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ORIGINAL ARTICLE

Development and performance analysis of PEMFC stack based on bipolar plates fabricated employing different designs

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Abstract A low-temperature proton exchange membrane fuel cell (LT-PEMFC) is a promising clean and effective technology for power generation because of its simplified water and heat management. Due to the non-uniform of H_2 and air distributions within fuel cells, the stack design is one of the key factors to enhance the performance and efficiency of LT-PEMFC. In this study, a single, two cells, 6 cells and 11 cells LT-PEMFC stack was investigated with cell active area 114 cm^2, Nafion membrane 112 and catalyst loading 0.4 mg/cm^2 working at 25 °C and atmospheric pressure using hydrogen and air as a fuel and oxidant, respectively. The power output that is obtained from each stack is presented and the overall power output is compared with single cell stack. The stack prototype has been fabricated, constructed and tested producing a maximum value of 70 W electrical power using 11 cells stack.

1. Introduction

Fuel cells are widely used in power-driven handy equipment such as battery charges, laptops, external power units and electronic devices. The advantages of portable fuel cell stack with respect to usual power supplies which are primary not reusable and secondary rechargeable batteries and at the same time environment friendly. PEMFC achieves most of portable fuel cell stack requirements applications, because of its high energy density, long operational time, immediate refilling and the self-discharge (Dyer, 2002; Colapn et al., 2008).

The critical step to set up the system performance is assembly process of PEMFC (Ge et al., 2006; Chang et al., 2011, 2007; Yim et al., 2010, 2008; Gatto et al., 2011; Lin et al., 2008; Escribano et al., 2006) and Alcaide et al. (2010) as well as Wen et al. (2009). In the beginning the performance of the small stacks could be enhanced by using optimized gas diffusion layers as well as optimized current collectors. Santarelli

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Figure 1 Membrane electrode assembly.

et al. (2007) described in detail the effect of cathode flow stoichiometric ratio on PEMFC stack output (power and voltage) experimentally. The experimental results obtained proved that an increase in air stoichiometric ratio causes a considerable positive effect (increment) on stack power output, particularly at high-current density, and up to the value of about two stoics. The temperature of the outlet cathode flow increases due to heat produced by irreversibility. At low current densities the effect of flooding connected to the situation water flow rate (GW), flooding (FL > 0) is more significant. Cozzolino et al. (2011) investigated the thermal management of a PEMFC stack. They established experimental setup to define the behavior of a water-cooled PEMFC stack by using a test station which it holds a number of measurement instruments and controlling devices. They introduced to the many of researchers working in numerical models a lot of experimental records helping them to study the behavior and the performance analysis of the stack which its components are complex and some of different energy conversion system. Perna et al. (2011) studied the performance analysis of the fuel processing system (FP-PEMFC) to define the best possible parameters of this system. They approved that how can varying the main operating conditions of both the reforming reactor and the membrane water gas shift reactor are highly sensitive to the fuel processing system. The thermos-chemical model was developed mainly to perform sensitivity analysis of the fuel processing system. The data obtained by thermos-chemical model demonstrated that the thermal efficiency of the fuel processing system has been maximized. Schultz and Sundmacher (2006) reviewed an article and studied an intensive and extensive of PEMFC stack, with a discussion and analysis of single cell vs. stack-level performance, cell voltage uniformity, influence of operating conditions, durability and degradation, dynamic operation. Scott et al. (2012) introduced a new PEMFC stack design with experimental validation. Experimental study of a new stack design showed that the stack can yield outputs similar to current fuel cell stacks with a maximum power output of 234.56 W for 6 cells, equating to a power density of 0.390 W/cm^2. Neto et al. (2013) described the experimental characterization of a self-humidified 1 kW PEM fuel stack with 24 cells. The stack accomplished 40% electrical efficiency at current 32 A with a total energy recovery (electricity to heat) of 84% above this current. 815 W maximum power was attained at maximum current. To study the stack ability to produce electrical power at low and high current without relevant oscillations many of stability tests have been executed. The experimental results showed that at larger currents for the individual cell voltages were smaller values close to the cooling plates; the reasons of these smaller values could be due to the partial channel flooding. They introduced details of the losses produced at different current loads by doing an energy balance of the fuel cell stack.

In the present work the setup was prepared for a 70 W PEMFC stack experimentally. In the following sections the fuel cell performance of two different bipolar flow patterns was studied. The experimental polarization curves and the power density curves for the two bipolar plate designs were investigated to select the best design which will be suitable for the stack design.

2. Fuel cell assembly

2.1. Fabrication of bipolar plates

The fabrication of bipolar plate has been selected based on the optimum design of the flow pattern of the rib channels. It shows the fuel cell performance of two different bipolar flow patterns six serpentine flow channels with square bends and six serpentine flow channels with curvilinear bends (Youssef et al., 2012).

2.2. Electrode and membrane preparation and assembly

Prior to fabricating electrodes, the Nafion 212 membrane was boiled in 5 wt.% H_2O_2 solution for 1 h to remove organic impurities, then it was rinsed in boiling double distilled water for 1 h to remove excess H_2O_2. In order to remove metallic contaminants on the membrane surface and exchange Na^+ for H^+ in the membrane, it was boiled in 0.5 M H_2SO_4 for 1 h. Finally, it was rinsed again in boiling double distilled water for 1 h.

The catalyst ink was prepared by mixing of the electrocatalyst powder with 5 wt.% Nafion solution in an ultrasonic bath at 60 °C for a few minutes (the percentage of the Nafion to the catalyst was 2–1), then the catalyst ink was pasted on a carbon paper. The suspension was coated uniformly over carbon paper. 0.4 mg cm^{-2} was chosen to be the electrocatalyst loading for both anode and cathode electrodes. The cathode and anode electrodes were made of 30 wt.% Pt/C E-Tek. The electrodes were sandwiched the membrane by hot pressing at 120 °C and 50 bar for 1.5 min to produce the membrane electrode assembly The electrodes were sandwiched by hot pressing at 120 °C and 50 bar for 1.5 min to produce the membrane electrode assembly as shown in Fig. 1.

2.3. Fabrication and measurement

The MEA was homemade which used catalyst 30% Pt/C was conditioned at 0.6 V for 1800 s, then 0.4 V for 1800 s and last