Stack performance optimization of low power PEM Fuel Cell

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Abstract—**For a PEMFC under operation, different causes of performance loss exist. Performance loss can increase when the system is scaled up to higher power. In this work the performance of low-power stacks manufactured in CICY is optimized through studies of the behavior and performance of single cells and stacks of own fabrication. The electrochemical technique polarization curve is used to provide insight into the performance of the cell and stack in operation. The design and materials of the components of the stack were established and the results demonstrate that for cells with catalyst layers deposited by electrospray the maximum power density of the single FC is higher than for cells prepared with the technique of dropping. The increase is significant, from 208 to 270 mW/cm2. Also, the optimization of the hot-pressing process of the MEA resulted in an improvement of the maximum power density up to 310 mW/cm2, while minimizing the canal-rib ratio improved the FC performance with about 16%. Compared to commercial PEMFCs, the performance however, is still low, which is related to the type of materials used.**

I. INTRODUCION

The fuel cell proton exchange membrane (PEMFC) is an electrochemical device that transforms the chemical energy of a reaction into electrical energy with high efficiency. The high power density at low temperatures and long life makes it attractive to DC to be used in stationary, mobile and portable systems, such as for backup systems energy, automotive and electronic entertainment equipment industry, respectively. The fuel cell is mainly composed of five parts: end plates, current collector plates, gaskets, bipolar plates and membrane electrode assembly. The union of anode-membrane-cathode is known as MEA, it is considered the heart of the cell because it is in the catalytic layer where the electrochemical reactions take place. On the surface of the anode hydrogen is oxidized, while oxygen is reduced at the cathode. The catalytic layer is basically the joining of a catalyst, a carbonaceous support and ionic conductor; typically this layer can be applied on the membrane or on the gas diffuser. Generally the most used materials for the MEA is carbon supported platinum catalyst, Nafion, electrolyte membrane, paper or carbon cloth as a gas diffuser. There are several ways to apply the catalytic layer as a liquid mixture of catalyst and solvent in the electrolyte solution through the dropping technique that involves depositing ink, with a micropipette, drop by drop to the diffuser; Another way is by electrospray technique of applying the same way that ink dropping but applying a potential difference (10 to 11 kV) between metal needle pipette and the diffuser surface. Arrangements FC connections in series are to raise a potential difference and put this potential for practical use. Such connections are provided and are improved by bipolar plates. Other functions of the plates are: being a way by which the heat is removed and water, provide mechanical support to the

cells, provide a thermal contact between the coolant, driving electrons generated in the reactions, the reactant gases lead to all cells and all your work surface through channels[1][2]. It is important that the materials plates have high electrical conductivity such as metals, polymers or composite graphite whit flow channels of different configurations for conducting the fuel and oxidant. Individual PEMFC is characterized by delivering direct current at low potential difference, relatively, this means that to get a potential to use in conventional electrical equipment is required series connection of the cells. Each cell produces a voltage of 1.23V theoretically, this potential is ideal, in a real cell performance losses are various causes, under standard operating conditions and may be increased if more cells connected in series are added[3] to learn the electrical performance of the electrochemical cell operation polarization curve technique is used.

II. MATERIALS Y METHODS

The materials used were diffusers carbon cloth BASF Fuel Cell Inc. A6NCV2.1 ELAT and carbon paper EC-TP1-060T, Nafion membrane (DuPont), Nafion Solution 5% (SIGMA ALDRICH), catalyst Pt/C 20% and 2-propanol (reagent grade). The only known diffusers carbon cloth have Teflon coated fabric, a microporous carbon layer vulcan and measured 0.36mm thick; carbon paper is treated with 30% Teflon and 0.19mm thickness, these data are given by the manufacturer[4]. The electrochemical characterization made to all cells in all tests were through a polarization curve using the testing station (FCT-50, BioLogic) for controlling the operating conditions and the potentiostat / galvanostat (VSP BioLogic) with booster 10 A - 20 V (BioLogic, VMP3B-10) for the polarization curves, they were conducted with a scan rate of 10mV / s OCP to 0V and operating conditions, which we will call conditions standard in this work, were 60 C, 50 ML / min / cm2 flow of gases (H2 / O2) to 100 % relative humidity (RH).

