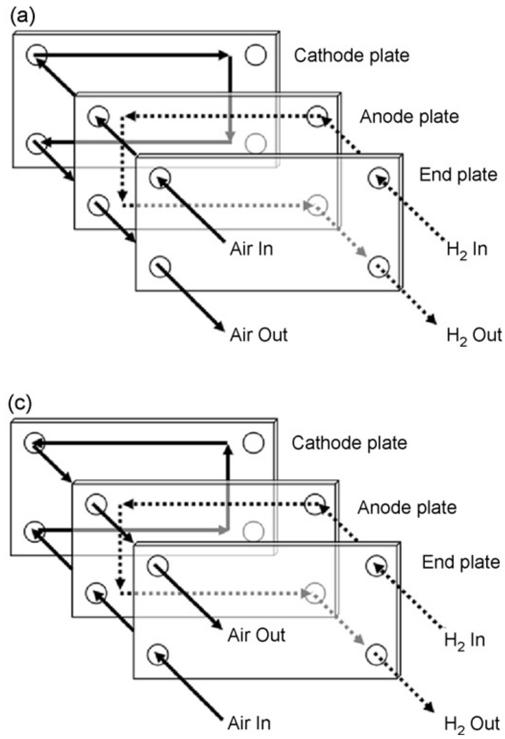


Fig. 2. Reactants feeding methods into the stack.

the stack, the humid reactants passing the manifolds were easily condensed in the manifolds, and the condensed liquid water fed into the channels and caused the severe performance loss. In actual, the liquid water was observed in the external-manifolds of E-1 stack during the stack operation. Hence, it was necessary to insulate the external manifold to prevent the water vapor condensation problems. However, the insulation of the external-manifolds resulted in increasing stack volume, which reduces the advantage of external-manifolds. In conclusion, internal-manifolds were employed as a more effective reactants feeding method in the present study.

The present PEMFC stack was designed to operate under low humidifying conditions without any humidifying devices to minimize the system volume. In that case, it is expected that the gas feeding method such as the position of gas inlet and outlet will also change the gas humidity of the cell in the stack and affect the stack performance and stability. Fig. 2 shows the four cases of reactants feeding method in the I-1 stack. They have different positions of air and hydrogen feeding into the end-plate of the stack. When we tested the stack performance for the four cases under very dry gas conditions, RH 20%, the initial performance was very similar. However the stack stability with respect to time revealed different behavior as shown in Fig. 3. When the air and hydrogen were fed into the stack to the same position such as Fig. 2(a) and (d), both up or down, the stack performance was slowly decreased with time and it revealed relatively lower stack voltage compared to (b) and (c) cases by 0.5–0.8 V after 40-min operation. In cases (a) and (d), dry hydrogen and dry air gases are introduced to the same position, both up or down direction of the stack, which make the MEA dry, particularly at the inlet part of the cell resulting in performance decrease. However, when the reactants were fed into the stack to the different position such as (b) and (c) cases, the stack showed relatively stable behavior compared to (a) and (d), and (b) case revealed the most stable performance with operating time. In cases (b) and (c), the fuel inlet position is opposite, which makes it possible to exchange the water vapor between dry hydrogen and humid air or dry air and humid hydrogen because hydrogen inlet is close to air outlet and air inlet meets hydrogen outlet. This water exchange between anode inlet gas and cathode outlet gas or anode outlet gas and cathode inlet gas will make the relatively uniform water distribution across all cells in the stack, which can make stable stack performance. For case (c), air flow direction in the cell is opposite to gravity, hence, this caused poor water discharge in the exit of cathode cell. This is the main reason of the relatively lower stack performance of case (c) than that of case

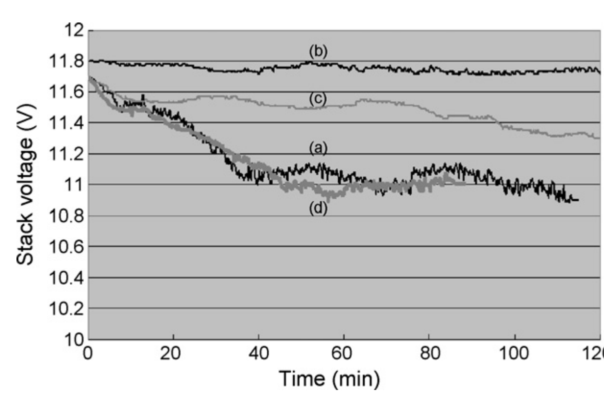


Fig. 3. Effect of reactants feeding methods on the I-1 stack performance (stack temperature 60 °C, RH 20%, fuel utilization: air/H_2 = 2.5/1.4, loads: 3 A constant current).

