Effect of Collector Plate Resistance on Fuel Cell Stack Performance

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ABSTRACT

The electrical resistance of the collector plate (both bulk and surface resistance) plays a major role in fuel cell stack performance. Energy Partners (EP) has developed molded graphite composite plates with enhanced electrical conductivity, as an alternative to expensive machined graphite. By optimizing collector plate materials, compounding and molding processes, the resistance of the molded collector/backing layer sandwich was reduced by about 12 mΩcm². This resulted in an improvement in performance of more than 50 mV per cell at 1 A/cm² in a 10-cell stack with 300 cm² active area.

INTRODUCTION

Proton Exchange Membrane (PEM) fuel cells can convert chemical energy to electrical energy with high efficiency. They generate electrical power, heat and water, and when operating on hydrogen they generate essentially “zero emissions”. PEM fuel cell stacks consist of series connected cells, they are very reliable, have high power density, and are suitable for both transportation and stationary applications. Recently, considerable effort in the fuel cell industry has been directed toward reducing component manufacturing and assembly costs, to allow penetration into automotive markets.

One of the most critical components in the fuel cell stack is the bipolar collector/separator plate. The first function of the collector plate is to provide series electrical connection between individual cells in a fuel cell stack. The second function is to direct fuel and oxidant gas streams to individual cells, to distribute gas streams within individual cells, and to remove product water from individual cells. The third function is to provide separation of fuel and oxidant gas streams between the series connected cells. The fourth function is to assist in the thermal control (via heat removal) of the fuel cell stack. In addition to these functions, the collector plate must be corrosion resistant in the demanding fuel cell environment (1). Graphite has typically been used as a collector plate material due to excellent corrosion resistance. However, pure graphite is not practical from a cost perspective, since it requires machining of the flow field channels.
To preserve the power density of state-of-the-art fuel cell stacks while reducing cost, the U.S. Department of Energy has specified target bulk resistance of 10 mΩcm or lower for alternative bipolar plate materials (2). Work on graphite composite bipolar plates at Los Alamos National Laboratory (LANL) recently produced materials with bulk resistance of 8.3 mΩcm (3).

Energy Partners has developed graphite composite technology as a means of lowering the manufacturing cost for bipolar collector plates. Since 1991 EP has built several large active area fuel cell stacks (780 cm²) with molded graphite/composite plates. The use of a polymer binder in the composite plate enables net shape or near net shape molding, but also compels an increase in collector plate resistance. By optimizing material selection, compounding and molding processes we have developed a new generation of molded collector plates with significantly improved electrical properties. This paper investigates the effect of increased collector plate resistance on performance of 10-cell PEM fuel cell stacks.

EXPERIMENTAL

The bulk resistance of the molded composite plate was measured with a 4-point probe method as described by Smits (4). This method allows measurement of bulk resistivity of thin plates by applying a geometry dependent correction factor to the measured value of resistivity. Measurements were performed on thin circular samples (7.62 cm diameter × 3 mm thick).

Total electrical DC resistance (including contact resistance) was also measured with different contact materials and at various contact pressures to simulate conditions in the fuel cell stack. Measurements were performed on the same thin circular samples by pressing the sample between two gold plated copper surfaces (as shown in Figure 1), and measuring the voltage drop while passing a current of 1 A/cm². An electrode backing material (ELAT from E-TEK) was then inserted on both sides of the sample and the same DC resistance measurement was performed.

RESULTS/DISCUSSION

The results of bulk resistivity are shown in Table I. The old material had bulk resistivity of 6.8 mΩcm. By optimizing the binder materials, compounding and molding procedure we were able to significantly improve the electrical properties in the new generation molded collector plates. The resulting bulk resistivity is close to that of pure graphite (2.9 and 1.4 mΩcm, respectively).

Bulk resistivity of either material would not make much difference in fuel cell performance. For example, a 3 mm thick collector/separat or plate would contribute 0.4
and 2.0 mΩcm$^2$ to the cell resistance (0.4-2.0 mV drop at 1 A/cm$^2$), for graphite and graphite/composite respectively. This, of course, would be negligible since the membrane has about two orders of magnitude higher (ionic) resistance.

However, in an actual fuel cell, the hardware (collector plate) resistance is much higher and typically of the same order of magnitude as the ionic resistance in the membrane. This is mainly due to contact resistance. The results of total resistance (contact and bulk) resistance measurements as a function of clamping pressure are shown in Figure 2. The resistance of a 3 mm thick graphite plate is found to be about 5 mΩcm$^2$ when inserted between two gold plated copper surfaces with a clamping pressure of approx. 1.9 MPa. If an electrode backing material (such as E-TEK’s ELAT) is inserted on both sides of the graphite plate the resistance increases to about 20 mΩcm$^2$. Resistance of the graphite/composite collector plate/ELAT sandwich is much higher (>40 mΩcm$^2$).