III. MATERIALS COMPARISON FOR DIFFUSERS

Two MEAs of 1cm2 were prepared with platinum loading of 0.5 mg/cm2, both with parameters membrane electrode assembly EROSA(2011) [5], temperature 120C, 4 minutes pressing time and 1814.4 kgf / cm2 (4000 lbf / cm2), a diffuser MEA carbon cloth and the other of carbon paper. The obtained MEAs were placed in the hardware with flow field single serpentine configuration, both cells under standard conditions for evaluation by polarization curve operated.

IV. CATALYTIC INK DEPOSITION METHOD COMPARISON

The method of dropping was selected to be simple to implement in very small cells and electrospray by to be controlled deposition. Two MEAs were prepared with platinum loading 0.5 mg/cm2, one for each method, using hot-pressing parameters (temperature, pressure and time) proposed by EROSA (2011) whit carbon paper diffusers. Two MEAs obtained were

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placed on the same hardware in the previous section and is operated under standard conditions. The electrochemical characterization was by a polarization curve.

V. COMPARISON OF METHOD OF MEMBRANE-ELECTRODE ASSEMBLY

To carry out the comparison of two methods of membrane assembly electrode with optimized parameters for each author, two MEAs of 4 cm2 were prepared with platinum loading of 0.5 mg/cm2, one with each method, was used electrospray to apply the catalyst ink in the diffuser of carbon paper. The membrane electrode assembly parameters of OKUR(2013)[6] are: temperature 97 C, 3.6 minutes, 66 kg/cm2 (145.5051 lbf/cm2) of pressure press and the method of EROSA(2011) are: temperature 120C, 4 minutes pressing time and 1814.4 kgf/cm2 (4000 lbf/cm2)

For electrochemical characterization of obtained MEAs, was used a hardware with flow field single serpentine configuration and were electrochemically characterized by polarization curve, both cells operated at standard conditions.

VI. COMPARISON OF ELECTRICAL CONTACT RATIO

To know the effect of the electrical contact ratio (ECR) variation of the flow field in the cell performance, mainly resistance electrical contact and diffusion of gases, were evaluated electrochemically two designs of flow fields with two different reasons of electrical contact. ECR for plates were 0.2 and 0.5, the depth of channel designs were both 1 mm, the channel width and rib were variable in both designs according to the limitations of the tools and materials used for the manufacture of plates. Cells were characterized electrochemically by polarization curves operated at standard conditions.

VII. CHARACTERIZATION OF OPTIMIZED MEAS IN THE STACK

Graphite diffuser plates were made (two end plates and two bipolar plates), and three MEAs and the others components were made to use in the stack according the results of this work. The polarization curves were run simultaneously to all cells in the stack to standard operating conditions. The range was from open circuit potential to 0 V at a scan rate of 10 mV/s, were performed graphs current density versus potential (I-V).

VIII. RESULTS AND DISCUSSION

A. Carbon cloth and carbon paper as diffusers

In the first part of this work was to study what diffuser which offered higher power density, as shown in the polarization curve in Figure 1 a) the MEA made with carbon cloth diffuser showed better performance than MEA paper diffuser, showing that the peak power density of the MEA with carbon cloth and the MEA with carbon paper was 214 and 208 mW/cm2, respectively. Likewise, it can be seen that the performance of the MEA with paper falls faster than the MEA with cloth, especially in the region of higher current density. This could indicate a problem of diffusion of gases through the diffuser of the MEA with paper and attributed to the

highly disorganized, irregular and compact structure of carbon paper severely limits mass transport when the cell operates at high relative humidity; in addition, its relatively smooth surface makes the water drop separating harder, resulting in water on the cover surface so therefore increased waste mass transfer[7]. Some studies report that the high porosity of the material used as diffusers are necessary to improve the operation of the FC[8], others report that diffusers with low amounts of Teflon in its structure are best to increase cell performance[9][10][11][12].

