

## Development of small polymer electrolyte fuel cell stacks

V.A. Paganin<sup>\*</sup>, E.A. Ticianelli, E.R. Gonzalez

*Instituto de Química de São Carlos, USP, CP 780, 13560-970 São Carlos, SP, Brazil*

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### Abstract

The results on the research and development of small polymer electrolyte fuel cell stacks, including the assembly of single cell, 6-cell and 21-cell modules, are described. The important characteristics of the systems are: (i) membrane and electrode assemblies were made with Nafion<sup>®</sup> 115 and 117 membranes and particularly low catalyst loading electrodes presenting a geometric area of 20 cm<sup>2</sup> and a catalyst loading of 0.4 mg Pt/cm<sup>2</sup>; (ii) bipolar plates were fabricated using a nonporous graphite material in which a series/parallel flow field was machined out; (iii) external distribution of gases to the cells was done using parallel manifolding; (iv) cooling systems were tested employing water/air cooling plates distributed every three cells throughout the stack; (v) the reactant gases were externally humidified using temperature controlled humidification bottles. Testing of the stacks was conducted in a specially designed test station employing nonpressurized H<sub>2</sub>/O<sub>2</sub> reactants and measuring the individual and the overall cell voltage vs. current under several conditions for the overall system operation. © 1998 Elsevier Science S.A.

### 1. Introduction

The polymer electrolyte fuel cell (PEFC) has been one of the most studied fuel cell systems, because of several advantages for transportation applications. Research involved fundamental aspects related to the water transport and the fuel cell reactions [1,2], practical aspects related to the optimization of the structure and operational conditions of gas diffusion electrodes [1–6], and technological aspects related to water management and the engineering of operational sized fuel cell modules [7–13]. In many of these works, it is observed that very satisfactory results regarding the performance of low catalyst loading electrodes (0.15–0.4 mg Pt/cm<sup>2</sup>) have been obtained in single cells [2–6]. However, the use of such electrodes is not yet being considered for building fuel cell stacks and, although not usually mentioned in the literature [7–13], fuel cell modules are assembled employing electrodes presenting catalyst loading in the range of 2–4 mg Pt/cm<sup>2</sup>.

In this work, the results on the research and development of small polymer electrolyte fuel cell stacks employing low catalyst loading electrodes are described. The systems include the assembly of single cell, 6-cell and 21-cell modules. Testing of the stacks was conducted in a specially designed test station employing nonpressurized

H<sub>2</sub>/O<sub>2</sub> reactants and measuring the individual and the overall cell voltage vs. current characteristics under several operational conditions for the system.

### 2. Experimental

The working electrodes were prepared by a combined filtration/brushing procedure using platinum-on-carbon (Pt/C) catalysts (E-Tek), carbon powder (Vulcan XC-72, Cabot), a carbon cloth substrate (PWB-3, Stackpole), a Polytetrafluoroethylene (PTFE) suspension (Teflon T-30, Du Pont) and a Nafion<sup>®</sup> solution (Aldrich, 5 wt.% in 10% water/low aliphatic alcohols). Except where mentioned, the electrodes employed in the modules were made with 20 wt.% Pt/C, 1.1 mg Nafion<sup>®</sup>/cm<sup>2</sup>, 0.4 mg Pt/cm<sup>2</sup> in the catalyst layer and 30% PTFE in the diffusion layer of 50 μm thickness. All the details regarding the procedures for the membrane and electrode assembly preparation were presented previously [6].

The main characteristics of the fuel cell stacks are summarized in the scheme presented in Fig. 1. The bipolar and end plates were fabricated using a nonporous furfural impregnated graphite material in which a series/parallel flow field was machined out. The gaskets were cut out from a silicon rubber fiberglass cloth. The cells with an active electrode area of 20 cm<sup>2</sup> (geometric) were clamped

<sup>\*</sup> Corresponding author.

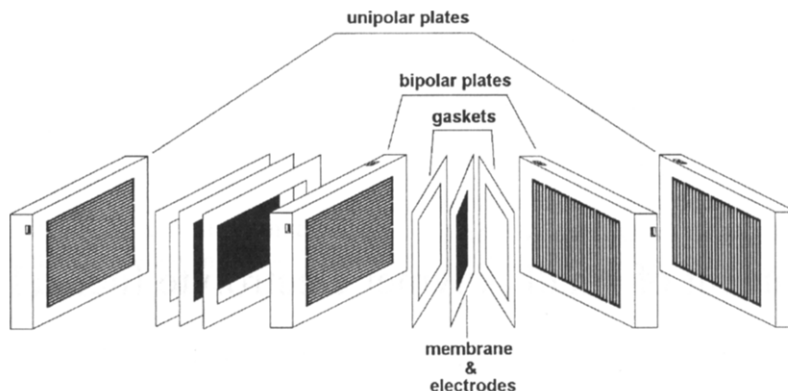


Fig. 1. Scheme of the configuration of the multi-cell stacks.

between aluminum plates. The distribution of gases to the cells was done using an external parallel manifold system made with stainless steel and containing individual needle valves for the control of the gas flow rates for each cell. In the present experiments, an excess of flow was applied in the cells.

