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# STUDY ON THE BEHAVIOR OF IN-HOUSE BUILT FUEL CELLS

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***Abstract.*** *This work reports the capacity of design, construction and testing of proton exchange membrane fuel cells at laboratory scale, with the objective of reaching a set of reference conditions to be used for further testing of other types of fuel cells using similar geometrial configurations. Two configurations were adopted in this initial approach, both with an active membrane area of 25 cm$^2$, but using different layouts for the anode and cathode gas flow channels. The used membranes were from DuPont reference H25-bMEA5 with a NAFION layer of 25 μm thickness. One of the configurations used a pair of serpentine channels, for each gas flow, whereas the other used single serpentine flow channels. The twin serpentine configuration had two independent entries for hydrogen and air. With this layout the two serpentines available for each gas flow, could either be connected in series or in parallel. Both cells were then tested in a laboratory scale test rig, by feeding pure hydrogen to the anode and air to the cathode. Experiments were carried out for different combinations of operating temperatures of the gas flows, of the cell operation and also for different degrees of humidification of the hydrogen and air flows. Experimental data are shown as plots of polarization curves of the cells under analysis and explanations for the obtained results are discussed.*

***Keywords****. fuel cells, hydrogen, proton exchange, membranes.*

## 1. Introduction

Proton exchange fuel cells or polymer electrolyte membrane fuel cells PEMFC have this particular name owing to the special polymeric membrane used as electrolyte (Springer et al., 1991; Appleby and Faulkes, 2000; Cappadonia et al, 2000). The most common used fuel is pure hydrogen (Kordesch and Simader, 1996). Other fuels, which must be previously converted to hydrogen like for example methanol, ethanol or methane (Cappadonia et al, 2000) are also used. Variations of this basic approach are direct methanol fuel cells DMFC and direct formic acid fuel cells, DFAFC (Hirschenhofer et al, 1998; Rice et al., 2002; Larminie and Dicks, 2004; Dunn-Rankin et al., 2005). The most common membrane used in PEMFC's is composed by NAFION a trade mark from DuPont, which when conveniently humidified allows proton conduction from the anode to the cathode. Due to the need of membrane humidification operation temperatures are relatively low, below 100 ºC, even working under high pressure, Hoogers (2003). Low operating temperatures requires the use of catalysts to increase the reaction rate; the most common catalyst are platinum based and are highly sensitive to CO poisoning although they tolerate $CO_2$ (Joon, 1998).

The single liquid product of this type of cell is water and because of this the polymer electrolyte membrane fuel cells have no corrosion problems, are easily built and can work with high current densities and when used a liquid fuel like methanol or formic acid, the fuel handling, storage and transportation problems are reduced (Hirschenhofer et al, 1998; Rice et al., 2002; Dunn-Rankin et al., 2005).

There are many results published about this type of fuel cells through experiments carried out all over the world (Nguyen and White, 1993; Mosdale et al., 1996; Barbir and Gómez,1997; Sridhar et al., 2001; You and Liu, 2002; Evans, 2003; Wang et al., 2003; Ge and Yi, 2003; Larminie and Dicks, 2004; Wang and Hongtan, 2004, Steidel et al., 2004;), but many of the available data refer to cells bought at suppliers external to the research team. In the present work the objective was to go towards an in-home design and construction process, in order to start a family of fuel cells working with different fuels, but having close physical configurations and comparing their operating performances. The data now being presented and discussed refer to the initial step of the study, i.e. a hydrogen fuelled cell.

## 2. Construction of fuel cells

Two fuel cells were designed and built at INEGI with the exception of the MEA's (MEA - membrane electrode assembly) which were purchased at DuPont Fuel Cells. Each fuel cell is composed by:

- Two closing metallic plates;
- Two electron collecting plates;

- Two carbon plates;
- One MEA bought at and external supplier.

One of the cells, called INEGI 1, had a single continuous serpentine for the hydrogen flow while the other, named INEGI 2, had two serpentines which could be connected in series or in parallel.

### 2.1. Closing plates

Closing plates are of aluminum 10 mm thick and of 115×115 mm size. Each plate has six holes of 5mm diameter to allow different combinations of fuel and oxidant inlet and outlet connections. Eight threaded holes of 6.5 mm were available for final fitting. Figure 1 shows a drawing of the closing plate.

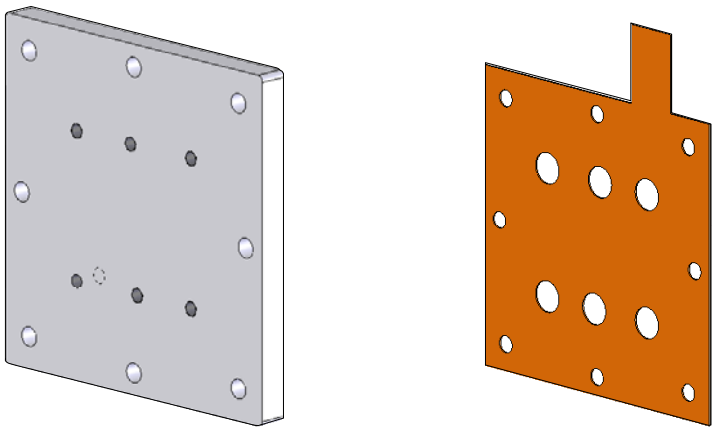


Figure 1. Closing plate and electron collecting plate.