(b). Actually, in case (c), the stack performance restored its initial value when the air flow was fully increased to discharge the liquid water accumulated in the stack. Based on the above results, it can be concluded that the internal manifolds configuration and fuel feedings to opposite direction can be an effective reactants feeding methods to enhance the stack performance and stability under low humidifying conditions.

3.2. Optimization of the stack operating conditions under reformed gas condition

The present PEMFC stack was designed to integrate with the miniaturized methanol reformer for portable power applications. Because trace levels of CO containing in the reformed gas can decrease the stack performance seriously, the fuel reformer is generally designed to control the CO concentration less than 10 ppm, particularly in the stationary power applications. In case of small PEMFC system, it is not easy to control the CO concentrations below 10 ppm in the fuel reformer due to its limited reactor volume. In addition, the general stack operating conditions, low humidified reactants and low stack temperature, are not favorable to CO tolerance. Therefore, it is very important to examine the effect of CO contained in the reformed gas for the stack performance at different stack operating conditions. Fig. 4 shows the stack voltage behaviors at different humidity and stack temperature during the 3 A constant current operation of the stack. When the stack was operated with highly humidified fuels, 75% of RH, maintaining low stack temperature, 40 °C, the stack voltage was slowly decreased up to 1 h and it was rapidly decreased after that time without any steady behavior. The stack voltage decreased from 13.5 V to 10.3 V for 90-min stack operation using the simulated reformed gas including 10 ppm CO. This amounts to 0.17 V of average cell voltage decrease. When the anode gas feeding was switched from reformed gas to pure hydrogen, the stack voltage was rapidly increased and restored about 80% of its initial voltage. This strongly indicates that just 10 ppm of CO can seriously deteriorate the stack performance at low stack operating temperatures. At the high stack temperature, 60 °C, and low gas humidity, RH 30%, the stack also showed continuous decrease of stack voltage with respect to time without any steady up to 140 min of stack operation. However, when the stack was operated at high temperature, 60 °C, and highly humidified conditions, RH 85%, the stack showed stable behavior at about 12.5 V of stack voltage without further voltage decrease. Some voltage fluctuations in that condition were resulted from the cell flooding inside the stack and the discharge of the liquid water from the stack. These results on the stack stability at different operating conditions under reformed gas condition indicate that the stack should be operated at high temperature and fully humidified gas conditions to minimize the CO deterioration contained in the reformed gas. The two operating conditions including high stack temperature and high fuel humidity should be satisfied simultaneously to operate the stack stably. However, in practical point of view, those operating conditions are not easy to employ to the small PEMFC systems, and the fully humidified condition can make another cell flooding problems. Therefore, we tried to air-bleeding method as another strategy to control the CO contained in the reformed gas.

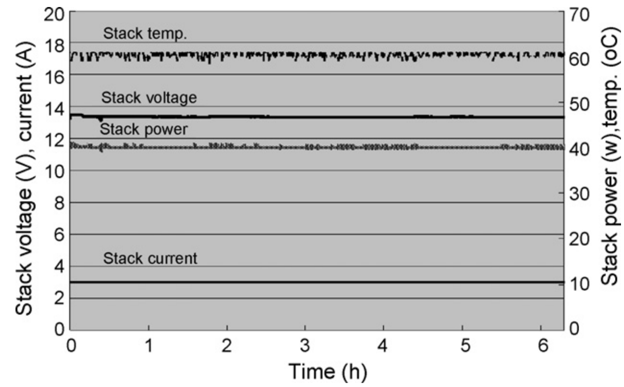


Fig. 5. Air-bleeding operation of I-2 stack under reformed gas conditions (stack temperature 60 °C, RH 30%, fuel utilization: air/H_2 = 2.5/2.0, loads: 3 A constant current, 1 vol.% air bleeding).

