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Use of galvanostatic charge method as a membrane electrode assembly diagnostic tool in a fuel cell stack

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HIGHLIGHTS

- A galvanostatic charge method can be used as a MEA diagnostic tool in a fuel cell stack.
- The EAS, double-layer capacitance, and H_2 crossover current can be calculated.
- The cell ohmic resistance also can be obtained by the voltage transient.
- The RH and temperature have great effects on the measurement.
- The suggested measurement conditions are a certain working temperature and 100% RH.

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ABSTRACT

To better measure and monitor the membrane electrode assembly (MEA) status in polymer electrolyte membrane fuel cell (PEMFC) stack, a galvanostatic charge method is improved. The electrochemical active surface area (EAS), double-layer capacitance, hydrogen crossover current, and cell ohmic resistance can be measured by this method. In this method, two or more constant currents are applied to the fuel cell stack, and the voltage response between two electrodes of each cell is recorded and analyzed. Tests on a two-cell stack which is supplied with hydrogen in anode and nitrogen in cathode are carried out, and the influences of temperature and relative humidity (RH) on the MEA parameters are investigated. Results show that with an increase of RH, both double-layer capacitance and EAS increase, while hydrogen crossover current and cell ohmic resistance decrease. With an increase of temperature, hydrogen crossover current increases, cell ohmic resistance decreases, and EAS and double-layer capacitance show little change. The galvanostatic charge method shows a convenient way to research cell consistency and MEA lifetime in a fuel cell stack.

1. Introduction

The membrane electrode assembly (MEA) is one of the most important parts of a polymer electrolyte membrane (PEM) fuel cell, and greatly impacts on fuel cell performances. The MEA aging is the main aspect of fuel cell aging, and the MEA inconsistency is the main factor of cell inconsistency in a stack. Main parameters relating to the MEA aging status and the cell consistency include catalyst active surface area, hydrogen crossover rate, cell resistance and double-layer capacitance.

The cell resistance is one of the reasons resulting in cell voltage drop. The resistance values under different conditions are usually disparate because various factors affect the resistance, such as temperature, membrane thickness, humidification and pretreatment [1]. Techniques such as current interruption [2,3], electrochemical impedance spectroscopy (EIS) [2], and polarization curve have been popularly used to measure the cell resistance.

The double-layer capacitance is physically linked to the space charge (formed by H^+ or H_3O^+) appearing on the electrode–electrolyte interface [4], and its value increases with the area of the double-layer [5,6]. It has been found that the double-layer capacitance is one of the influences on the dynamic performance of a fuel cell [7]. In the past, the double-layer capacitance is measured by the electrochemical methods of EIS [5,6] and cyclic voltammetry (CV) [8].

The hydrogen crossover current is often used to examine leakage or monitor the end of the MEA lifetime [9,10]. Even though the hydrogen crossover current keeps a constant value

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for almost the whole lifetime of the fuel cell, it increases sharply in the end and leads to fuel cell inefficiency [11]. It makes the open circuit voltage decreased [12], and leads to the degradation of the catalyst layer and membrane [13]. Linear sweep voltammetry (LSV) [14,15] is an electrochemical technique of limiting current to measure the crossover current.

The electrochemical active surface area (EAS) of catalyst layer is an important factor that affects the fuel cell output performance [16–19]. The EAS of catalyst is usually measured by CV, and sometimes the CV cycle is used to make fuel cell decay rapidly [8,20,21]. In CV, a scanned potential is applied between anode and cathode, and the current caused by the cyclic oxidation and reduction of the reactants is measured. We then calculate the total charge of the hydrogen adsorption/desorption process, and get EAS of the catalyst layer.

Previous studies proved that the aging of fuel cell was mainly caused by the degradation of the membrane and catalyst. The degradations of membrane and catalyst usually show in the following ways: i) loss, oxidation, and particle agglomeration in the catalyst layer, resulting in a decrease in EAS [22,23]; ii) PEM thinning, resulting in an increase in gas crossover [24]; iii) aging in membrane, resulting in an increase in resistance [25]. The parameters of the MEA can clearly show the MEA status in the PEM fuel cell, but the methods above need multiple equipment and some of them are not suitable for the measurements of the fuel cell stack. It is necessary to develop a convenient method to investigate the parameters of the MEA in a PEM fuel cell stack.

