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Internally humidified polymer electrolyte fuel cells using water absorbing sponge

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Abstract

Polymer electrolyte fuel cell (PEFC) mounted with two strips of polyvinyl alcohol (PVA) sponge is presented and the effect of operating conditions on the cell performance is investigated. Mounting the sponge wicks is advantageous for the humidification of dry inlet air and for the removal of liquid water in the cell. It was found that dry inlet hydrogen could be internally humidified by water diffusion from the cathode to anode when operating in a counterflow mode. The results show that the relative humidity of the inlet gases could have little effect on the performance of the cell mounted with two sponge wicks under certain operating conditions. At a cell potential of 0.5 V, the current densities of the sponge-mounted PEFC operated with dry air are 5% and 31% higher than those of the conventional one without wicks operated with saturated and dry air, respectively. The molar percentage of water vapor to total water exiting the cathode (R_{gas}) is an important parameter to gauge the cell performance with dry gases. A very large R_{gas} may cause the membrane dehydration and subsequently a low cell performance.

Keywords: PEM fuel cell; Internal humidification; Water management; Wick; Counterflow

1. Introduction

Polymer electrolyte fuel cells (PEFCs) are receiving much attention due to their promising properties as a power source for small- [1–4] and large-scale applications [5–8]. However, the PEFC system is currently too complex and its weight and volume need to be further decreased to make this power generator suitable for mobile applications. To make a compact fuel cell system, the operation of PEFCs without external humidification of the reactant gases is attractive [9]. The issue of water distribution and water transport in the cell operated with dry gases has been the subject of several experimental and theoretical studies [9,10–16].

Proper water management is a key to ensuring successful cell performance. Perfluorosulfonate membrane, such as Nafion, is commonly used as electrolyte for the PEFC. The proton conductivity of this membrane decreases with decreasing water content [17–19]. To retain the water hydration within the membrane, the reactant gases have traditionally been humidified before entering the cell [20–23]. However, a high humidity of the inlet reactant gases may lead to cathode flooding, which limits the oxygen to approach active surface of the catalyst particles [24–28]. Water flooding is known to be the main limiting factor of the cell performance at high current densities [29–32]. In a fuel cell stack, the presence of liquid water may block flow channels and lead to a non-uniform, cell-to-cell gas distribution [33].

In recent years, many innovative methods for keeping the membrane wet were explored: (i) liquid water introduced into the membrane through wicks [18]; (ii) preparation of a self-humidifying polymer electrolyte membranes by embedding catalyst particles into the membrane [34–37]; (iii) humidification of the dry entering reactant gas by acquiring some moisture from the wet exiting gas utilizing a double-path-type flow field that has two gas inlets and outlets, respectively

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[10]; and (iv) internal humidification of hydrogen and air by operating the cell in the counterflow mode [9]. However, all of these methods have intrinsic disadvantages. Methods (i) and (ii) require a complex cell or membrane structure. Furthermore, it is a challenge to avoid short circuit due to the conductive catalyst particles embedded into the membrane. Method (iii) needs to reduce the influence of gas bypass—air can flow from the inlet through the porous diffusion layer directly to the adjacent gas outlet. Method (iv) is very attractive, but the experimental and simulation results showed that the cell performance obtained was lower than that measured when both gases were humidified [9,15].

In this paper, a fuel cell mounted with two strips of absorbent polyvinyl alcohol (PVA) sponge was investigated. The effectiveness of the sponge wicks to humidify dry inlet gas and to remove the product water was demonstrated. In addition, the effect of the operating conditions on the cell performance was investigated.

