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Experimental evaluation of an ambient forced-feed air-supply PEM fuel cell

*Guo-Bin Jung**, *Kai-Fan Lo*, *Ay Su*, *Feng-Bor Weng*, *Cheng-Hsin Tu*, *Teng-Fu Yang*, *Shih-Hung Chan*

Department of Mechanical Engineering and Fuel Cell Centre, Yuan Ze University, 135 Far East Road, NeiLi, TaoYuan, 320 Taiwan, ROC

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ABSTRACT

Increasing interest in utilizing proton exchange membrane fuel cells for sub-kilowatt mobile applications has prompted the need for fundamental understanding of operating characteristics of polymer electrolyte membrane (PEM) fuel cells. However, there is a few published data regarding related information, especially for PEM fuel cells with ambient force-feed air-supply and their stack design which is the subject of this study. Although the air for the cathode was directed from ambient atmosphere with variable humidity, the flow rates were controlled in order to simulate their effects on the cell performance under real conditions. In addition, the steady-state performance and transient response for H_2/air PEM fuel cells were investigated under a variety of load cycles and operating conditions. Impact of H_2 humidity on the performance was negative for this simplified stack design under appropriate operation current output and the dry H_2 was utilized for the rest of this study. It was found that the humidity of cathode inlet gas had a significant effect on fuel cell performance. When the air relative humidity was higher than 55%, the stack operation resulted in more stable and higher performance. In addition, high moving rate of fuel cell stack (i.e. 20.3 km h^{-1}) was found necessary for supplying air to the fuel cell directly and indirectly in order to prevent stack from over-heating.

1. Introduction

The proton exchange membrane fuel cells (PEMFCs) are of high interest in energy research due to their potential for direct conversion of chemical energy into electrical energy with high efficiency, high power density, low pollution and low operation temperature [1,2]. The PEMFCs are, therefore, considered to be an attractive power source for stationary co-generation units as well as for mobile applications. However, the PEMFCs have to overcome some engineering and economic problems before they can become commercially successful.

At present, the most severe problems of the PEMFCs are low durability and high material costs. Cost effectiveness can be obtained by using alternative electrode materials, cheaper and thinner membranes, and also by reducing the need for auxiliary equipment [1], such as a gas humidification section. Hence, operation under low humidity conditions is of great advantage for the energy conversion efficiency and a goal of low cost. Moreover, the low humidified conditions could avoid a problem of flooding of the cathode region. It is, however,

*Corresponding author. Tel.: +886 3 463 8800 2469; fax: +886 3 455 5574.
E-mail address: guobin@saturn.yzu.edu.tw (G.-B. Jung).

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considered that low humidity conditions accelerate the decay of the electrolyte membrane which is a key material for the PEMFC. Proper hydration of the membrane is critical for maintaining membrane conductivity and mechanical stability [3,4]. Therefore, maintaining a suitable humidity of the inlet fuel and air without additional humidification will be beneficial for both long life performance and low cost. Thanks to its geographic position surrounded by the Pacific Ocean, the ambient air in Taiwan usually is more humid than in other areas or countries, with relative humidity usually above 50–70% which might be suitable for PEMFC operation. In this study, the air is used directly from the ambient with natural air humidity of that experimental day, and its impacts on the cell performance were studied from a more realistic point of view.

A practical fuel cell power source is usually composed of a number of single cells. Such a combination of single fuel cells is called as fuel cell stack, which provides higher voltage and power. Although there are a variety of fuel cell stacks with different sizes, shapes, materials, and power ranges, most of them are of bipolar/planar designs [5]. The bipolar design means that two adjacent cells share one bipolar plate that provides fuel for one cell's anode and air for the other's cathode and also serves as current collector. These bipolar plates are typically manufactured from graphite in combination with polymer materials [6] for better mechanical properties and for manufacturing reasons. In order to remove the generated water and heat, excess air and/or additional cooling system are needed for protecting the stack from overheating, resulting in higher system complexity and cost. Although air-supply PEMFC stacks have been reported [7–9], their detailed cathode flow field structure and transient response remain unclear. In this study, a simplified stack with forced-feed air-supply for both reaction and cooling was developed and its performance and transient response were evaluated at different operating parameters.