### 2.2. Electron collecting plates

Electron collecting plates are of copper recovered with a thin layer of gold. Their dimensions are of 100×100×0.6 mm, Fig. (1).

To guarantee the electrical isolation required for a correct working of the cell a thin film of acetate was placed between the electron collecting plate and the corresponding closing plate.

### 2.3. Carbon plates

The carbon plates have the channel layout shown in Fig. (2) for both configurations that were used, INEGI 1 and INEGI 2. Overall dimensions of these plates were 100×100×3.5 mm and channels were of 0.7 mm depth in the hydrogen side and 1.5 mm depth on the air side.

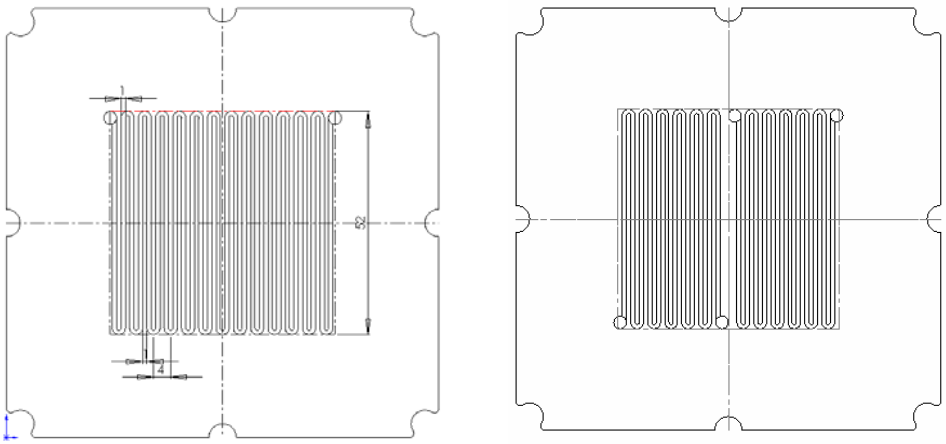


Figure 2. Carbon plates. Left plate INEGI 1, right plate INEGI 2.

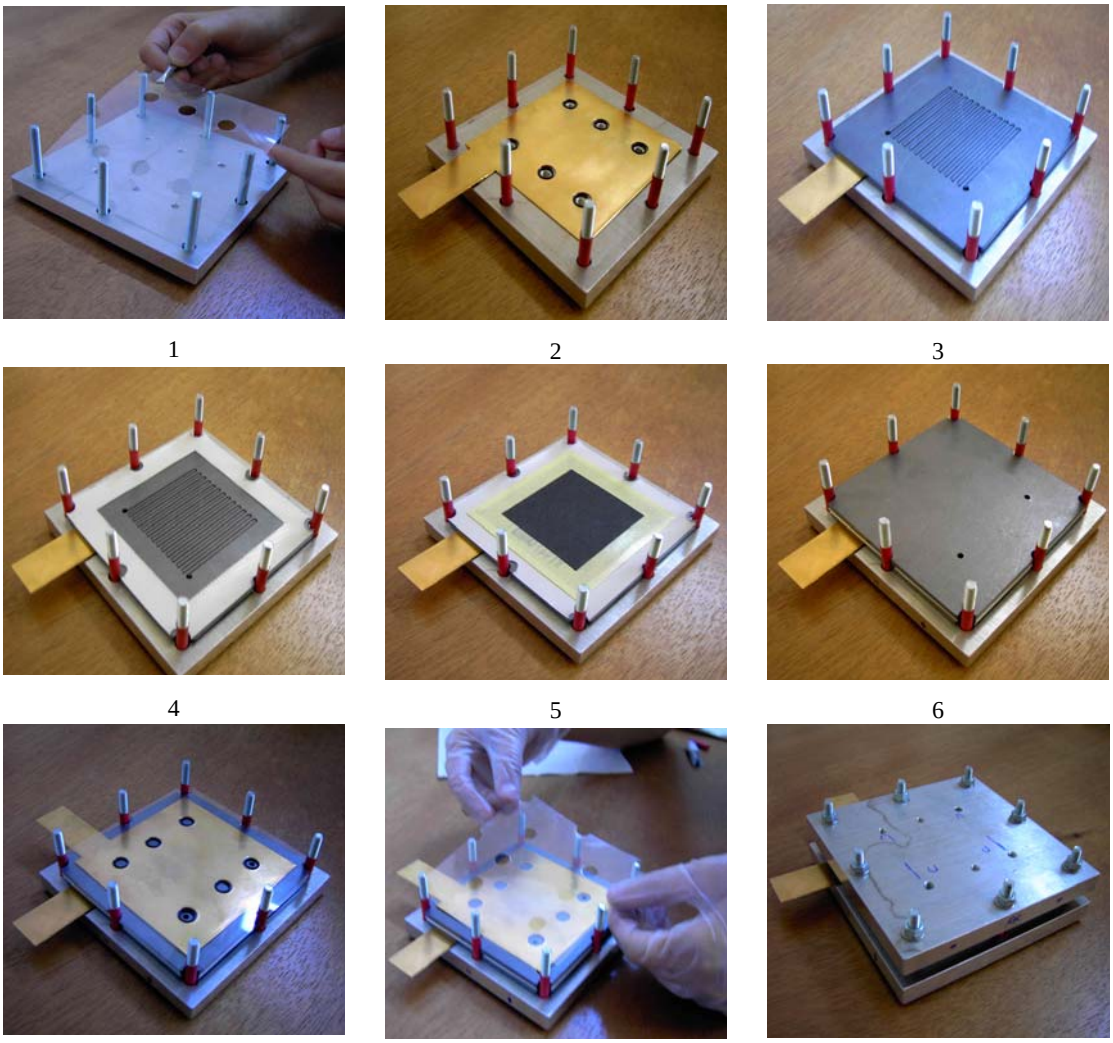
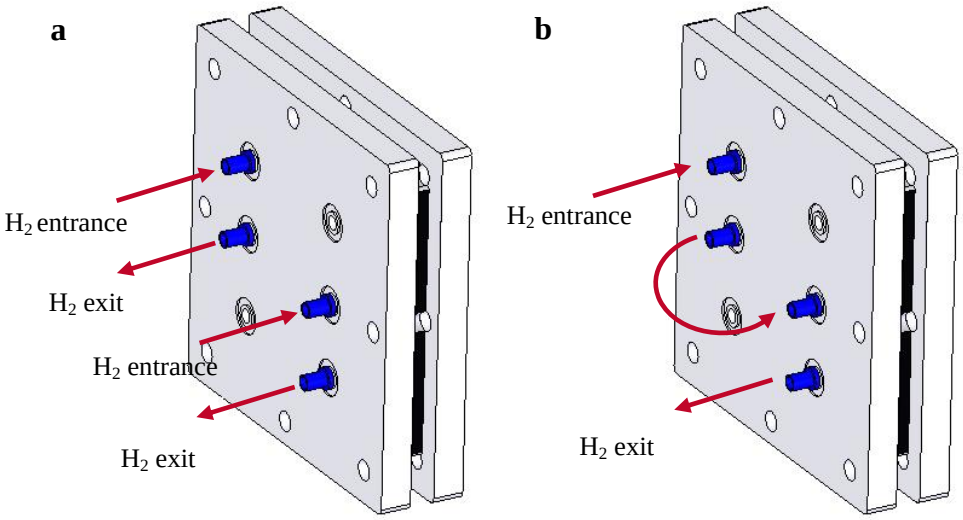



