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Short communication

Experimental study on clamping pressure distribution in PEM fuel cells

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Abstract

To study the effect of internal pressure distribution on the performance of a PEM fuel cell, a pressurized endplate was designed and fabricated. The endplate had a built-in hydraulically pressurized pocket with a thin wall facing the fuel cell assembly. Pressure sensitive films were used to measure the pressure distribution for both conventional and newly designed end plates. Fuel cell performance tests were conducted under selected conditions. It was found that the pressure distribution for the newly designed endplates was more uniform than for the conventional end plates, and an improved fuel cell performance was obtained with the newly designed end plates as well.

Keywords: Fuel cell; End plate; Clamping pressure; Pressure pocket

1. Introduction

Proton exchange membrane fuel cell (PEMFC) is an electrochemical device that can convert the chemical energy stored in hydrogen and oxygen into electricity, without generating pollutants. It has attracted much attention recently because of the prospect of being a clean energy converter and part of the solution to the present environmental problems. However, commercialization of fuel cell is still in its infancy and has a long way to go. High price and poor performance are two major barriers.

In a conventional PEMFC design, end plates are the two outermost components in a fuel cell assembly. They act as part of the clamping system to provide compressive force in order to unitize the single fuel cells together to form a stack. In addition, they also have some other important functions, such as ensuring good electrical contact between multiple layers within the fuel cell, ensuring good sealing at various interfaces, providing passages for the reactants, products and possibly cooling agents to enter and leave the fuel cell and in some cases providing electrical leads for connections to external loads.

Although the current design of fuel cell end plates can provide the above listed functions in a somewhat satisfactory manner, it is recognized that there are some existing problems to be solved, such as the following:

1. Deformation of end plates has an influence on fuel cell performance and is difficult to control.
2. End plates are typically bulky and heavy, as compared to the fuel cell stacks.
3. Tie rods tend to loosen up during service. This may cause leakage, bad electrical contacts and deteriorated performance of the fuel cell stacks.
4. Repeatability in pressure distribution can hardly be realized among the fuel cell stacks.

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To achieve good performance in a fuel cell, it is believed that there exists an optimum level in the pressure used for a certain cell configuration [1–6]. Too much pressure will obviously squeeze the gas diffusion layer and change its porosity ratio, which may choke the fuel cell by making the flow of gases and migration of water difficult. On the other hand, too little pressure will surely result in a high contact resistance between gas diffusion backing and the bipolar plates, which would hurt the fuel cell performance as well. Ideally, the optimum value is to be achieved throughout the fuel cell active area, but in reality it can only be achieved in a very small portion of the area because of the structure in the conventional end plates. Therefore, from the fuel cell performance point of view the most relevant shortcoming of the existing end plate design is the difficulty of achieving a uniform pressure distribution over the fuel cell active area.

In this regard, a significant amount of research work has been performed to improve fuel cell performance [3,7,8]. Unfortunately, very little scientific research has been focused on the pressure distribution between the fuel cell stacks. Modeling a fuel cell generally does not take into account the effect of non-uniform pressure distribution (e.g. [5]). Part of the reason is that the relationship between contact pressure and contact resistance has not been completely understood yet.

The goal of this study is to understand the influence of clamping pressure distribution on the fuel cell performance through an experimental test. The study is intended for future design of end plates to both enhance the fuel cell performance and reduce cost, weight and volume of the fuel cell stacks. The study proposes a prototype end plate for the investigation of the pressure distribution between the bipolar plates. In addition, a fuel cell integrating both conventional and newly designed end plates is fabricated and tested under predetermined conditions. Fuel cell performances are compared and the merits of a more uniform pressure distribution are analyzed.

2. End plate design

As shown in Fig. 1, a new design is proposed to integrate a pressurized and enclosed pocket filled up with hydraulic fluid (e.g., oil or air) by a hand-operated hydraulic pump into the end plate. The thin wall of the pocket (0.15 mm in thickness) facing the stack is used to transmit the hydraulic pressure inside the pocket to the bipolar plates. By doing so, this design will provide uniform pressure distribution to the stack not only on the perimeters but also on the central area.

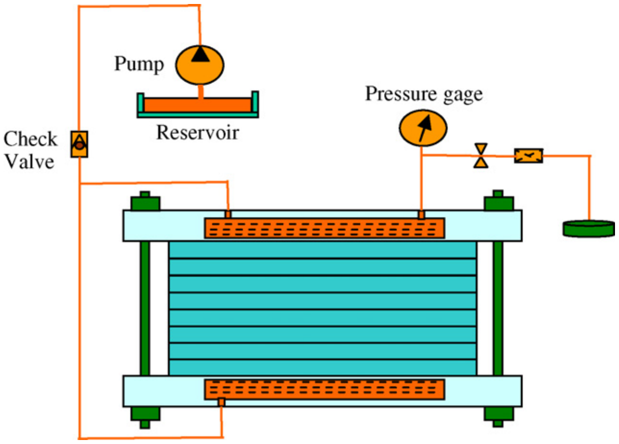

Fig. 1. Schematic of a new design for the end plate and compression system.