Fig. 5 shows the stack performance behavior at 3 A of constant current mode and air-bleeding operation at anode side under low humidifying and high stack temperature conditions. The 1 vol.% of air, which amounts to 12 $cm^3\ min^{-1}$ of air, was introduced to the anode side of the stack with 1200 $cm^3\ min^{-1}$ of anode stream containing the simulated reformed gas using mass flow controller, respectively. For 6 h continuous stack opera-

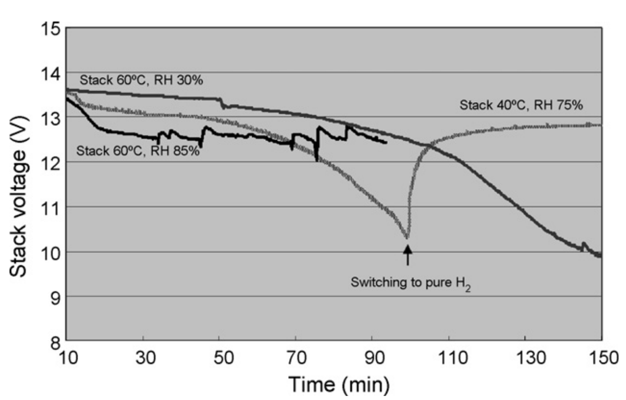


Fig. 4. Effect of stack operating conditions on the stack stability under reformed gas conditions (I-2 stack, fuel utilization: air/reformed gas = 2.5/2.0, loads: 3 A constant current).

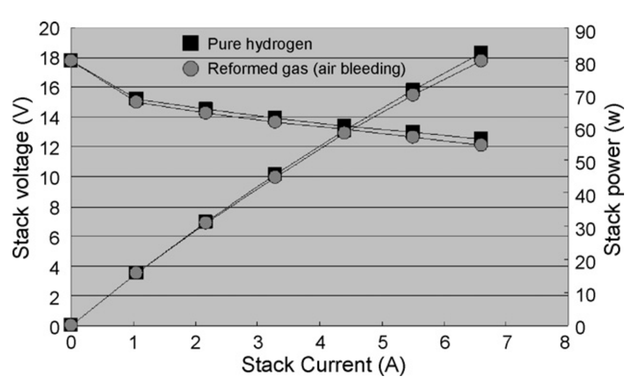


Fig. 6. Comparison of I-2 stack performance under pure hydrogen gas and reformed gas conditions (fuel utilization: air/H_2 = 2.5/2.0, 1 vol.% air bleeding for reformed gas).

tion at 3 A, the stack showed very stable behavior maintaining 13.5 V and 40 W of stack output. In air-bleeding operation, the gas humidity and stack temperature hardly affected the stack stability. As shown in Fig. 6, the stack performance in the air-bleeding mode was slightly lower than that of pure hydrogen conditions by 0.2–0.4 V. This result strongly indicates that the air bleeding can be very useful strategy for reformed gas conditions, particularly for small PEMFC stack to be used at real operating conditions.

4. Conclusions

Reactants feeding methods for stable operation of 40 W-class PEMFC stack under low humidifying condition were optimized. Although the external-manifolds can make the stack more compactable compared to the internal-manifolds, the performance was not good mainly due to the poor water management in the external-manifolds configuration. The opposite direction feedings of air and hydrogen into the stack enhanced the water exchange between anode and cathode resulting in even water distribution in the stack, which enabled the stack output very stable under low humidifying conditions.

The CO tolerance of the stack was strongly dependent on the stack temperature and reactants humidity. Even 10 ppm of CO deteriorated the stack performance under low stack temperature below 60 °C or low RH conditions. Hence, the stack should be operated at high stack temperature and fully humidified conditions for the stable stack performance under reformed gas conditions. On the other hand, in practical point of view, air-bleeding operation seems to be a good strategy for the stable stack operation under reformed gas conditions.

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