

PEFC Performance Improvement Methodology for Vehicle Applications

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ABSTRACT

For over a decade and a half, Toyota Motor Corporation has been developing fuel cell vehicles (FCVs) and is continuing various approaches to enable mass production. This study used new methods to quantitatively observe some of the mass transfer phenomena in the reaction field, such as oxygen transport, water drainage, and electronic conductivity. The obtained results are applicable to the design requirements of ideal reaction fields, and have the potential to assist to reduce the size of the fuel cell.

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INTRODUCTION

In response to growing concerns about energy issues, global warming, and air pollution, major automakers and energy corporations in Japan recently agreed on a scenario with the objective of starting the first phase of commercializing fuel cell vehicles (FCVs) starting in 2015⁽¹⁾. Following the philosophy "of the right vehicle at the right place and at the right time", Toyota Motor Corporation is developing various environmentally friendly vehicles to help society live in harmony with the global environment. Recognizing their potential as a clean, efficient, and quiet source of transportation, Toyota was the first automaker in the world to start sales of an FCV on a limited lease basis in December 2002. Toyota then started lease sales of the FCHV-adv (Fig. 1) in 2008 after incorporating a number of incremental advances and making progress toward the resolution of the main technical issues of cruising range and cold start capability^{(2), (3), (4), (5), (6), (7)}. During this period, Toyota also made continuous progress in the development of the fuel cell stack (Fig. 2), which is the most important component of an FCV for achieving popularization. This development also identified the potential for further increases in power density⁽⁸⁾ as well as the possibility of creating a

new chassis to enable greater freedom of installation for. This paper describes recent activities for improving the performance and reducing the size of the polymer electrolyte fuel cell (PEFC), and an example of analysis results obtained during these activities.



Figure 1. FCHV-adv.

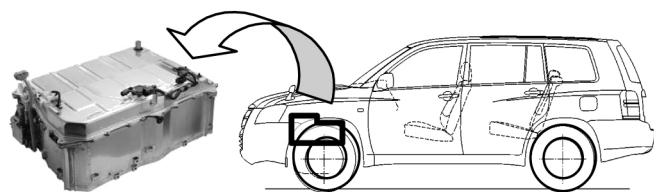


Figure 2. FC stack.

2. REDUCING FUEL CELL STACK SIZE

The area and thickness of the individual cells must be made smaller in order to reduce the size of the power generation portion of the fuel cell. The cell area consists of electrodes, the manifold that provides the paths for the fluids necessary for power generation (i.e., the fuel, oxidant, and cooling medium), sealing portions, and joints. The cell thickness is determined by the electrodes, the flow field of the fuel, oxidant, and the coolant paths on both side of the electrodes, and the separator between them. Since the voltage of a single cell is approximately 1 V, layers of several hundred cells are required after factoring in the operation voltage region and DC-DC converter efficiency of an automotive drive motor. In addition, seals are required between cell layers, materials for insulation, with a holding mechanism which maintains the surface pressure to enable proper electrode contact resistance. These components are referred to as the non-power generation portion. The volume of the stack is determined by the total of the power generation and non-power generation portions. However, since the electrodes generally make up a large percentage proportion of the power generation portion, an effective way of developing a smaller fuel cell stack is to reduce the size of this area.

3. REDUCING ELECTRODE AREA

Although the electrode area specified to provide the power required by the vehicle (current $\times$ voltage), it can be reduced by improving the voltage characteristics, providing that voltage can be maintained even at high currents. As shown in the example in Fig. 3, if twice the current can be achieved from the same voltage, then the electrode area can be reduced by half. If this can be accomplished, then the amount of catalysts, films, separators, and the like can also be reduced, which leads directly to lower cost and weight. Therefore, the improvement of voltage characteristics is regarded as a critical issue for improving the commercial appeal of fuel cells and research has made advances in this field.

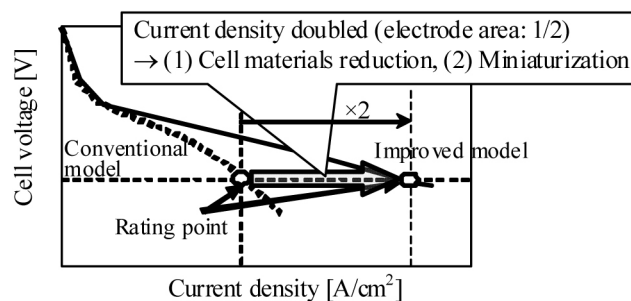


Figure 3. Comparison of IV curves.

4. IDEAL REACTION FIELD AND BEHAVIOR

The ideal reaction field and behavior for a fuel cell is as follows: Sufficient supply of fuel gas and oxidant to the power generation portion, rapid drainage of generated water from the cathode, and smooth oxidation reactions and high conductivity of disassociated hydrogen ions and electrons at the anode.

Reducing losses (i.e., generated heat) over the whole electrode surface and maintaining a favorable state in the reaction field help to improve the power generation performance.

An ideal reaction field depends on the following points: (1) hydrogen and oxygen supply, (2) electron conductivity, (3) generated water drainage, (4) hydrogen ion conductivity, and (5) heat conductivity. To achieve high voltage characteristics, the following two factors must be improved: the supply of oxygen, which is the dominant factor on the high current side (this is known as oxygen over-voltage), and resistance, which affects the gradient of the IV(Current/Voltage) curve.