The resistance in an actual fuel cell stack is higher than measured on the samples, as shown in Table I. The resistance in an actual fuel cell stack also includes the ionic resistance in the membrane, and was measured by the current interrupt method. Figure 3 shows that there is a linear relationship between the sample resistance and resistance of operational cells. The intercept on “y”-axis represents the membrane resistance, and the slope is due to reduced surface area of the actual collector plates because of the gas channels embedded on its surface. The total cell ohmic resistance in Energy Partners' fuel cell stacks with “old” material was in excess of 200 mΩcm$^2$. This created a significant voltage loss, >200 mV per cell at 1 A/cm$^2$. A new generation 10-cell stack with a 300 cm$^2$ active area was built with machined graphite collector/separato plates. During operation, an average cell resistance of 125 mΩcm$^2$ was measured. The resulting polarization curve is shown in Figure 4.

While the graphite collector plates result in very good performance (average cell voltage is about 0.65 V at 1 A/cm$^2$) the machining process needed to make the gas channels on the surface of the collector plate is prohibitively expensive. On the other side, graphite composite materials are moldable (thus no machining is necessary) but result in much higher resistance – about 100 mΩcm$^2$ higher than pure graphite (100 mV loss per cell at 1 A/cm$^2$ or more than 25% power loss at any given stack efficiency).

Significant efforts were applied to reduce those resistive losses, while at the same time preserving or even enhancing the molding properties of the graphite composite materials. By varying the binder materials, compounding and molding procedure we were able to significantly improve the electrical properties in the new generation molded collector plates. Bulk resistance was reduced to 2.9 mΩcm, and total resistance of a 3 mm thick plate was reduced to 28 mΩcm$^2$ (including the two electrode backing layers). Another identical 10-cell stack with the new generation collector plates was built and tested. The resulting polarization curve is compared with that of the stack with graphite plates in Figure 4. The average cell resistance was found to be about 155 mΩcm$^2$ which
means only about 30 mV per cell loss at 1 A/cm² as compared with pure graphite plates, or 50 mV per cell improvement as compared with EP old collector plates.

TABLE I Results of resistivity and resistance measurements

| Material   | Bulk resistivity* (mΩcm) | resistance (mΩcm²) |
|------------|-------------------------|--------------------|
|            |                        | Bulk | Bulk+ contacts | Bulk+ contacts+ backing | operational cell resistance |
| Ep old     | 6.8                     | 2.04 | 40.2           | 42.3                    | >200e,f                      |
| EP new     | 2.9                     | 0.87 | 17.1           | 28.2                    | 155e,g                       |
| graphite   | 1.4                     | 0.42 | 5.7            | 19.7                    | 125e,g                       |

a – measured by 4-point probe
b – calculated for a 3 mm thick flat plate
c – gold contacts, contact pressure 1.9 MPa
d – ELAT backing layer
e – includes both ionic and electronic resistance measured by current interrupt method in an operational multi cell stack with ~0.3 mm thick collector/separator plates
f – 780 cm² active area, multi cell stacks
g – ~300 cm² active area, 10-cell stack

CONCLUSIONS

The electrical resistance of the collector plate (both bulk and surface resistance) plays a major role in fuel cell stack performance. Energy Partners has developed molded graphite composite plates with enhanced electrical conductivity, as an alternative to expensive machined graphite. The DC resistance of the collector plate material sandwiched between electrode backing layers under suitable clamping pressure correlates with ohmic losses (measured by the current interrupt method) observed during multi-kilowatt fuel cell stack operation. By further optimizing collector plate binder materials, compounding and molding processes, the resistance of the molded collector/backing layer sandwich was reduced by about 12 mΩcm². This resulted in an improvement in performance of more than 50 mV per cell at 1 A/cm² in a 10-cell stack with 300 cm² active area. Current investigations are aimed at further reduction of contact resistance between the layers and improvements in materials properties.
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Fig. 1 Schematic diagram of experimental setup for measuring total (contact and bulk) resistance of graphite and molded graphite composite samples, including electrode backing layers.
Figure 2 Resistance (bulk and contact) of various collector plate materials (dashed lines include two electrode backing layers)

Figure 3 Relationship between sample electrical resistance and operational cell resistance
Figure 4  Polarization curves of two 10-cell stacks
(H₂/air, 300 cm², 300 kPa and 60°C)