B. Dropping and electrospray

In the results of the comparison of deposition techniques catalyst ink, in Figure 1 b), it can be seen that the MEA made with the ink by electrospray shows the best performance with maximum power density of 266 mW/cm2 compared to the value obtained by the drooping method was 208 mW/cm2. Also, the potential of the MEA-DROP falls faster than the polarization curve in areas of higher current densities (from 400 mA/cm2). This behavior could be due to a lower gas diffusion more sites of the catalytic layer, it mean, greater charge transport resistance, the porosity of the structure of the catalyst layer could be a factor that causes the variation of the operation, other words, it is possible that deposits made by dropping clusters exist that block catalytic active sites.

C. EROSA and OKUR and Okur

The effects of varying the parameters of the hot-pressing technique are shown in Figure 1 c), the OCP obtained MEA-OKUR is 1.008 V and the MEA-EROSA is 0.98 V, a higher OCP is one result of a better contact between the catalyst layer and the membrane[6]. Furthermore, the power density of the MEA-OKUR show be greater than the MEA-EROSA, 310 mW/cm2 for the first and 270 mW/cm2 for the second; the maximum current density of MEA-OKUR 1413 mA/cm2, while the MEA is 1113 EROSA mA/cm2. The highest value of the current density and maximum power is presented by the MEA-OKUR that can result in a more porous structure of the catalyst layer of the MEA-EROSA, however, other factors may be influencing that behavior. The decay of the power density may be due to a change in the structure of the MEA caused by high temperatures and pressures when preparing them. High pressures affecting the catalytic structure, which reduces the electron conductive network and causes mass transport problems[6], in other words, a higher pressure will result in the compaction of the porous structure, which affect the cell performance by mass transport problems, limiting the flow of the reactant gases through the active sites of the catalyst layer.

D. Electrical contact ratio, ECR 0.5 and ECR 0.2

In comparing of the electrical contact ratios in the flow field of graphite plates, the results shown in fig. **??** d) which shows that the single cell with ECR 0.2 provides better performance than obtained of the ECR 0.5, particularly at low potential (mass transfer losses). The maximum power density of ECR0.2 increased 11%, from 261 to 290 mW/cm2 compared to 0.5 ECR design, it increases with decreasing electrical contact ratio, in other words, to increase the area of gas contact with the diffuser, a smaller channel area means a wider rib, and

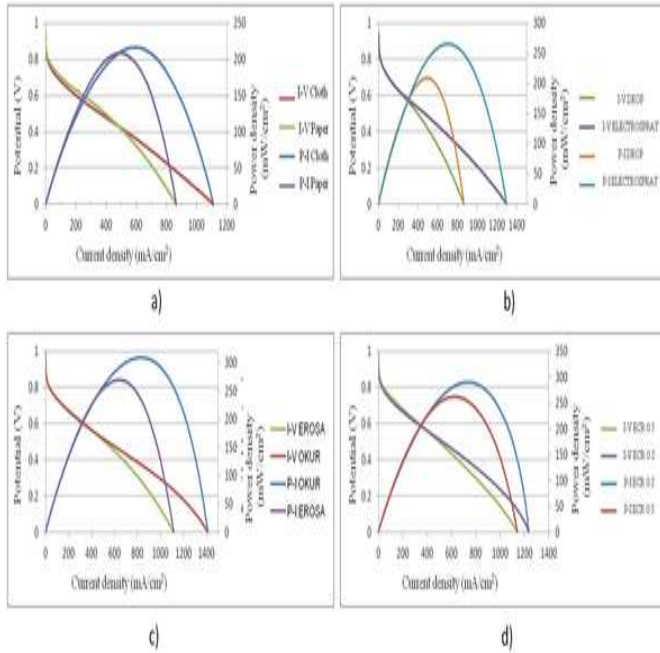gas diffusion behind the ribs becomes more difficult, it is also possible that water retention is higher.

