EFFECT OF AIR FLOW REGIME AND BPP CHANNEL LENGTH ON GLOBAL PERFORMANCE OF A PEM FUEL CELL

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ABSTRACT

In this work the effect of oxidant air flow regime and bipolar plate (BPP) channel length on the global performance of a Proton Exchange Membrane (PEM) fuel cell with 25 cm^2 area. For these tests 4 cathode gas flow field (GFF) designs, where the main variable was its total channel length (5, 7.5, 10 y 15 cm), were used. Another parameter tested in this work was the flow gas regime el of air used at the cathode, which is associated to the convective oxidant gas system. Tests were carried out at 70 °C and mainly consisted in the evaluation of fuel cell stability performance at a fix potential from 30 minutes to 1 hour. Along each test, electrochemical impedance spectroscopy (EIS) measurements were taken as a diagnosis technique, to detect hydration and/or transport processes which could appear or to monitor the evolution of the system to a potential flooded state. Results showed that a 5cm long channel design, induces a cell's global performance loss by dehydration of the electrolyte; on the other hand a GFF design of 15cm long channel, did not allow for an effective water removal (produced by the electrochemical reaction), taking the fuel cell to a loss of performance at the end of the test due to flooding. Designs with lengths of 7.5 and 10 cm showed a maximum in performance for a given value of flux. In each of these two cases, operating the fuel cell with the air feeding system at a higher regime of that maximum took the cell to a lower performance level as dehydration initiated. Operating the fuel cell at a lower regime than the maximum performance, also produced a loss in performance but this time due to flooding.

Key words: PE fuel cell design, channel length, EIS.

1. INTRODUCTION

PEM fuel cells, are still a major promise as Energy technology that takes advantage of the hydrogen chemical energy's direct transformation into electricity without any combustion. Besides its high efficiency in Energy conversion, the fuel cell works noiseless and does not produce any harmful emission [1,2].

Although in a limited fashion, it is possible to find fuel cell products in the market [3]. Despite that, the technology is in need of improving aspects that can give it competitiveness at different levels. Providing a fuel cell system with less severe and more controlled operating conditions are among the features desired for cheaper and simpler systems. PEM fuel cell designs and optimization of operating conditions, remain areas of great interest to developers and researchers. In literature, there are several proposed designs for flow field, ranging from classic to the issue-based fractal or self-mimicry [4,5]. It is important to say that all of them are functional, but only under certain operating conditions.

Introducing more in the design of flow field, we know that the GFF channel length is an important factor related directly to the global performance of a fuel cell [6], especially in those fed with air from air blowers or fans, as the high flow rates of air at a typically worked low pressure (near ambient) can become the principal problem when trying to establish optimum operating conditions. This low pressure limits gas transport to the catalytic layer (CL) [1,7], therefore rendering a low performance of the cell. On the other hand, increasing the air flow to compensate for a mass transport possible issue, puts the membrane in risk as this will promote dehydration of the membrane, which in turn produces loss of performance. An additional problem is that related to the inability of the air to remove electrochemically produced water, due to the low pressure from the convective air system taking the system to a potential flooding condition [2].

The effect of gas flow field (GFF) channel length and of air flow rate on the overall performance of a 25 cm^2 PEM fuel cell was evaluated and is presented in this paper. Cases tested correspond to potential designs for a fuel cell stack, so lengths had similar designs and only lengths were changed. Besides, different cathode air flow rates associated with the convective system used to test for optimal operating conditions.

2. METHODOLOGY

The main purpose of the experiment design was to establish steady state conditions for performance evaluation. Channel lengths tested were: 50, 75, 10 y 150 mm (named: L50, L75, L100 y L150, respectively). For this, one monopolar plate was manufactured for each design with width and depth of 1.5mm y 1.2mm, respectively.

For each GFF, different operating regimes for the convective air system were defined (see table 2.1), then performance was evaluated for each during 1 hour. Performance monitoring was realized through chronoamperometries at a cell's voltage of 0.3V and taking measurments of EIS along the tests to follow (if presented) the evolution of the complete system to dehydration or flooding states or the incapacity of the air system to supply sufficient air to the cell. All electrochemical tests were performed in a monocell hardware for 25 cm^2 of membrane electrode assembly's (MEA) active area. The MEA used was manufactured in the Hydrogen and Fuel Cell Laboratory of the Instituto de Investigaciones Eléctricas, with a Pt load of 0.7 mg Pt /cm^2, symmetrically deposited on a Nafion NRE-212 membrane. The gas diffuser used was a commercial carbon paper with a micro-porous layer: GDL-35-BC from SGL. The cell's operating temperature was 343.15 K (70°C). The anode was fed with pure hydrogen gas at a stoichiometry of 1 and a pressure of 34.5 kPa (5 lb/in^2). On the cathode side air was used as oxidant gas, and was fed with a voltage-controlled fan. In all cases, gases were fed without previous humidification. Pressure, temperature and hydrogen feeding were controlled using a test station Electro-Chem, Inc. MTS 150. Chronoamperometries and EIS measurements were performed at a cell voltage of 0.3V. Both types of measurements were performed using potentiostat-galvanostat Solartron 1287 coupled to a frequency response analyzer Solartron 1260 and a Solartron 1290 booster. The frequency range for EIS testing was 1 to 10000 Hz at an applied a.c. voltaje amplitud of 80 mV.

