INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 43 (2018) 1769–1780

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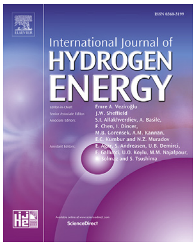

Different flow fields, operation modes and designs for proton exchange membrane fuel cells with dead-ended anode

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ARTICLE INFO

Article history:
Received 22 August 2017
Received in revised form
20 October 2017
Accepted 21 October 2017
Available online 23 November 2017

Keywords:
PEM fuel cell
Dead-ended anode
Flow field
Anode supply mode
Reservoir

ABSTRACT

Water and nitrogen can accumulate in the anode channel in proton exchange membrane fuel cells (PEMFCs) with dead-ended anode (DEA) and can affect cell performance significantly. In this paper, the cell performance characteristics in DEA PEMFCs with three different anode flow fields under two operating modes are studied through measuring the cell voltages and local current densities. The effect of the anode exit reservoir is also studied for the three different anode flow fields. The experimental results show that the interdigitated flow field has the most stable cell performance under both constant pressure and pressure swing supply modes. Parallel and serpentine flow fields lead to very non-uniform local current distributions under constant pressure supply mode and experience severe fluctuations and spikes in local current densities under pressure swing supply mode. The results also show that anode pressure swing supply mode can achieve more stable cell performance than anode constant pressure supply mode for parallel and serpentine anode flow fields. The anode exit reservoir can significantly improve cell performance stability for parallel and serpentine flow fields, but has no significant effect on interdigitated flow fields. Besides, the results further show that PEMFCs with DEA can maintain very stable operation with anode serpentine flow field and an anode exit reservoir under pressure swing operation.

Introduction

Dead-ended anode (DEA) configuration is usually used in proton exchange membrane fuel cells (PEMFCs) to simplify the fuel cell system and reduce cost [1–3]. However, water and nitrogen can diffuse across the membrane from the cathode and accumulate in the anode compartment [4–6]. Local water and nitrogen accumulation can lead to cell performance decrease [2,3,5–7] and irreversible cell degradation [8–15]. To remove the accumulated water and nitrogen, periodical anode purges are conducted [16,17].

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https://doi.org/10.1016/j.ijhydene.2017.10.137

The cell operating conditions and the anode purge process have important effects on local water and nitrogen accumulation, and significant efforts have been devoted to optimize the operating parameters [5,6,18–22] and anode purge strategy [16,23,24]. However, all the studies mentioned above were conducted under constant pressure operations. As the anode pressure is kept constant and hydrogen is continuously consumed by oxidation, hydrogen flows along the anode channel to the exit. Although the velocity of the hydrogen flow is very low, the hydrogen flow keeps dragging and pushing the water droplets and nitrogen to the anode exit.

To further reduce or eliminate local water and nitrogen accumulations in the dead-ended anode, some researchers developed novel anode supply modes [25–27]. Choi et al. [25] introduced hydrogen pulsations in a serpentine anode flow field to optimize water management in DEA fuel cells. They found that anode gas pulsation could reduce local accumulation of liquid water and thus significantly reduce anode purge frequency. Ichikawa et al. [26] developed a pressure swing gas supply technology in DEA fuel cells. Under the pressure swing operation, hydrogen was supplied intermittently, generating an oscillatory flow in the anode channel. Their results showed that the nitrogen distribution in the anode channel and the current distribution in the cell were much uniform than those under constant pressure operation. However, the pressure swing technology can also lead to cell performance fluctuations. Recently, Yang et al. [27] studied the mechanisms of the fluctuations. The experimental results showed that the backflow of impurities in the anode channel resulted in the fluctuations. Based on the mechanisms, it was also proposed to add an anode exit reservoir to mitigate cell voltage and local current density fluctuations. The results also showed that local hydrogen starvation near the anode exit occurred during cell performance fluctuations. Local hydrogen starvation could lead to severe local cell degradation [28–30].