The cooling system was tested employing water cooling plates distributed every three cells throughout the stack. The temperature control was conducted using thermocouples inserted in pre-determined places in the 6- and 21-cell stacks. The principle of operation is based in a constant coolant flow on/off concept, set to establish a maximum range of  $\pm 3^\circ\text{C}$  in the highest point of the fuel cell operating temperature.

Humidification of the reactants was carried out by bubbling the gases through water contained in stainless steel bottles thermostated to the desired temperature. Measurements of the cell potential as a function of the current density were made galvanostatically using an electronic load (HP-6050A, Hewlett Packard) and an IBM PC-compatible microcomputer equipped with a digital I/O and multiplexer plate (DAS-1600, Keithley). Testing of the stacks was conducted in a specially designed test station [14] employing nonpressurized  $\text{H}_2/\text{O}_2$  reactants.

### 3. Results and discussion

Fig. 2 shows the cell potential vs. current density characteristics obtained at several cell and humidification temperatures for the single cells with 5 and 20  $\text{cm}^2$  electrodes assembled with Nafion<sup>®</sup> 117 membrane. The results obtained at a cell temperature of  $80^\circ\text{C}$  with the humidifiers at  $T_{\text{H}_2} = 95^\circ\text{C}$  and  $T_{\text{O}_2} = 85^\circ\text{C}$  show that the increase in the electrode area from 5 to 20  $\text{cm}^2$  resulted in a small diminution in the performance of the system. This appears as an increase of the slope of the linear region of the curves which is an evidence that the problem is related with an increase of the ohmic resistance of the membrane due to a diminution of the water content. In the larger cell, it is expected that the overheated and vapor-saturated reactant gases are cooled and the vapor condensed through

the longer path of the gas distribution channel located in the graphite plates, leading to a less effective membrane humidification.

Fig. 2 also shows that a pronounced increase in the slope of the linear region of the polarization curve is observed for  $T = 80^\circ\text{C}$  when the humidification of the reactant gases is carried out at the same temperature of the cell. However, the situation is less critical for lower temperatures, and a leveling of the performance occurs for temperatures below  $70^\circ\text{C}$ . The described behavior have also been observed with the 5  $\text{cm}^2$  single cell and has been attributed to differences on the membrane resistance due to differences in the water balance [6,15] established at each temperature. If the water content is constant, the tendency is for the membrane to present higher resistivity at lower temperatures. However, due to a smaller rate of water evaporation, the equilibrium content of water must increase with the decrease of temperature leading to an increase in conductivity which approximately compensates the other tendency.

The average cell potential vs. current density characteristics at  $80^\circ\text{C}$  of the single cells with 5 and 20  $\text{cm}^2$  electrodes and of the 6 cell stack with 20  $\text{cm}^2$  electrodes assembled with Nafion<sup>®</sup> 115 membrane are presented in Fig. 3. It is observed that in the case Nafion<sup>®</sup> 115, there is also a diminution of the single cell performance when the

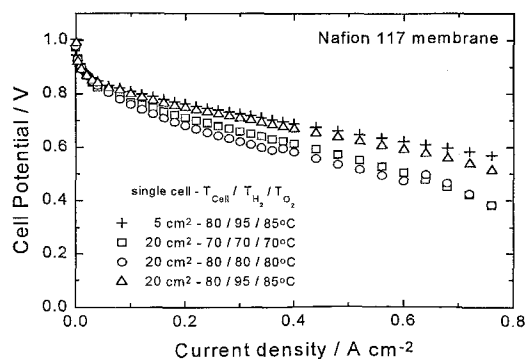


Fig. 2. Cell potential vs. current density plots for the single cells with 30 wt.% Pt/C, 0.8 mg Nafion<sup>®</sup>/cm<sup>2</sup> electrodes.

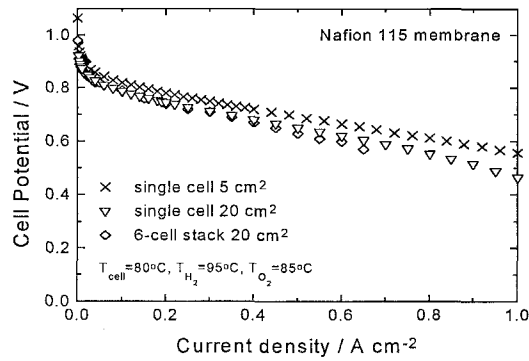


Fig. 3. Average cell potential vs. current density plots for the single cell and 6-cell stack.

electrode area is increased from 5 to 20 cm<sup>2</sup>. Besides a small increase in the slope, the effect of the electrode scale-up is observed as a parallel down shift of the polarization curves, probably arising from an apparent decrease of the catalyst active area due to partial drying of a fraction of the polymer electrolyte impregnated into the catalyst layer of the electrode. Possibly this occurs simultaneously with a gas crossing-over effect, as indicated by the smaller open circuit potential observed for the 20 cm<sup>2</sup> compared with that of the 5 cm<sup>2</sup> cell. In spite of these additional problems, it should be noted that, due to the smaller thickness, the performance of the 20 cm<sup>2</sup> cell presents better characteristics with Nafion<sup>®</sup> 115 than with Nafion<sup>®</sup> 117, as can be seen from the comparison of the results on Figs. 2 and 3.