Figure 3. Mounting sequence of a fuel cell.




INEGI 2 paralel configuration INEGI 2 series configuration

Figure 4. INEGI 2 fuel cell: a) parallel configuration, b) series configuration.

### 2.4. MEA and cell mounting

The used membranes were from DuPont reference H25-bMEA5 with a NAFION layer of 25 µm thickness. The active membrane area of the membranes is of 25 $cm^2$. Gaskets to ensure proper joining among the different plates were also bought at Dupont. The mounting sequence of the fuel cell is shown in Fig. (3).

Figure (4) shows the two hydrogen connecting configurations that could be used with INEGI 2 fuel cell.

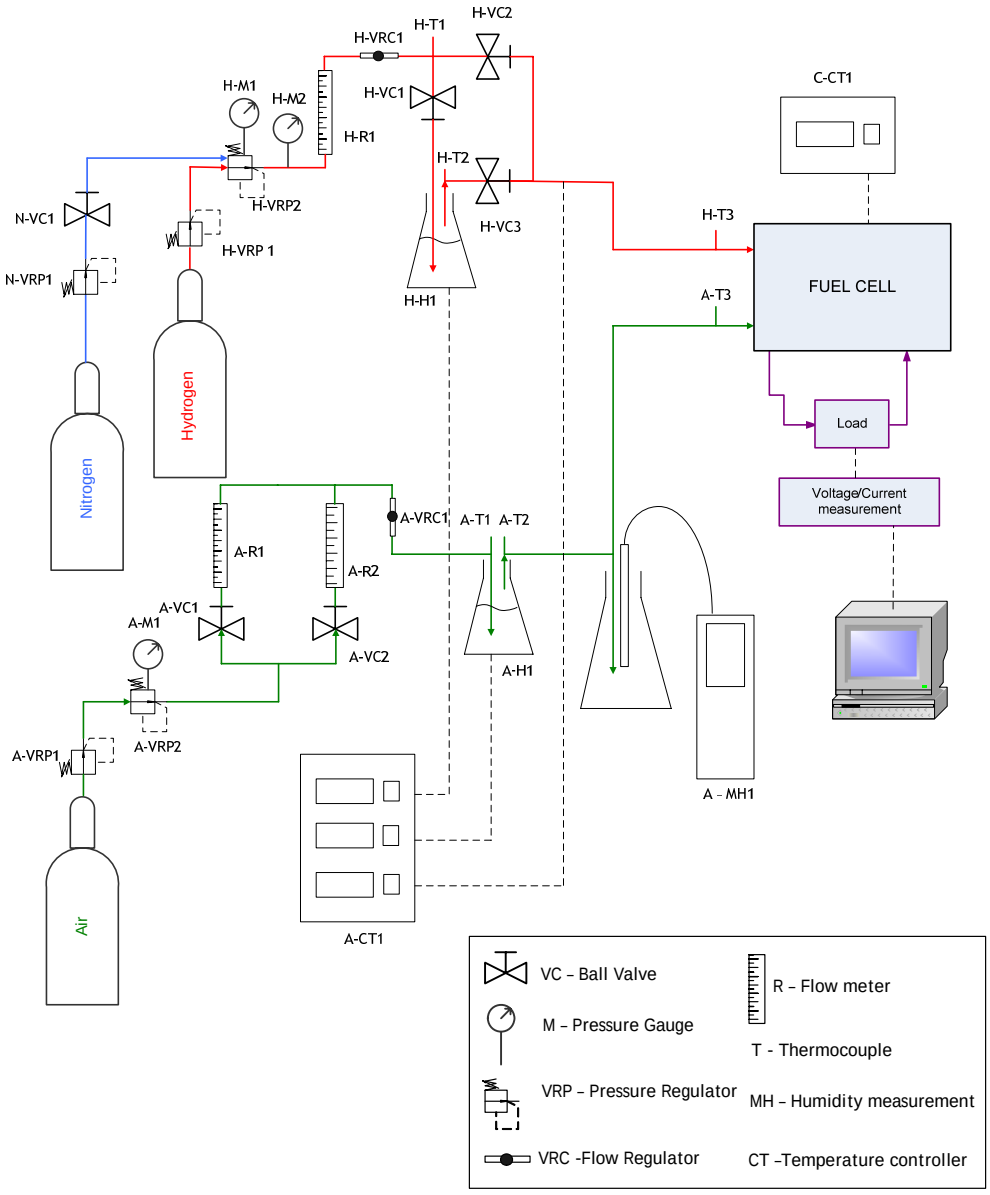



Figure 5. Schematic layout of the experimental setup.

### 3. Experimental setup and procedure

The experimental rig used for the testing of the fuel cells is schematically represented in Fig. (5). Feeding gases came from gas cylinders and their flows were measured through KDG-Mobrey rotameters. For the air flow two rotameters were used, a KDG-Mobrey 2-D-150 B2S for air flow in the range of 0.6 to 4.6 l/min and other reference 6-A-150 B6G for the air flow range of 3 to 15 l/min, both ranges measured at 1 atm gauge and 30 ºC. For hydrogen flow measurement a rotameter, also from KDG-Mobrey ref 1.6-A-150 S, was used for the gas flow range of 0.8 to 1 l/min at 0.4 atm gauge and 30 ºC. During testing, two types of gas feeding situations were considered, flow source and pressure source. In the first instance the hydrogen flow is kept constant during the experiment and the output hydrogen flow from the cell should also be measured to account for the fuel consumption; in the second instance the hydrogen feeding is being kept at constant pressure and no hydrogen output flow is allowed from the cell. To account for the hydrogen output during the flow source experiments two soap bubble meters were used, one with three volume ranges of 1, 10

