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Operation characteristics of air-cooled proton exchange membrane fuel cell stacks under ambient pressure

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HIGHLIGHTS

- Effect of cell order on air-cooled stack performance can be neglected.
- Thickness and PTFE content in GDL are founded with optimization values.
- Temperature distribution should remain at proper range.

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ABSTRACT

Air-cooled proton exchange membrane fuel cells (PEMFC) simplify the traditional cooling and air supply system. Three air-cooled stacks are assembled with different cells to investigate the effect of the polytetrafluoroethylene (PTFE) content in the gas diffusion layer (GDL), air flow rate, as well as the stack temperature on the stack performance. The results show that GDL with appropriate thickness and PTFE content can optimize the stack operation performance. The effect of the cell order on its performance can be neglected. A thermal equilibrium resulting from the heat generation and loss in the stack is achieved near the ambient temperature at low current density of 150 mA cm^{-2}. The output power increases with the increase of air flow rate. However, when the air flow rate exceed 44.7 L min^{-1} or the stack temperature is higher than 65 °C, the stack performance decreases.

1. Introduction

Proton exchange membrane fuel cell (PEMFC) is an energy conversion device that directly converts the chemical energy stored in hydrogen and oxidant into electrical energy. The PEMFC is a promising alternative to batteries as a power supply for consumer electronics, sensors and medical devices, and it is considered to be the first choice for the 21st century clean, efficient power generation technology [1–8]. The efficiency of conventional PEMFC stack is about 50% and the rest of the energy is released in the form of heat [9–13]. The PEMFC stack temperature would increase rapidly if the generated heat cannot be efficiently removed from the stack continuously. The increased temperature of the cell makes the membrane dehydrated and lowers the proton conductivity of the membrane, causing poor performance of the fuel cell and eventually leading to irreversible damages. Thus adequate attention must be paid to the design of an efficient cooling system for PEMFC stack [14–18]. In order to achieve higher efficiency, the membrane of PEMFC should be kept at a certain hydrated level to facilitate proton transport and the conventional PEMFC stack should have a special humidification system to keep the reaction gas at certain humidity. Consequently, additional auxiliary system must be applied to the PEMFC stack, which increases the complexity of PEMFC system and limits its application as a portable power system. Air-cooled PEMFC stack could simplify the cooling system, humidification and air compressor or pump system. Special channel has been designed to combine air supply and cooling system to make its applications more convenient in the field of portable power systems [19,20].

Extensive research efforts, both numerical modeling [21–25] and experimental investigations [26–31], have been conducted on air-cooled PEMFC stack. Ying [21] investigated the effect of

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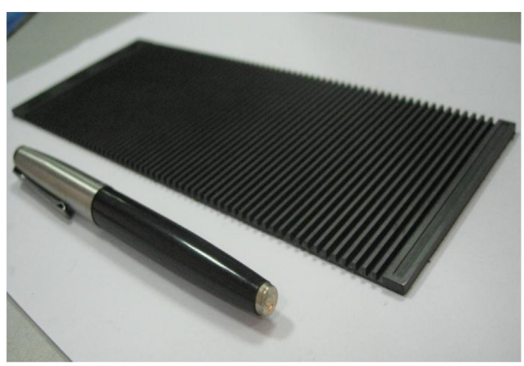
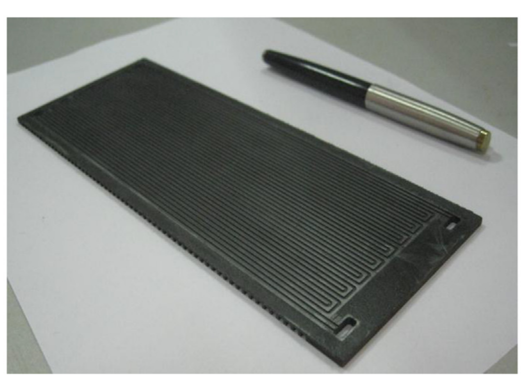
channel configuration on air-breathing fuel cell performance, and the results showed that an optimal performance could be obtained in the cell with cathode channel width of 3.0 mm (open ratio of 75.9%). Schmitz et al. [26,27] investigated an air-breathing PEM fuel cell and demonstrated that the inlet size of the cathode and the wetting properties of the GDL have an important effect on stack performance. It was revealed that the cathode flow with the 80% opening ratio is the optimal value. The hydrophilic or hydrophobic property of GDLs has little effect on stack performance. Finally, the authors gave two design rules for air-breathing PEMFCs. Ous [28] studied the water management in an air-breathing PEMFC. Their result showed that the gas stoichiometry had little effect on the water removal from the channels. Hottinen [29] studied the cold-start behavior of free-breathing PEMFC. They found that the freezing of product water inside the cell would damage the stack irreversibly at low temperature. The free-breathing PEMFC stack can start successfully at −5 °C when the cell was initially dry. Air-breathing PEM fuel cell stack has low power density and poor power output, which limits its application. In contrast, air-cooled PEM fuel cell stack usually uses an air fan at the edge of the open cathode manifolds to force air flow which guarantees sufficient oxidant supply and cools the stack, resulting in a wide power output range from 300 W to 4 kW. Wu [30] designed an air-cooled single PEM fuel cell and a 5-cell air-cooled stack to investigate the effects of critical operating conditions on the output performance. It was indicated that the cell temperature and hydrogen humidifier play important roles in reducing the fuel cell ohmic resistance. It was also observed that a hydrophilic treatment of the cathode flow field channels could improve the water management. Rosa [31] studied the influence of different operating parameters on the performance of the stack in an 8-cell air-cooled PEM fuel cell stack. They concluded that the stack performance could be significantly increased while operated with forced air convection instead of natural convection and the stack performance was practically not affected by hydrogen partial pressure. Sohn [32] analyzed the effect of relative humidity, the temperature of the stack, the utility ratio of the reactant gas on the performance of an air-cooling PEMFC. Kim [33] studied the effects of the cathode channel size and operating conditions on the performance of the air-blowing PEMFC. It was found that the output of the PEMFC stack could be improved with the decrease of the cathode channel size at the normal operating temperature. Massive flooding limits the decrease in the cathode channel size. Transition current density between the humidification and the flooding region decreased with decreasing cathode channel size and operating temperature.

Although both air-breathing and air-cooled PEM fuel cells have been studied, little attention has been devoted to the systematic development of cell components characteristic and operating conditions, such as GDL characteristics, air flow rate and stack temperature. In this work, a study of several crucial parameters, such as the GDL thickness, PTFE content of GDL, air flow rate, and cell temperature, was carried out on the performance of an air-cooled PEM fuel cell stack, and the results can provide in situ diagnostic data for the maintenance of stable power generation station equipped with air-cooled PEM fuel stack.



(a)Cathode flow field of cell (width: 2.0 mm; depth: 1.8mm; land: 1.2 mm, length of channel: 80mm.)



(b) Anode flow field of cell (2-channel serpentine flow field)

Fig. 1. Graphite bipolar-plate of air-cooling stack.