To quantitatively identify the oxygen supply performance (point (1)), the oxygen concentration is measured below the ribs of the flow field. For point (3), the correlation between the differences in generated water at the flow field ribs and the power generation performance has been clarified by identifying the relationship between the water distribution at the interface between the gas diffusion layer (GDL) and catalyst layer and the limiting current density. For the resistance components in points (2) and (4), it is important to identify the electronic resistance distribution on a microscopic level. This research measured and investigated the electronic resistance at 0.1 mm intervals.

When considered in terms of the pitch of the ribbed flow field, a porous cell structure with a rib interval approximately one decimal place smaller (Fig. 5) than a conventional flow field with a millimeter-order indentation interval (Fig. 4) has a smaller distance from the bottom to the top of the ribs, which should help to form the ideal reaction field. The water distribution, limiting current density, and resistance were measured in both flow field structures. It was found that the new porous cell structure doubled the current density with the

same voltage as in the conventional structure. This study then compared the volumetric power density of the structures simulating their use in a fuel cell stack. In the same way as the preliminary investigation, it was found that the power generation performance at the electrodes was approximately doubled. This paper describes these test methods and results.

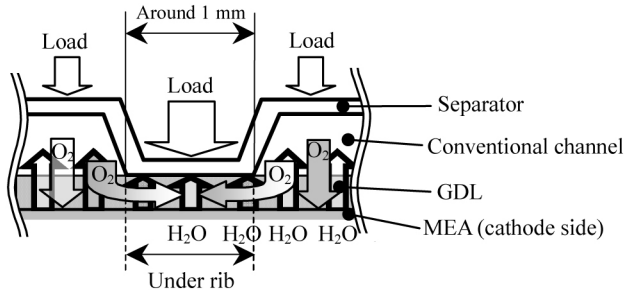


Figure 4. Schematic of cross-section of cell with conventional type flow field.

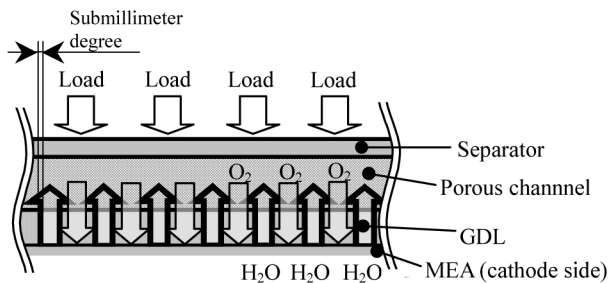


Figure 5. Schematic of cross-section of cell with porous channel type flow field.

5. TESTS AND RESULTS

5.1. OXYGEN SUPPLY: MEASUREMENT OF OXYGEN PARTIAL PRESSURE FOR POWER GENERATION UNDER CATHODE FLOW FIELD USING PRESSURE SENSITIVE PAINT(PSP)

Pressure sensitive paint (PSP) was coated on the side surfaces of the electrode at the ribbed portion of the cathode flow field. This was used to measure the O_2 partial pressure on power generation. Figure 6 shows the configuration of the measurement device.

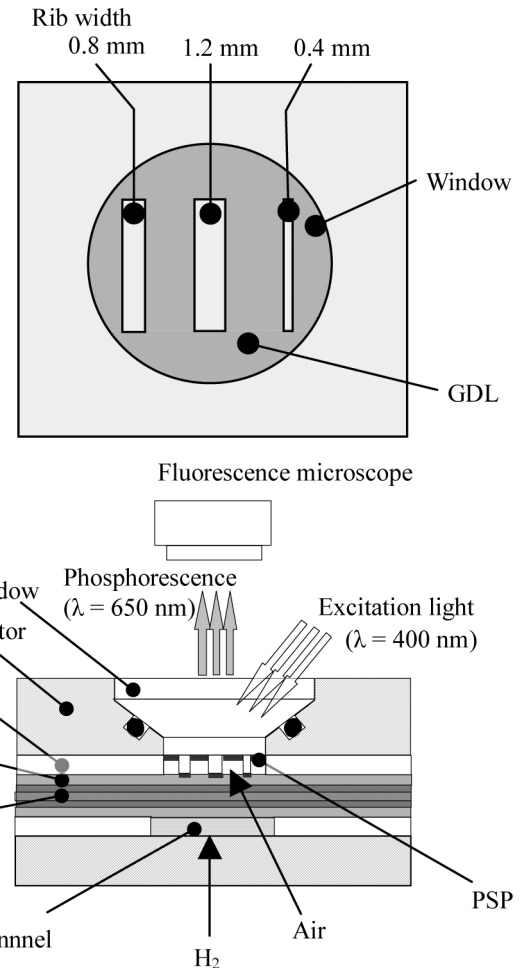


Figure 6. Configuration of PSP measurement.

The PSP measurement device measured the O_2 partial pressure using hydrogen and air under normal fuel cell power generation conditions and a spatial resolution of $150 \mu m$. This configuration was fully capable of measuring changes in O_2 partial pressure caused by structural differences⁽⁸⁾.

Assuming a general channel flow field shape, three rib widths (0.4, 0.8, and 1.2 m) were set and the O_2 partial pressure distribution was measured at three current densities (0.5, 1.0, and 1.5 A/cm^2). The temperature was $70^\circ C$, the relative humidity of the supplied gases was 100% at the anode and 0% at the cathode, and the gas outlet pressure at both electrodes was 140 kPa-abs. Figure 7 shows the obtained O_2 partial pressure distribution and Fig. 8 shows the qualitative relationship between the position in the rib width direction and the O_2 partial pressure.