and 500 ml and other with a graduated range of up to 25 ml. The data presented and discussed in this work refer only to the flow source feeding of hydrogen.

For the humidification of the air and hydrogen flows, bubbling of the gases through deionized water inside Erlenmeyer flasks was adopted. To control the humidification temperature each Erlenmeyer flask was thermally isolated and surrounded with an electrical resistance (50 W/m) activated by a Osaka OK 31 digital temperature controller. The same procedure was applied along the connecting pipes from the humidification point up to the entrance of the fuel cells, to guarantee the temperature stabilization of each reacting gas flow, as well as to control the operating temperature of the fuel cell.

For the measurement and control of the cell electrical output an electric load reference LD300 300W DC Electronic Load from TTI was used. This device could work with five different operating modes:

- Constant current – two possibilities were available, 0 to 8 A (with 1 mA resolution) and 0 to 80 A (10 mA resolution), with a precision of ±0.2 %+20 mA;
- Constant voltage – two possibilities were available, Vmin up to 8 V (1 mA resolution) and Vmin up to 80 V (10 mA resolution (were V min is 10 mV for low power situation and 2 V for 80 A). Precision is ±0.2 %+2 digits;
- Constant power – the available power range goes from 0 till 320 W, with a precision of 0.5 %+2 W;
- Constant conductance - operating range from 0.01 up to 1 A/V (1 A/V resolution) and from 0.2 up to 40 A/V (resolution of 0.01 A/V) with a precision of 0.5 %+2 digits;
- Constant resistance – operating range from 0.04 up to 10 Ω (0.01 Ω resolution) and from 2 to 40 Ω (with 0.1 Ω resolution) with a precision of 0.5 %+2 digits.

This load was connected to a data acquisition system composed by Advantech boards installed in a desktop computer through which data were collected and treated. The used data acquisition software was GENIE version 2.12.

Temperature measurement data were also collected with the data acquisition system.