Table 2.1. Different voltages of a controlled fan used to produce different flux regimes

Design (channel length)	Fan voltaje (V)
L50 (50 mm)	5, 8.5 y 12
L75 (75 mm)	6, 9, 12 y 18
L100 (100 mm)	9, 12, 15 y 18
L150 (150 mm)	12 y 18

3. RESULTS

Figure 3.1 presents results of the characterization of the 4 channel lengths tested in this work. In there, it can be observed that the design with a cannel 100mm long reached the highest performance (0.32 A/cm^2) when operated at the flow regime achieved at an air fan voltage of 12V. Lower (9V) or higher voltages (15 and 18V), produced lower performance. A similar behavior was obtained for a cannel length of 75mm, which reached its maximum performance at an air fan voltage of 9V. Design with lengths of 50 and 150mm, showed in general, a lower performance at the different tested fan voltages.

Even though these results indicate that the design with 100mm cannel length showed the best performance under the operating flow regimes, they do not show any evidence as to which were the reasons for other designs worse performance. Analysis of EIS results do provide detailed information of the cell's state regarding dehydration and limitation of mass transport either due to flooding or air feeding inefficiency at the cathode [Félix 2009]. For the particular L50 design, Nyquist diagrams showed in figure 3.2, give the main reason of the low performance attributed to dehydration under steady state in the cell. That is, the internal resistance of the cell increased from 0.47 to 0.98 Ohm, when the air system operated at 5V; from 0.5 to 1.07 Ohm in the case of fan operation at 8.5V, and finally an increase from 0.55 to 1.6 Ohm for an operating air system voltage of 12V. Additionally, Bode diagrams indicated that by the end of the hour test there was not indication of flooding n the cathode even when this was detected in the beginning of the tests (8b).

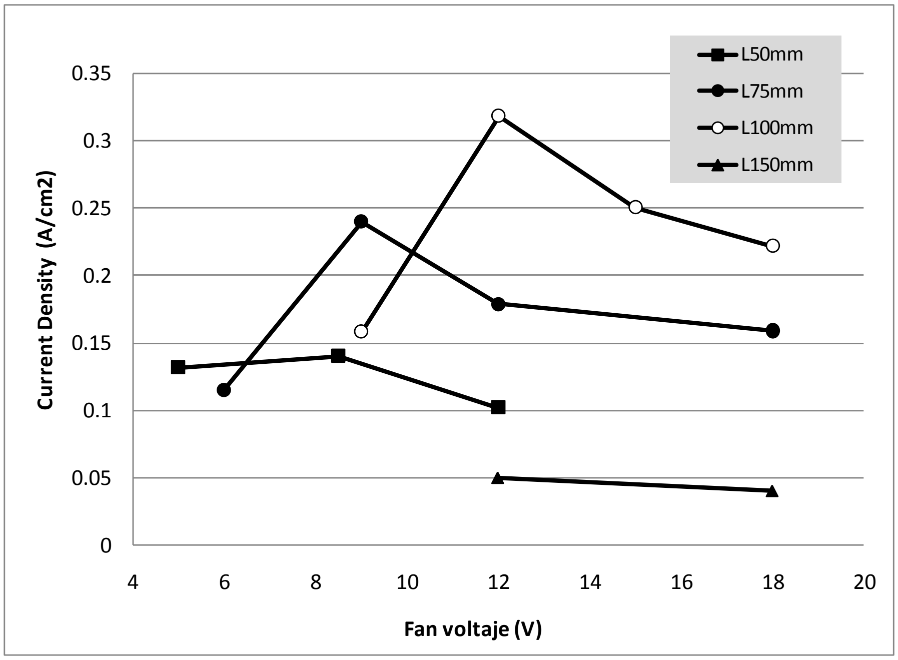
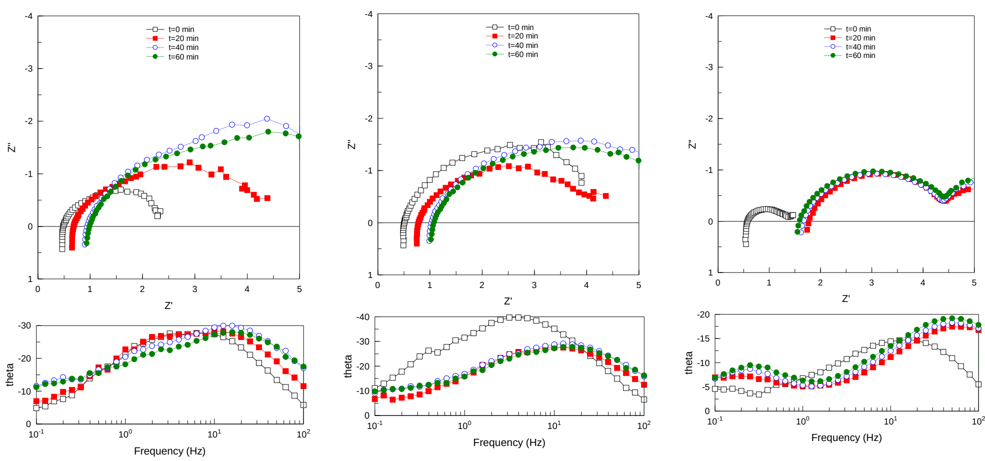