2. Experimental

2.1. Preparation of membrane electrode assemblies

Both the anode and the cathode consist of a backing layer, a microporous layer and two catalyst layers. The microporous layer is coated on one side of polytetrafluoroethylene (PTFE)-proofed carbon paper (GDL 30BA, SGL) and consists of carbon powder (Vulcan XC-72, Cabot) and polytetrafluoroethylene (Electrochem. Inc.). The carbon loading was 2 mg/cm^2 and PTFE content was 30 wt.% in this layer. The catalyst layer consists of a hydrophobic and a hydrophilic layer. Two slurry formulations were used to prepare catalyst layer. One was composed of Pt/C (20 wt.% Pt on Vulcan XC-72, E-TEK), PTFE and isopropyl alcohol. The other was composed of Pt/C and isopropyl alcohol. The hydrophobic catalyst layer was contacted with the microporous layer. The weight ratio of Pt/C to PTFE was 9:1. The Pt loadings of these two catalyst layers were both 0.2 mg/cm^2. Nafion solution (Aldrich) was impregnated into the catalyst layer. The Nafion content of the electrode was 0.86 mg/cm^2.

The membrane was pretreated with H_2O_2 and H_2SO_4 solution according to Ticianelli et al. [20]. Membrane electrode assemblies (MEA) of 50 cm^2 (7.7 cm × 6.5 cm) were prepared by hot-pressing a Nafion 112 membrane (DuPont) between the two electrodes for 90 s at 135 °C and at 7.5 MPa.

2.2. Cell structure

Fig. 1 shows the flow field structure of the cell with two strips of polyvinyl alcohol sponge (Medtronic Solan). The flow channels were machined onto the surface of the graphite plate. The horizontal top and bottom flow channels (1.5 mm in width, 2 mm in depth) are connected with three or six parallel channels with a cross section of 1 mm × 1 mm. In Fig. 1, only nine parallel channels (total 39 channels, in an upright position) are schematically shown. The length of the parallel flow channels is 65 mm. The width of the ribs is 1 mm. The structure of the hydrogen flow field is symmetrical to the airflow field. Only the airflow field plate was mounted with wicks. Each wick is 0.32 mm in thickness, 3 mm in width and 77 mm in length. As it can be seen from Fig. 1, PVA with a width of 3 mm is placed on the outer rim of the electrode (width of 65 mm). The lower half of the top wick is in close contact with the horizontal flow channels (width of 1.5 mm located on top and bottom), respectively, while the upper halves are in contact with the gasket. By this arrangement, electrical resistance introduced by the PVA is minimal and issues related to cell compression/sealing are not significant.

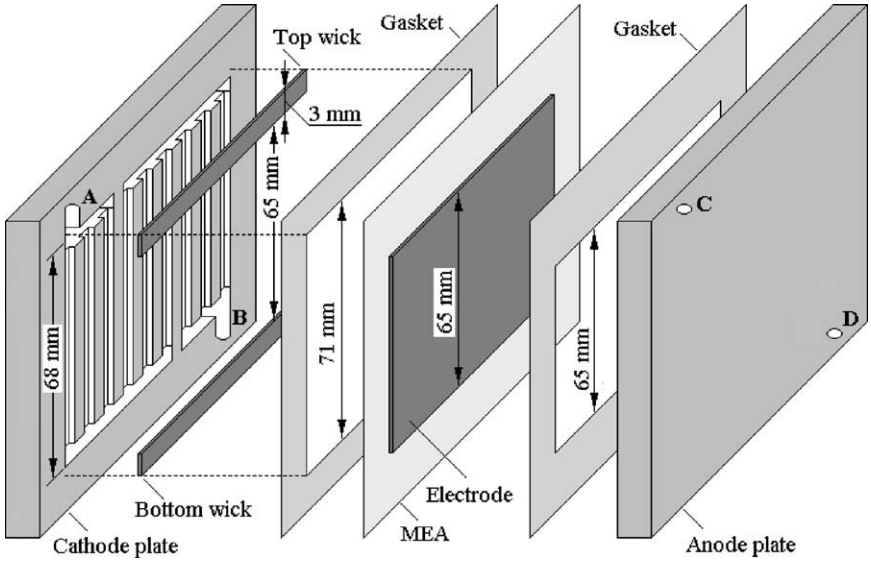

Fig. 1. Schematic of the cell structure with two strips of absorbent wicks.