## 4. Experimental results

The experimental results referred herein present the performance of INEGI 1 and INEGI 2 series and parallel cells at several different operating conditions. Four operating temperatures for the cells, 20, 40, 60 and 80 ºC, four humidification temperatures, 20, 40, 60 and 80 ºC, for the hydrogen flow and four humidification temperatures 20, 40, 60 and 70 ºC, for the air flow, were chosen.

Table 1 – Performance of INEGI 1 fuel cell with hydrogen humidification.

| **T humd $H_2$ (ºC)** / **T cell (ºC)** | 20 | 40 | 60 | 80 |
|---|---|---|---|---|
| 20 | 7.20 W<br>12.56 A | 7.28 W<br>12.5 A | 7.43W<br>12.5 A | 7.88 W<br>13 A |
| 40 | 5.04 W<br>10.5 A | 7.51 W<br>12.79 A | 7.12 W<br>12 A | 7.7 W<br>13 A |
| 60 | ----- | ----- | 4.20 W<br>9.6 A | 7.47 W<br>12.6 A |
| 80 | ----- | ----- | ----- | 3.59 W<br>8.5 A |

### 4.1. Humidification of the flow of hydrogen

This first set of data concerns the influence of the temperature of humidification of the hydrogen flow upon the performance of INEGI 1 fuel cell. Table (1) has the overall results whereas Figs. (6) and (7) present the polarization curves for INEGI 1 cell operating at 40 ºC and 60 ºC.

At a cell operating temperature of 20 ºC its performance is similar for all hydrogen humidification temperatures, Tab. (1). As the cell operating temperature rises it is realized that higher hydrogen humidification temperatures result in better cell performance. This is quite clear from the analysis of Tab. (1), as cell temperature increases the number possible operating conditions decreases and at an operating temperature of 80 ºC the cell only works provided the hydrogen humidification temperature is equally high. For any cell operating temperature the best performance is always achieved with the hydrogen humidification temperature of 80 ºC.

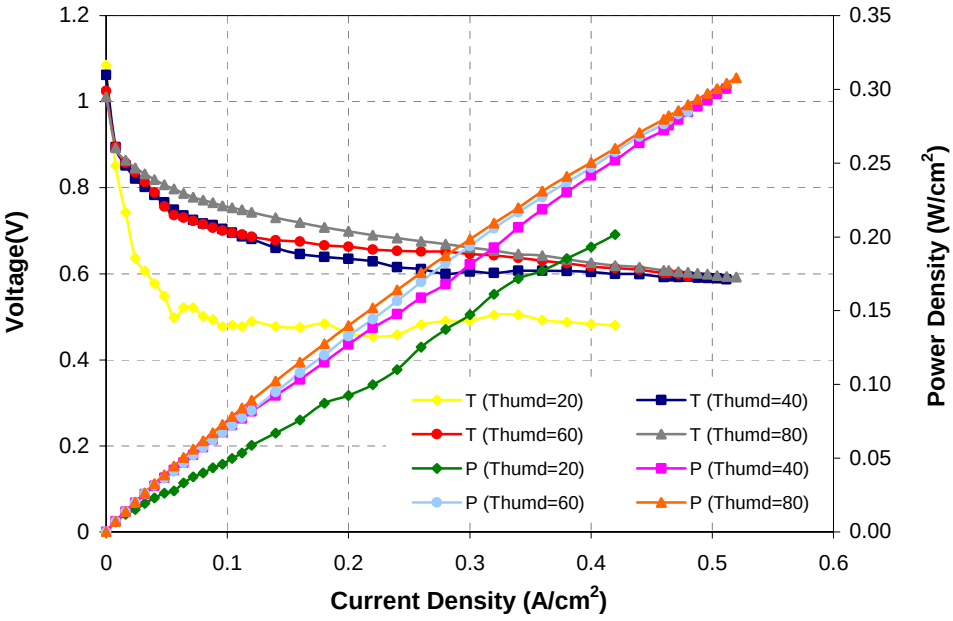



Figure 6. Polarization curves for INEGI 1 fuel cell at the operating temperature of 40 ºC.