Figura 3.1. Cell performance at steady state conditions after 1hr operation.



a) 5 V

b) 8.5 V

c) 12 V

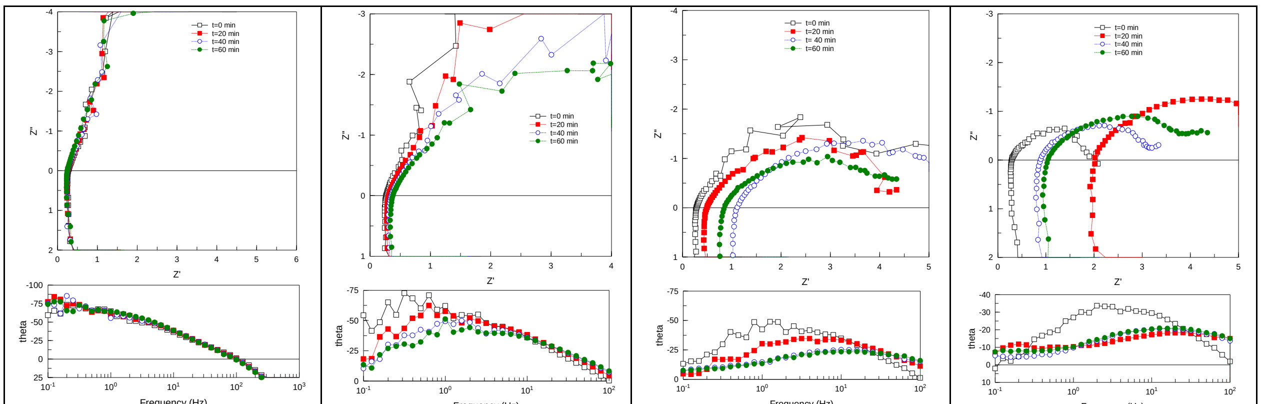
Resistance change: 0.47 to 0.98 Ohm.

Resistance change: 0.5 to 1.07 Ohm.

Resistance change: 0.55 to 1.6 Ohm.

Figura 3.2. Nyquist and Bode diagrams. Cells monitored for a 50mm channel length.

The 75mm long cannel design was somewhat different, when operated with an air system at 6 V, the high phase angle value seen in the Nyquist plot (theta=75), measured in the low frequency extreme, indicates that the fuel cell system presents mass transport problems from the very beginning of the test, i.e. the air flow regime established by the air fan system at 6 V, limits the electrochemical reaction (i.e. the cell's performance), as the required oxygen is not sufficiently supplied. The air fan system operating at 9 V, considerably decreases these mass transport problem, reaching a theta value of 15, without affecting considerably the internal resistance of the cell (a variation from 0.26 to 0.38 Ohm). As a result of this, the fuel cell system presents its best performance. On the other hand, the increase in air flow regime corresponding to an air fan voltaje of 12 and 18V (figures 3.3c and 3.3d), result in a major dehydration of the fuel cell system, which can be seen by the increase in the internal resistance of the cell, going from 0.27 to 0.85 Ohm (case c) and from 0.25 to 1.0 (case d).