2. Experimental

The forced-feed air-supply PEMFC stack composed of 6 cells connected in series with the active area of each cell of 5.0 cm × 5.0 cm was designed and constructed. The graphite bipolar plates were grooved with serpentine channels on the anode side, as shown in Fig. 1(a) and open grid channel structure was applied on the cathode side, as shown in Fig. 1(b). The open structure of cathode flow field was chosen to make use of ambient air directly and to allow removal of water and generated heat. The MEAs and gas diffusion layers were purchased from W.L. Gore & Associates. The platinum catalyst loading was 0.4 mg cm^{-2} on the anode and 0.6 mg cm^{-2} on the cathode. Fig. 2 shows the PEMFC system with the geometric stack parameters and operating conditions detailed in Table 1. The high purity hydrogen (99.99%) was used without humidification. The air-supply to the cathode was forcedly obtained by convection from ambient

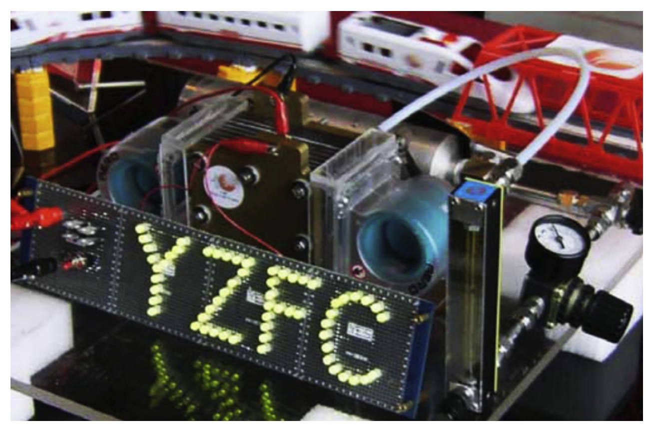

Fig. 2 – Schematic illustration of the forced-feed air-supply PEMFC stack (electricity generated from the PEMFC stack was used to power LED and kit train).

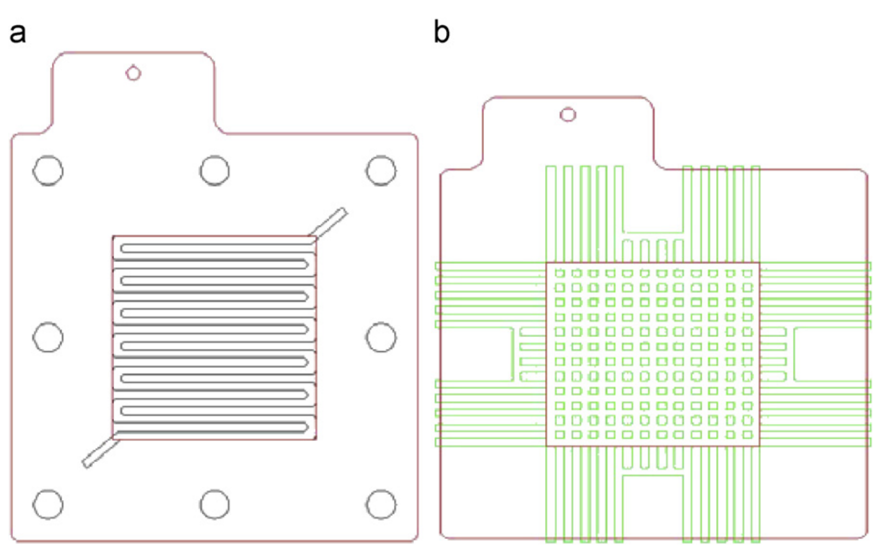

Fig. 1 – (a) Serpentine flow field for anode and (b) open grid flow field for cathode.