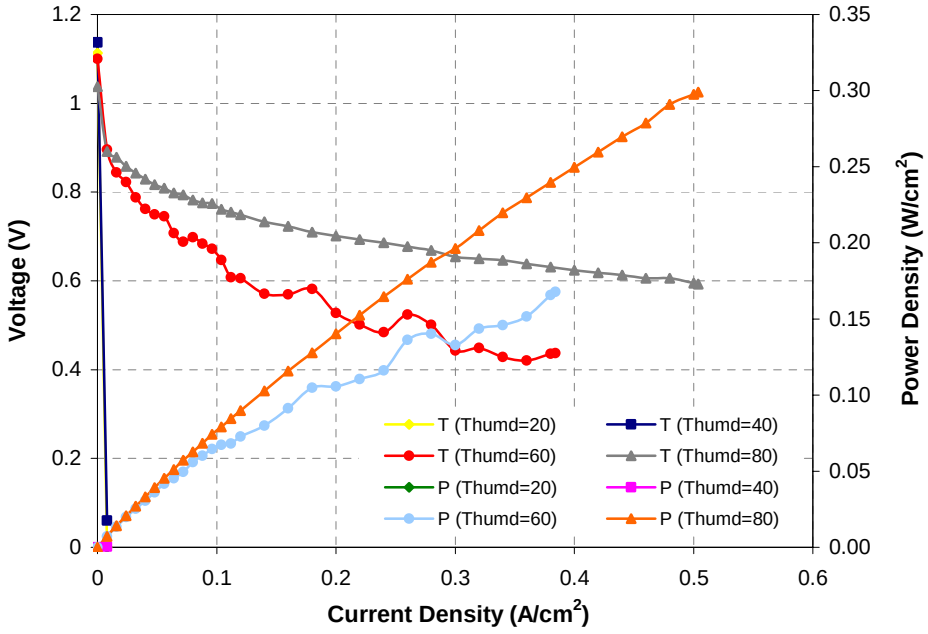



Figure 7. Polarization curves for INEGI 1 fuel cell at the operating temperature of 60 ºC.

Table (2) concerns the performance of the INEGI 2 series fuel cell as a function of the humidification temperature of the hydrogen flow. Once again, Tab. (2), as the cell operating temperature raises its performance reduces for lower humidification temperatures and for every cell operating temperature that was tested, the best performance was found for the hydrogen humidification temperature of 80 ºC. Figure (8) shows the evolution of the polarization curves for this cell at an operating temperature of 40 ºC. Only one plot of a polarization curve is shown for this INEGI 2 series cell to avoid repetition of similar graphs, as the overall evolution is similar to what was found for INEGI 1 fuel cell.

Table 2 – Performance of INEGI 2 series fuel cell with hydrogen humidification.

| **T humd $H_2$** (ºC) / **T cell** (ºC) | 20 | 40 | 60 | 80 |
|---|---|---|---|---|
| 20 | 3.02 W<br>7.23 A | 4.44 W<br>8.17 A | 5.39 W<br>9.52 A | 5.76 W<br>10.3 A |
| 40 | 2.49 W<br>6 A | 2.44 W<br>6.4 A | 6.10 W<br>10.79 A | 6.15 W<br>10.56 A |
| 60 | ----- | 0.19 W<br>1.3 A | 2.01 W<br>5.48 A | 4.45 W<br>8.4 A |
| 80 | ----- | ----- | 0.39 W<br>1.4 A | 2.41 W<br>6.02 A |

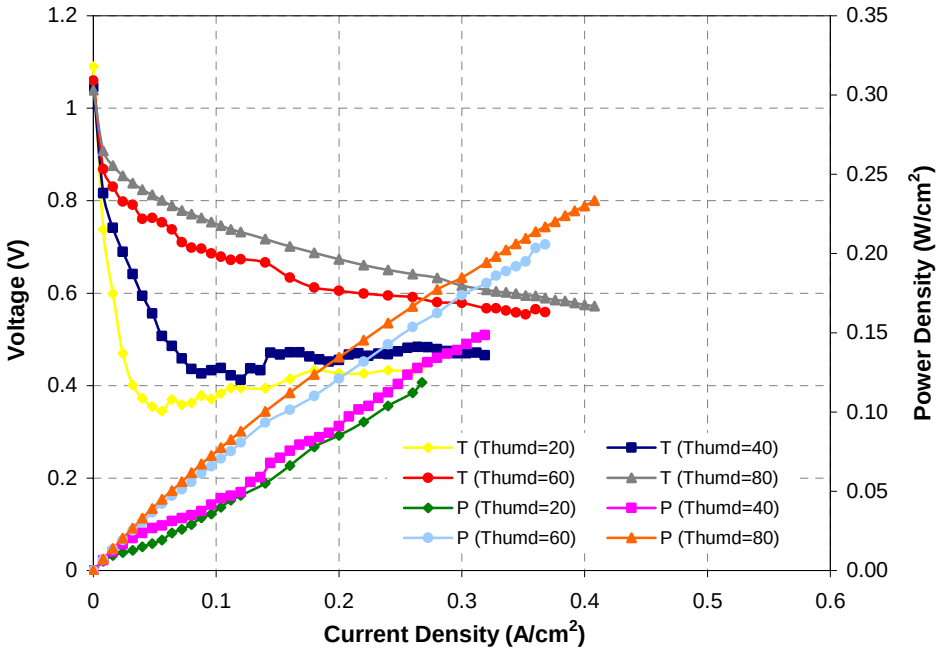



Figure 8. Polarization curves for INEGI 2 series fuel cell at the operating temperature of 40 ºC.

Table (3) refers the overall results for the performance of INEGI 2 fuel cell with the parallel lay out. Once again at lower operating temperature the performance of the cell is only slightly dependent upon the humidification temperature of the incoming hydrogen. However, with the increase of the operating temperature of the cell, this dependence becomes more clear and it can be said that the best performance is always obtained for a humidification temperature of the hydrogen of 80 ºC.