Fig. 1. Curves of current density-potential and current density and power density, operated under standard conditions of monocells: (a) of 1 cm2 with cloth and paper diffuser, (b) of 1 cm2 made by the dropping and electrospray techniques, (c) made by EROSA and OKUR method, (d) made by two plates diffuser designs, ECR0.2 ad ECR 0.5.

E. Characterization in the stack of optimized MEAs

In fig. **??** the polarization curves of the three cells in the first two loss zones (ohmic and activation) are very similar; the difference between cells highest OCP is 0.008 V (8 mV), while at 500 mA/cm2 the difference is 0.022 V (22 mV); cell C1 has the highest potential and the cells C2 and C3 of less at 500 mA/cm2, these values can be seen in table 1. Furthermore, in the concentration loss zone behave very different, the difference between the highest potential cell at 800 mA/cm2 and the less is 0.170 V (170 mV), the cell potential was greater C1, followed by C2 and C3 in the same order from highest to lowest. In the table **??**, the potential cell and stack are observed in three different points of each curve, OCP, 500 mA/cm2 and 800 mA/cm2.
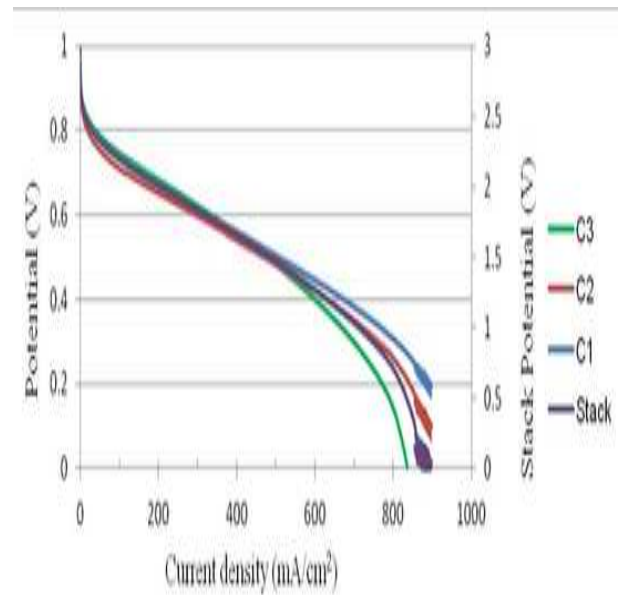

Fig. 2. Polarization curves measures to stack and its three cells simultaneously. The tests were conducted under standard operating conditions

TABLE I. POTENTIAL STACK AND POTENTIAL CELLS AT THREE DIFFERENT CURRENT DENSITIES REPRESENTATIVE OF LOSSES ZONES (ACTIVATION, OHMIC AND MASS TRANSPORT) OF THE POLARIZATION CURVE.

Component	Value
L	5 μH
R	1000 Ω
C	100 μF
switching frequency	30 KHz

Different behavior between the performances of the three cells at high current densities is observed, particularly, in the concentration losses zone. The inputs of both gases of the stack were sided in one side, near to C1; there could be within the stack has bad distribution gas flow that difficult the arrival of one or both gases to the cells, causing an absence of fuel or the oxidant. Linked to poor gas distribution, it could also be added, low elimination of water produced by reactions in cells that do not arrive gases; that reason affect the pores of electrode surface, obstructing the gases flow through the catalytic layer. Another reason that can be attributed that difference is the lack of standardization of manufacturing and assembling the components of the cell, starting from the MEA, diffusers graphite plates, seals, etc; emphasizes that in developing the MEAs, to press them with heat, the membranes were dehydrated and loss their original shape.