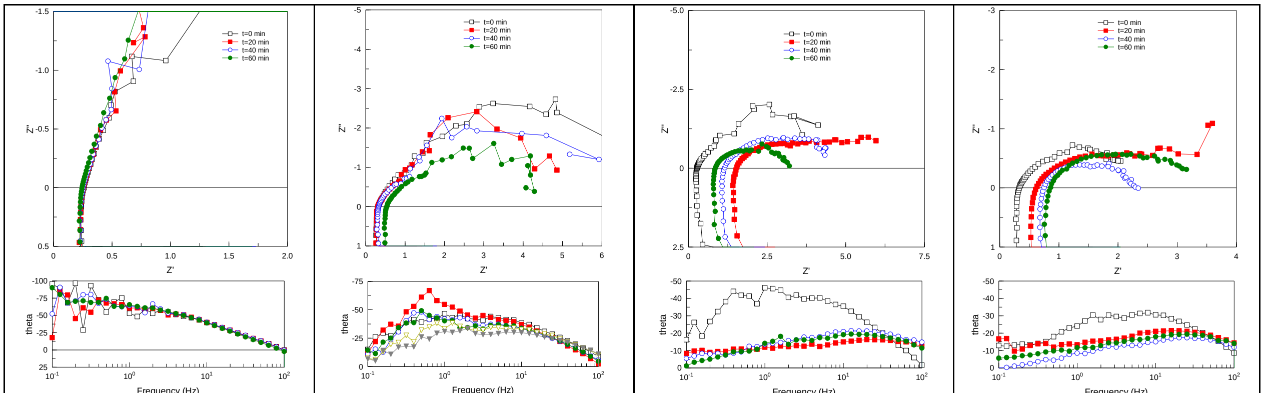


a) 6 V	b) 9 V	c) 12V	d) 18 V
Resistance change: 0.27 to 0.245 Ohm.	Resistance change: 0.26 to 0.38 Ohm.	Resistance change: 0.27 to 0.85 Ohm.	Resistance change: 0.25 to 1.0 Ohm.

Figura 3.3. Nyquist and Bode diagrams. Cells monitored for a 75mm channel length.

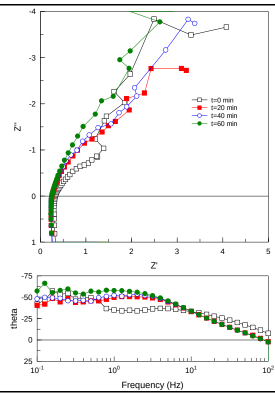
The L100 design (figure 3.4), has a similar behavior as the L75 design, except that the first reached its maximum performance with an air system operating at 12 V. Under this value (9 V) the lower performance was due to mass transport limitations (figure 3.4a). At higher regime of air fan voltage (i.e. larger air flux) 12 V, the fuel cell system suffered from dehydration, going from 0.27 to 0.86 Ohm at a 15 V operating voltage (figure 3.4c) and from 0.33 to 0.85ohm at 18V (figure 3.4d).

Design L150 performance was an extreme case. At both tested voltages (12 and 18 V), the fuel cell presented gradual flooding along the test (gradual increase in phase angle theta), indicating that at this air flow regime, the air system was unable to remove the excess water produced at the cathode.



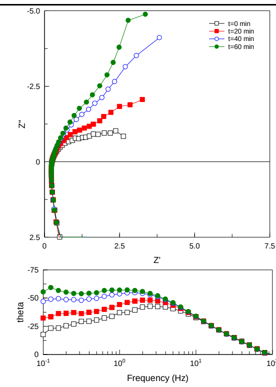
a) 9 V	b) 12V	c) 15V	d) 18 V
Resistance change 0.26 to 0.245 Ohm.	Resistance change 0.3 to 0.53 Ohm.	Resistance change 0.27 to 0.86 Ohm.	Resistance change 0.33 to 0.85 Ohm.

Figura 3.4. Nyquist and Bode diagrams. Cells monitored for a 100mm channel length.



a) 12V

Resistance change 0.33 to 0.25 Ohm.



b) 18V

Resistance change 0.25 to 0.25 Ohm.

Figura 3.5. Nyquist and Bode diagrams. Cells monitored for a 150mm channel length.

4. CONCLUSIONS

Based on the results, we can say that for the range of air flow rates tested, the cathode flow field channel length, has a direct effect on cell performance, which in turn is determined by the water removal capability that allows the design. This removal capability can produce two effects: a beneficial when water removal prevents the flooding of the cell, and a harmful when it causes dehydration. In the particular case studied, the design L100, was the most appropriate to give the best performance when it was operated at an air flow rate corresponding to 12V fan.

However, analysis of results from the perspective of the EIS, can extend the conclusions of this work beyond just choosing the length of channel that provides the highest performance: to set or modify operating conditions more assertive, so that it can potentiate the performance of each design or even propose a rethinking of the same. For example, the L50 design, is functional for ultra low power systems and requires a low speed air supply. On the other hand, the performance of the L150 design, could be increased considerably, even above the L100, if you have an air supply system, which provides a greater flow and higher discharge pressure, so that it is capable remove the water produced by the reaction.

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