Considering the overall behavior of the fuel cells which can be deduced from the analysis of Tab. (1) to Tab. (3) it is observed a better performance of the fuel cell for a given value of the corresponding operating temperature the higher is the humidification temperature of the hydrogen flow. This is because the warmer is the hydrogen flow the more elevated is its capacity to carry moisture leading to better humidification of the membrane. At lower cell operating temperatures the hydrogen flow saturates sooner through the humidification and consequently the positive effect of this action is more important. For higher cell operating temperatures, the situation is the opposite, it is more difficult to lead the hydrogen flow close to saturation conditions and thus it enters the cell in a dryer condition and the membrane does not get as well humidified as before. The cell performance will be then enough only for the highest humidification temperatures.

For the same reason, for a given humidification temperature, a higher cell operating temperature leads to lower cell performance. It is known that at lower temperatures the oxygen reduction needs a higher voltage drop to produce the same current intensity, but on the other end the membrane resistance is lower at lower temperatures (You and Lui, 2001) and water activity is then higher. As the cell performance is better at lower temperatures, or at least the cell is more forgiving towards lower hydrogen humidification temperatures it can be concluded that the importance of proper membrane humidification exceeds the losses associated to the voltage drop. The influence of the humidification

temperature is stronger for low current densities, a situation were the membrane is never fully hydrated. As current densities raise, the water production rate in the cathode increases and the electro-osmosis water displacement humidifies the membrane reducing the weight of the external humidification procedure.

Table 3 – Performance of INEGI 2 parallel fuel cell with hydrogen humidification.

| **T humd $H_2$ (ºC)** / **T cell (ºC)** | 20 | 40 | 60 | 80 |
|---|---|---|---|---|
| 20 | 4.79 W<br>9.20 A | 4.89 W<br>8.50 A | 4.84 W<br>8.08 A | 5.79 W<br>9.49 A |
| 40 | 2.96 W<br>6.69 A | 3.71 W<br>7.97 A | 5.14 W<br>9.20 A | 5.83 W<br>10.20 A |
| 60 | ----- | ----- | 2.57 W<br>5.60 A | 4.73 W<br>8.20 A |
| 80 | ----- | ----- | ----- | 3.28 W<br>7.00 A |

When the external humidification of the hydrogen flow is not enough the cell performance oscillates because of the lack of uniformity of water distribution inside the membrane.

Finally looking at the plotted polarization curves it can be observed that these cells have no concentration polarization region because the amount of supplied hydrogen and air are well above the minimum required rates, i.e. there are not mass transfer resistances. The performance of INEGI 1 is superior to the two adopted configurations for INEGI 2 and the reason is the slightly higher contact area with the MEA in the first case. INEGI 1 has a channel contact area of 1354,5 $mm^2$ whereas INEGI 2 has a contact area of 1253,6 $mm^2$. INEGI 2 is more sensitive to changes in the hydrogen humidification temperature because of its lower contact area. As far as the two configurations that were adopted for INEGI 2, the series and the parallel configuration, no clear advantage was detected.

### 4.2. Humidification of the flow of air

This second set of tests was only carried out for the INEGI 1 cell as this cell showed better performance in the experiments of hydrogen humidification. Four operating temperatures were chosen (20,40,40 and 80 ºC) and four air flow humidification temperatures were also chosen (20, 40, 60 and 70 ºC). The choice of the maximum temperature of air humidification was limited by the available heating power. Table (4) presents the overall results for the performance of INEGI 1 cell for this situation of the humidification of the air flow.

Table 4 – Performance of INEGI 1 fuel cell with air humidification.

| **T humd Air (ºC)** / **T cell (ºC)** | 20 | 40 | 60 | 80 |
|---|---|---|---|---|
| 20 | 6.69 W<br>11.88 A | 7.10 W<br>12.12 A | 7.10 W<br>11.94 A | 6.55 W<br>11.31 A |
| 40 | 6.08 W<br>10.87 A | 5.92 W<br>10.45 A | 6.15 W<br>11.13 A | 5.93 W<br>9.7 A |
| 60 | 0.17 W<br>0.55 A | 1.04 W<br>3.0 A | 5.63 W<br>9.47 A | 5.11 W<br>8.87 A |
| 80 | | 0.18 W<br>0.57 A | 0.59 W<br>1.92 A | 1.52 W<br>4.93 A |

Figure (9) presents the polarization curves for INEGI 1 cell operating at 20 ºC and four different air flow humidification temperatures, while Fig. (10) presents the equivalent polarization curves but for the INEGI 1 cell operating at 80 ºC.

From the observation of both figures, Fig. (9) and Fig. (10), as well as from Tab. (4), it is evident the better performance of the cell for higher air humidification temperature, while the increase of operating temperature has an opposite effect.

The better cell performance with the increase of air humidification temperature leads to higher relative humidity of the incoming air flow enhancing the humidification of the membrane, but if the cell operating temperature raises the relative humidity of this air flow diminishes and the membrane humidification becomes less efficient.

Similarly to what was observed through the humidification of the incoming hydrogen flow, the influence of the humidification temperature of the air flow for low current intensity is stronger when the water release rate is still low and membrane humidification is not perfect, but as the water release rate increases the membrane humidification augments and the weight of influence of external air humidification upon cell performance diminishes.