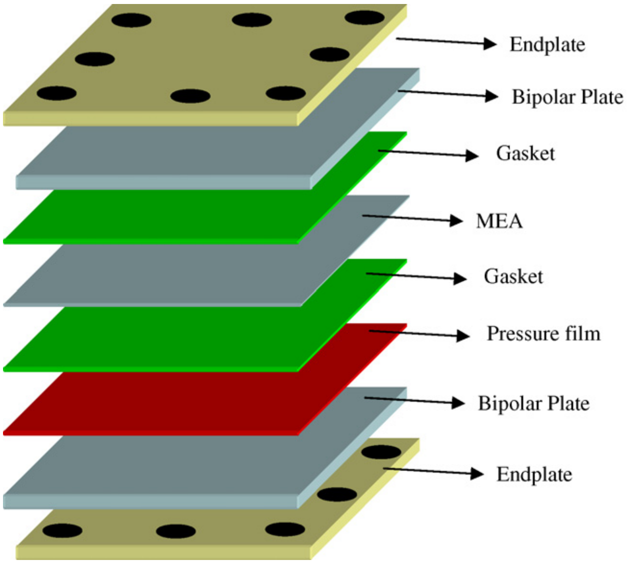

Fig. 2. Schematic showing the pressure film in the fuel cell stack.

With this new design, the rigidity of the end plate is not as important because the uniform pressure distribution is not achieved by very thick and rigid end plates. Therefore, an end plate can be made thinner and therefore lighter. It may be made of plastic materials as opposed to metals, which will further result in a weight reduction.

A pressure gage was built into the system as shown in Fig. 1 to facilitate the real-time monitoring or regular examination of the pressure. A needle valve and a shut off valve are used to make adjustments in the fluid pressure. Therefore, the problem of loosening up of bolts during service can be solved. The more uniform pressure distribution will lead to better electrical contact and mass transport and in turn an improved fuel cell performance.

3. Pressure test

To reveal the actual pressure distribution, some pressure tests were conducted on both the conventional and the newly designed end plates. Pressure sensitive films were used during the testing process. In these tests, ‘Super Low’ and ‘Ultra Low’ films were used under different experimental conditions. The pressure ranges of the ‘Super Low’ and ‘Ultra Low’ films used were 70–350 $\text{lb}_\text{f}\,\text{in.}^{-2}$ (0.483–2.413 MPa) and 20–80 $\text{lb}_\text{f}\,\text{in.}^{-2}$ (0.138–0.552 MPa), respectively. A square piece of film was cut with the dimension of 3.5 in. (8.89 cm) × 3.5 in. (8.89 cm) and was inserted between the membrane–electrode assembly (MEA) and the diffusion layer as shown in Fig. 2. A torque of 25 in. lb_f (282.46 N cm) was applied on each bolt in a certain sequence. Then the pocket was pressurized to a predetermined pressure level. After approximately 5 min, the pressure in the pocket was

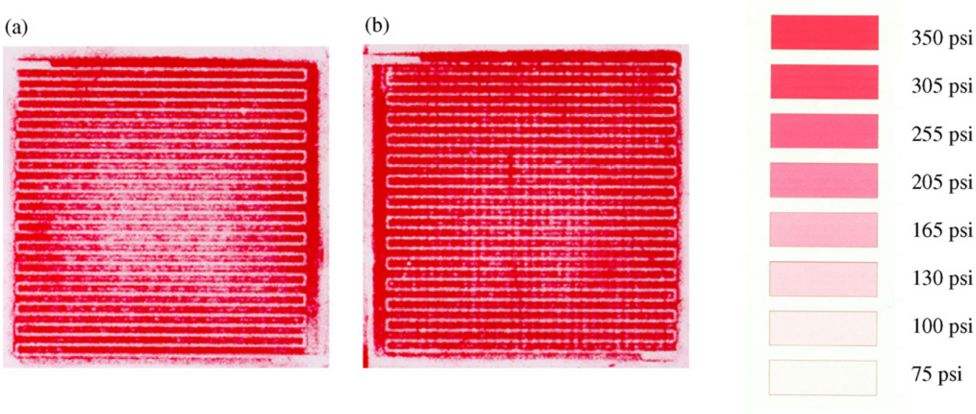

Fig. 3. Pressure distribution profiles between bipolar plates for: (a) conventional end plates; and (b) newly designed end plates.

released so as to loosen up the bolts and to take the film out. The intensity of the red color on the film indicates the level of the local pressure applied.