IX. CONCLUSIÓNES

The electrospray technique allowed depositing catalytic layer on the diffuser homogeneous and scalable compared to the dropping technique. In addition, it was possible to increase the maximum power density only by varying the deposition technique from 208 to 270 mW/cm2, the optimized method OKUR (2013) for the development of MEAs allowed improving yields of these, the reduction of electrical contact ratio of the flow field allowed to increase the maximum

power by 11Stack maximum power was 762 mW/cm2, and each one of its cells was 270, 254 and 243 mW/cm2. The potential in the polarization curves of the three cells of the stack at 500 mA/cm2 were 0.50, 0.48, 0.48 V, a difference of potential between the highest and lowest cell of 22 mV. The cells in the stack had a very similar behavior due to the selection of materials and methods suitable for preparation of homogeneous cell components.

REFERENCES

[1] S. S. Dihrab, K. Sopian, M. a. Alghoul, and M. Y. Sulaiman, Review of the membrane and bipolar plates materials for conventional and unitized regenerative fuel cells, Renewable and Sustainable Energy Reviews, vol. 13, no. 67, pp. 16631668, Aug. 2009.

[2] R. a. Antunes, M. C. L. Oliveira, G. Ett, and V. Ett, Corrosion of metal bipolar plates for PEM fuel cells: A review, International Journal of Hydrogen Energy, vol. 35, no. 8, pp. 36323647, Apr. 2010.

[3] A. Dicks, Fuel Cell Systems Explained, Second Edi. John Wiley & Sons Ltd, 2003.

[4] A. Pfrang, D. Veyret, F. Sieker, and G. Tsotridis, X-ray computed tomography of gas diffusion layers of PEM fuel cells: Calculation of thermal conductivity, International Journal of Hydrogen Energy, vol. 35, no. 8, pp. 37513757, Apr. 2010.

[5] E. Renovable, Centro de Investigacin Cientfica de Yucatn , A . C . ESTANDARIZACIN DEL MTODO DE FABRICACIN DE ENSAMBLES MEMBRANA- TIPO PEM Tesis que presenta JUANA ARELY EROSA SOLIS En opcin al ttulo de MAESTRO EN CIENCIAS EN ENERGA RENOVABLE, 2011.

[6] O. Okur, . yign Karada, F. G. Boyac San, E. Okumu, and G. Behmenyar, Optimization of parameters for hot-pressing manufacture of membrane electrode assembly for PEM (polymer electrolyte membrane fuel cells) fuel cell, Energy, vol. 57, pp. 574580, Aug. 2013.

[7] Y. Wang, C. Wang, and K. S. Chen, Elucidating differences between carbon paper and carbon cloth in polymer electrolyte fuel cells, vol. 52, pp. 39653975, 2007.

[8] B. Millington, S. Du, and B. G. Pollet, The effect of materials on proton exchange membrane fuel cell electrode performance, Journal of Power Sources, vol. 196, no. 21, pp. 90139017, Nov. 2011.

[9] K. Wikander, H. Ekstrm, A. E. C. Palmqvist, and G. Lindbergh, On the influence of Pt particle size on the PEMFC cathode performance, Electrochimica Acta, vol. 52, no. 24, pp. 68486855, Aug. 2007.

[10] L. Giorgi, E. Antolini, A. Pozio, E. Passalacqua, C. R. Casaccia, V. Anguillarese, and S. M. Galeria, Influuence of the PTFE content in the diffusion layer of low-Pt loading electrodes for polymer electrolyte fuel cells, vol. 43, no. 24, pp. 36753680, 1998.

[11] E. Antolini, R. R. Passos, and E. A. Ticianelli, Effects of the cathode gas diffusion layer characteristics on the performance of polymer electrolyte fuel cells, pp. 383388, 2002.

[12] J. Lobato, P. Caizares, M. a. Rodrigo, C. Ruiz-Lpez, and J. J. Linares, Influence of the Teflon loading in the gas diffusion layer of PBI-based PEM fuel cells, Journal of Applied Electrochemistry, vol. 38, no. 6, pp. 793802, Feb. 2008.