Fig. 4 shows the comparison of the average performance of the cells in the 6-cell and 21-cell stacks at 50°C with that of a single cell operating under the same conditions. In all cases the cells were assembled using a Nafion<sup>®</sup> 115 membrane and electrodes with 20 cm<sup>2</sup>. From the results presented in Figs. 3 and 4, it is observed that at 80 or 50°C and for current densities up to 0.8 A/cm<sup>2</sup>, the increase in the number of cells from 1 to 6 introduces only a small decrease in the average cell performance. On the other hand, the decrease in the performance of the individual cells in the 21-cell stack is higher than that of the

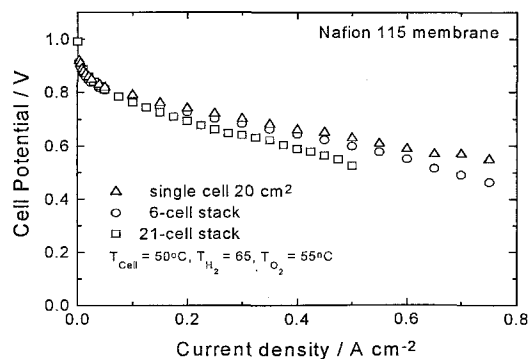


Fig. 4. Average cell potential vs. current density plots for the single cell, the 6-cell and the 21-cell stacks at 50°C.

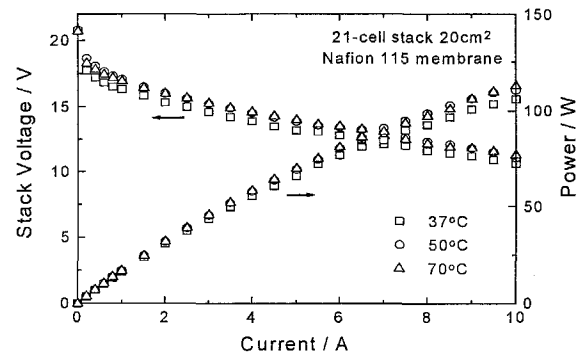


Fig. 5. Voltage and power of the 21-cell stack as a function of current. Hydrogen humidified at 15°C and oxygen humidified at 5°C above the cell temperature.

6-cell stack, compared with that of the single cell. In all cases, the effects are associated with an increase in the slope of the linear region of the polarization curve due to a higher membrane resistance and indicates that the problems regarding the water management become bigger when the number of cells in the module is increased.

The effect of temperature on the performance of the 21-cell stack is presented in Fig. 5. It is observed that the increase in temperature introduces a positive effect in the 21-cell stack performance up to 50°C, which is seen as a parallel upward shift of the polarization diagram. This is probably due to an increase of the conductivity of the polymer impregnated into the catalyst layer of the electrodes leading to an increase of the electrochemical active area. At 70°C, the performance is similar to that at 50°C, indicating that the increase in the conductivity promoted by the increase of temperature is compensated by a decrease in the equilibrium water content of the polymer.

As a final remark, it should be noted that, compared with the modules assembled employing high catalyst loading electrodes [7–13], the 21-cell module presents a smaller power generation per unit of stack volume and weight. On the other hand, the performance of the stack assembled in this laboratory with low catalyst loading electrodes shows that the power generation per unit of platinum weight is of the order of 0.35 kW/g Pt at 0.5 A/cm<sup>2</sup>. In the same region of current densities, the values reported for high platinum loading electrodes are in the range of 0.05 to 0.1 kW/g Pt [7–13] thus showing that low catalyst loading electrodes provide a better platinum utilization. This is a very satisfactory situation to be considered, when the restrictions related to the module weight and volume are of minor importance.

#### 4. Conclusions

The following observations can be made from the results of this work: (i) for Nafion<sup>®</sup> 117, the scale-up of the electrodes from 5 to 20 cm<sup>2</sup> introduced a small increase in

the slope of the linear region of the polarization curves which is due to an increase of electrolyte resistance probably associated with the water balance; (ii) for Nafion® 115, the effect of the electrode scale-up is related to a parallel shift down of the curves, probably associated with an indirect diminution of platinum effective area; (iii) the increase in the number of cells in the stack leads to an increase in the slope of the linear region indicating problems regarding the water management; and (iv) the performance of the stack assembled in this laboratory shows that low catalyst loading electrodes provides a better performance with respect to platinum utilization.

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