Shown in Fig. 3 are examples of the pressure distribution profiles inside the fuel cells with the conventional and newly designed end plates, respectively. A fuel cell that had an active area of 25 cm^2 was used and the pressure inside the pocket was 200 psi (1.38 MPa) for the new end plates. It can be clearly observed in Fig. 3(b) that the pressure distribution for the new end plates is much more uniform than that for the conventional end plates. Similar results have been obtained for different thickness combinations of gas diffusion layers and gaskets, and also for a two cell stack, which indicates that the new end plates can provide a much more uniform pressure distribution, tolerate more variations in the plate thickness and work well for both single cell and stack cell. On the other hand, it was noticed in the tests that the pressure distribution inside a fuel cell was greatly influenced by the thickness difference between the gas diffusion layers and the gaskets for conventional end plates, which indicates that a careful design of the assembly is needed to achieve a reasonably good performance for a conventional fuel cell.

Fig. 4 is a proof-of-concept pressure test performed by replacing the MEA and gaskets with a 5 mils (0.127 mm) think Teflon patch of the same size as the active area. It can be found that the pressure distribution on this area is much more uniform for the new end plates, while due to the deformation of the conventional end plates; the pressure in the center of the active area is significantly lower than the surroundings in Fig. 4b. This proves that part of the pressure applied to the fuel cell assembly on the perimeter has been shifted to the center portion by the pressurized pocket and therefore the new plates can provide a more uniform pressure distribution.

Another proof-of-concept pressure test was conducted and is shown in Fig. 5. Pressure distribution was measured over the interface between one end plate and the adjacent bipolar plate. It is obvious from Fig. 5 that the pressure distribution is different between the conventional and the newly designed end plates. When pressure was further transmitted inward towards the center of the fuel cell assembly, the differences in pressure distribution were generated between the end plate designs.

4. Fuel cell performance testing

In the previous section, it was examined that the pressure distribution profiles were different for the conventional and the newly designed end plates. In this section, the fuel cell is tested and the test results are reported to confirm the benefits of the uniform pressure distribution in the fuel cell. The fuel cell performance testing is focused on the performance of the PEM fuel cell with the newly designed end plates and compared with that of the conventional end plates.

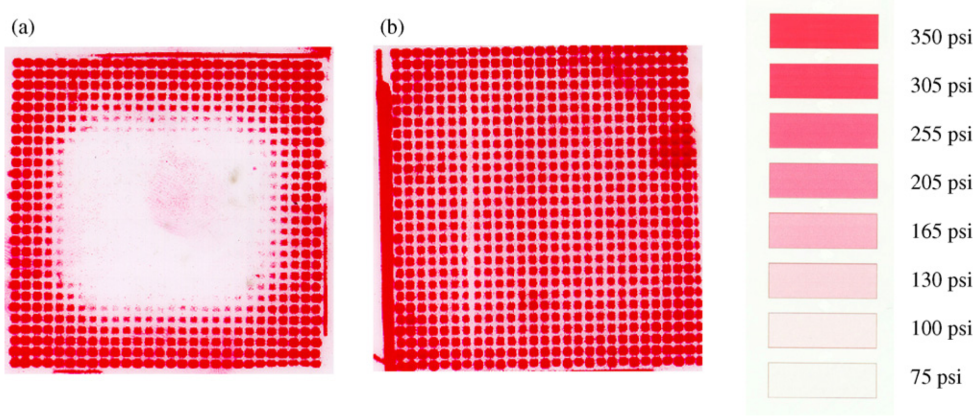

Fig. 4. Pressure distribution profiles between bipolar plates with a Teflon insert for: (a) conventional end plates; and (b) newly designed end plates.