The cell performance characteristics in DEA PEM fuel cells with parallel or serpentine anode flow field have been widely studied in previous studies under both constant pressure and pressure swing modes [5,6,22,25,26,31,32]. However, very limited results on the cell performance characteristics of DEA PEM fuel cells with interdigitated anode flow field can be found in the literature. It has been shown that the current density with an interdigitated flow field in a conventional PEM fuel cell is much more uniform than that with a serpentine flow field [33–35]. It is reasonable to expect similar or better results in DEA PEM fuel cells with interdigitated flow fields since water and nitrogen accumulate near the end of the channel in parallel and serpentine flow fields. On the other hand, comparison of different anode flow fields are essential for the optimization of flow field design in DEA PEM fuel cells. Thus, a systematic experimental study is conducted to compare cell performance characteristics with three different anode flow fields under both constant pressure and pressure swing operation modes with and without an anode exit reservoir. To ensure proper comparisons, the patterns of different anode flow fields have the same geometric parameters and all the experimental conditions are kept the same. Besides, the variations of local current densities at different locations along the anode flow channel are carefully studied.

Experimental

Experimental system

Three single PEM fuel cells with an active area of $4 \times 4\ \text{cm}^2$ are assembled with identical conditions. The MEAs consist of a Nafion 211 and two identical gas diffusion layers with micro porous layers. Three graphite anode flow field plates with different flow fields, parallel flow field, serpentine flow field and interdigitated flow field, are designed and manufactured. Fig. 1 (a) shows the schematic diagram of the three different anode flow field plates. Geometric parameters of the three patterns of flow fields are the same to ensure appropriate comparison of cell performance. Channel widths, channel depths and shoulder widths are 2 mm, 1 mm and 2 mm respectively. There are 10 channels and 9 shoulders in the graphite plates. For each flow pattern, the serpentine flow field is used in the cathode and the flow arrangement is co-flow. The fuel cells are placed on the horizontal plane and the pathways in the anode and the cathode are horizontal.

Fig. 1 (b) shows the experimental system which is identical to our previous study [27]. Dry hydrogen (purity>99.99%) is supplied at the anode and fully humidified air is supplied at the cathode. The experimental system includes a fuel cell test station (FCTS-16, Fuel Cell Technologies. Inc., USA) and an electrochemical workstation (HCP803, Bio-Logic. Inc., France). The operating parameters, including the cell operating temperature, gas flow rate and gas humidification temperature are controlled by the fuel cell test station. The electrochemical workstation is used to supply the fuel cell load. A pressure regulator and a normally-opened solenoid valve are installed at the anode inlet to control the anode gas supply. The normally-opened inlet solenoid valve is closed periodically to control the hydrogen pressure in the anode channel. A normally-closed solenoid valve is installed at the anode outlet to accomplish the DEA operation and anode purges.

Current distributions are measured using the current distribution measurement gasket developed by Sun et al. [36]. Local currents are collected by the gold-plated copper strips of the gasket. Every strip collects current from one shoulder and two half-channels [35–37]. To minimize its effect on cell performance, the measurement gasket is placed between the anode flow field plate and the anode gas diffusion layer. The measurement gasket consists of 11 current conducting strips which are numbered from No. 1 to No. 11. Strips of No. 2 to No. 10 correspond to the 9 shoulders from the inlet to the outlet. The currents from strips No.1 and No.11 are also collected, but not used in the analyses due to the asymmetry of the areas they cover [35–37].

Experimental protocol

The three experimental fuel cells are fully activated by an identical conditioning process. During DEA operation, the cell operating temperature is 333 K and the cathode backpressure is atmosphere pressure. The experimental fuel cells are operated under galvanostatic mode ($400\ \text{mA cm}^{-2}$). The cathode gas flow rate is 217.6 sccm (air stoichiometry 2.0 for the operating current). During the constant pressure operation, the anode supply