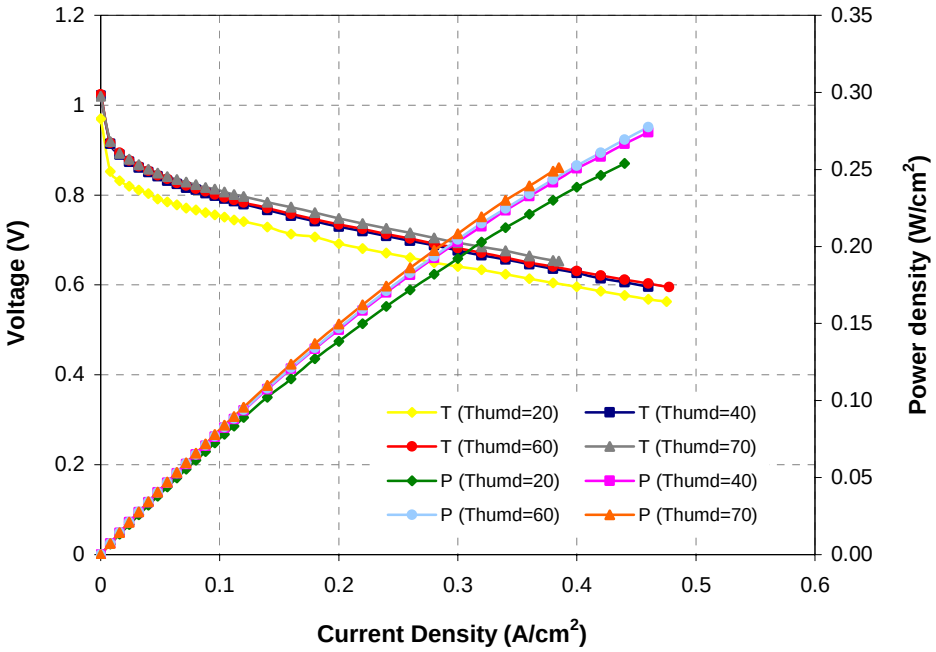



Figure 9. Polarization curves for INEGI 1 fuel cell at the operating temperature of 20 ºC.

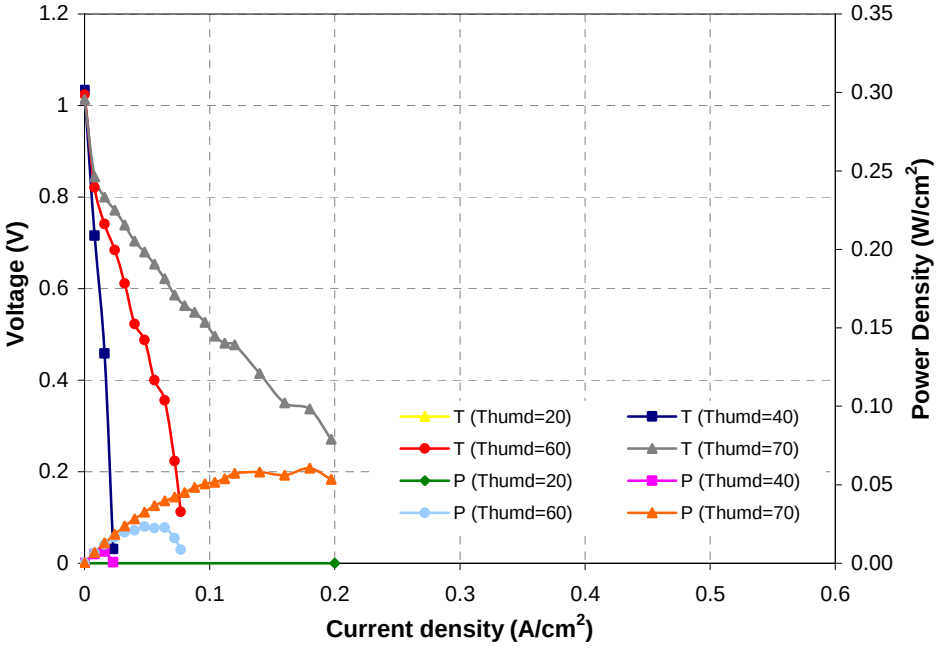



Figure 10. Polarization curves for INEGI 1 fuel cell at the operating temperature of 80 ºC.

## 5. Conclusions

In this work it was shown that a team without much experience is able to built polymer electrolyte membrane fuel cells (PEMFC) with a reasonable level of performance. Two different fuel cells were built (INEGI 1 and INEGI 2) and in one of them two gas flow layouts were possible (INEGI 2 series and INEGI 2 parallel).

INEGI 1 fuel cell showed the best performance and the reason was the available higher contact area.

Results on the analysis of the performance of the cells with different humidification degrees of the hydrogen and air flows were presented and discussed. From the such results the conclusion is that for low current densities air humidification is more important than hydrogen humidification, while at high current densities the humidification of hydrogen induces a better cell performance.

In the present analysis, where the humidification of a single gas flow was accounted for, it was found that for a given humidification temperature of the gas flow, be it hydrogen or air,, cell performance degrades with the increase of its operating temperature and the higher this operating temperature the higher the performance degradation.

As a general rule it was also found that whatever is the cell operating temperature, in the tested temperature range – 20 to 80 ºC, the better cell performance is obtained with the higher gas humidification temperature.

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