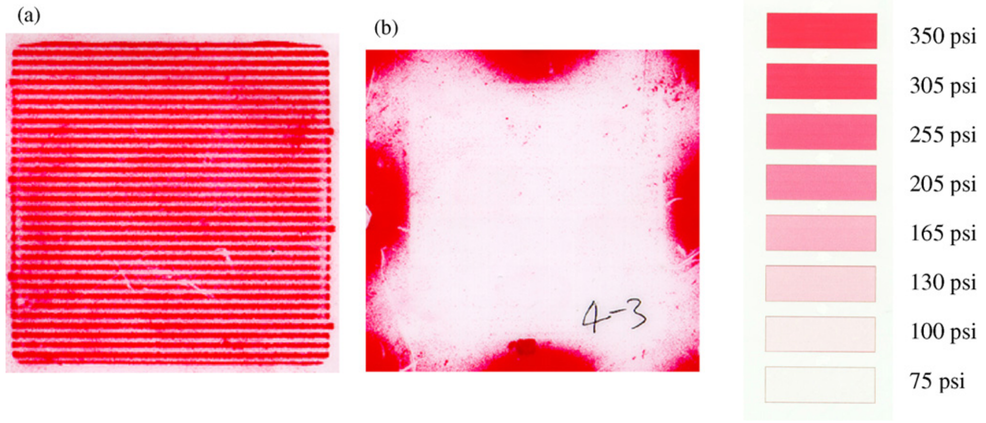

Fig. 5. Pressure distribution profiles between end plate and its adjacent bipolar plate for: (a) conventional end plates; and (b) newly designed end plates.

In the performance testing process, polarization curves were obtained when the pressure inside the pressure pocket was varied from 0 psi (0 MPa) to 100 psi (0.69 MPa), and then to 200 psi (1.38 MPa). All of the data reported was obtained with the in-house MEA coated with catalyst layers (0.5 mg cm^{-2} Pt on the cathode side and 0.4 mg cm^{-2} Pt on the anode side with a nominal thickness of 50 µm). The active area of the membrane was 25 cm^2; the gas diffusion layers had a thickness of 0.368 mm. Teflon of 0.635 mm thickness was used for the gaskets. The bipolar plates with a single serpentine flow field were made by Electrochem Inc. Eight bolts of size #10–32 were used to provide the clamping pressure and a torque of 25 in. lb$_f$ (282.46 N cm^{-1}) was used for each bolt. The bolts were tightened in a certain predefined sequence to ensure that the compressive force was reasonably close to each other for the eight bolts. An in-house test stand was used with a 100A Model 890B Scribner load box, which had imbedded software for current interrupt resistance measurement.

In obtaining the polarization curves, current was stepped up from zero to the maximum current density with an increment between 10 and 100 mA cm^{-2}. Duration for each current density was 5 min.

The cell comprising the newly designed end plates was tested at room temperature under the atmospheric pressure. Pure hydrogen at a certified grade of 99.999% purity was used at anode. Air, as the practical oxidant to fuel cells, was used at cathode. Constant reactant utilization conditions were used: 33% hydrogen utilization, 25% oxygen utilization for air.

Cell internal resistance was measured and recorded at current densities higher than 100 mA cm^{-2} using the current interrupt technique with Scribner v.3.1b fuel cell software. Resistance values at lower than 100 mA cm^{-2} were not measured because the voltage loss at the lower current range was smaller than what could be accurately measured. The current interrupt resistance comprises mostly the ionic resistance of the conductive membrane and contact resistances.

Fig. 6 shows the fuel cell performance test results for the conventional end plates as well as the newly designed end plates with 100 psi (0.69 MPa) pressure and 200 psi (1.38 MPa) pressure inside the pocket. A small voltage increase from the conventional to 100 psi (0.69 MPa) and to 200 psi (1.38 MPa) pressure was observed, especially for higher current densities.

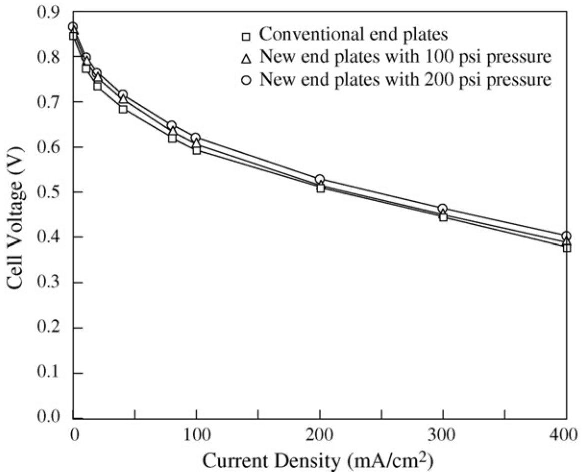

Fig. 6. Effects of different end plates and pressure on the pocket on polarization curve.

5. Conclusions

In this study, a pair of newly designed end plates is used to study the pressure distribution inside a single fuel cell and fuel cell stack. It is confirmed that by pressurizing the built-in pocket with hydraulic fluid, the new design can significantly improve the pressure distribution over the fuel cell active area and at the same time enhance fuel cell performance. It is believed that the optimum fuel cell performance could be achieved if the optimum pressure level were known, which needs a further study. Nevertheless, the benefit of uniform pressure distribution over the active area has been demonstrated with the newly designed end plates in this study.

Acknowledgements

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