In this paper, a galvanostatic electrochemical method was performed on a two-cell stack, and tests on the stack were carried out to investigate the effects of temperature and RH on the cell ohmic resistance, hydrogen crossover current, double-layer capacitance and catalyst active surface area.

2. Experimental method

2.1. Fuel cell testing system

Fig. 1 shows a schematic diagram of the experimental setup used in this study. The test station monitored and controlled the gas flow rate, temperature and pressure via the mass flow controller, T-type thermocouple and pressure transducer, respectively. A 3-way valve was easily switched between the air and nitrogen gas. The reactant gas came into the system through the humidifier, and relative humidity was decided by the dew-point temperature. In order to measure each cell voltage, the graphite plates were connected to an NI PXI-1033 data acquisition instrument. The circuit current was measured by a Hall current sensor, and the measurement signal was also collected by the NI PXI-1033 data acquisition instrument. An electronic load was used for the performance tests, while a power supply operated at constant current mode was used for the galvanostatic tests.

2.2. Experiment procedure

A two-cell stack with a 160 cm^2 MEA area was used for the tests in this study. Nafion® N112 membranes were obtained from DuPont de Nemours and the cathode platinum loading was 0.3 $mg\ cm^{-2}$. The graphite plates were used for both anode and cathode flow fields. The conditions of experiment procedures were showed in Table 1. An air intake system supplied hydrogen and air to the anode and cathode sides, respectively, for the performance tests. The fuel cell performance was measured as a polarization curve (I–V). After the performance tests, the hydrogen and nitrogen purging were performed for 30 min to avoid the negative impact of residual air. After the purging process, the galvanostatic tests were carried out, and the hydrogen and nitrogen were supplied to the anode and cathode,

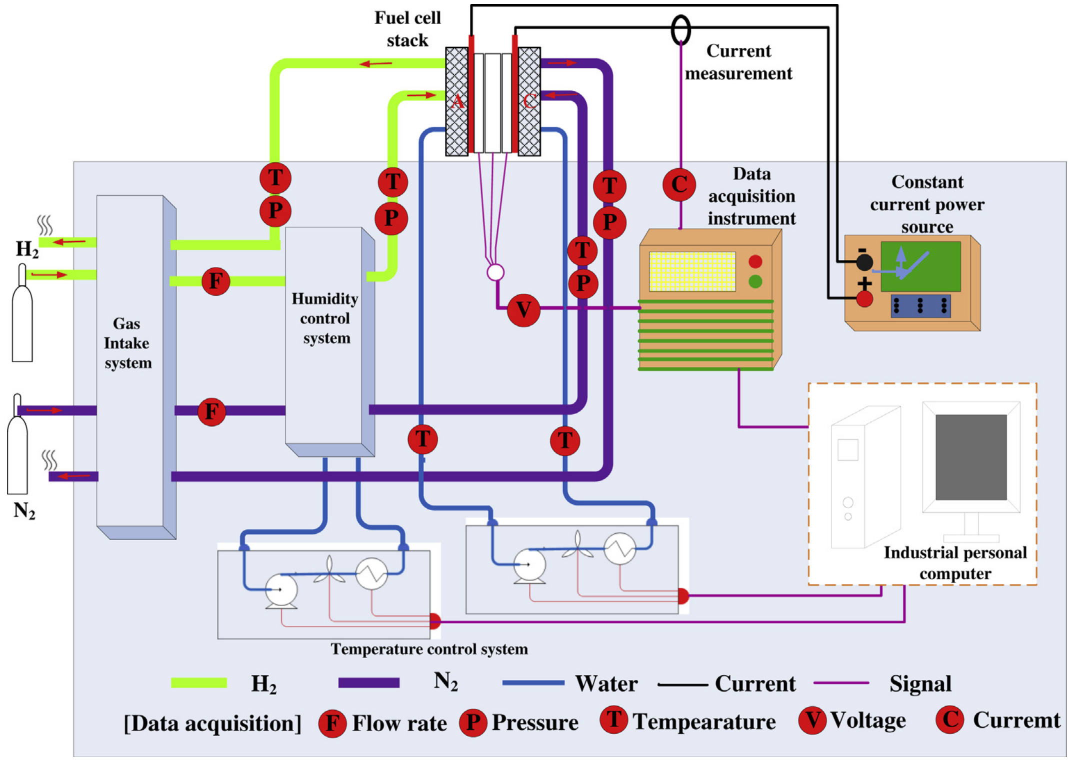

Fig. 1. Schematic diagram of the experimental setup used in this study.