Int. J. Electrochem. Sci., 5 (**2010**) 414 - 428

International Journal of
ELECTROCHEMICAL
SCIENCE
www.electrochemsci.org

Effect of a Rigid Gas Diffusion Media Applied as Distributor of Reagents in a PEMFC in Operation, Part II: Wet Gases.

C. Moisés Bautista Rodríguez [1,*], *M. G. Araceli Rosas Paleta* [2], *J. Antonio Rivera Marquez*[2], *J. Roberto Garcia de la Vega*[1]

[1] Alter Energías Grupo, Tepetitlan No. 63, Col Lomas del Sur, 72470 Puebla, Puebla
[2] BUAP. Facultad de Ingeniería Química. Av. San Claudio y 18 Sur -CU-, 72590 Puebla, Puebla
[*]E-mail: celso.bautista@thyssenkrupp.com

Received: 15 March 2010 / Accepted: 20 March 2010 / Published: 31 March 2010

Several mass transport phenomena occur during the operation of a PEMFC each one generates a resistance implying limitations during operation. The humidity in the reactive gas flows promotes the conductivity of the electrolyte membrane but increases the transport limitations at high current densities. The reactive gases are distributed in a conventional PEMFC by distributors with serpentine-shaped channel, transversely covering the surface of the electrodes. This paper applies and compares a rigid gas diffusion media as gas distributor, its porosity comprises mostly of macropores, their function is improve the gases reaction distribution with the aim of reducing resistance to mass transport, in turn collects (in the anode) or distributes (on the cathode) electrons generated in the reaction sites. The results determine a complex mass transport processes in the porous media when the reagents are moistened, however at pressures greater than 10 psig, the functionality of the PEMFC is increased significantly to moisture conditions in the reagents flow and it is very favorable for the case of conventional PEMFC design. The combined effect Pressure - Humidity reduces ohmic limitations to medium current densities, while the flow rate allows a reduction in transport resistance at high current densities. The presence of heavy metals in the structure of the commercial electrodes may generate over-potentials in the cell with capacity to affect the functionality of PEMFC..

Keywords: Polar plates, Wet Gases, Gas Diffusion Media, PEMFC Performance, PEMFC Power.

1. INTRODUCTION

Polymer electrolyte membrane fuel cell (PEMFC) is an electrochemical power generator developed in the 60's of last century under military and space targets, mainly in Apollo's NASA missions and during the 80's it was applied in hybrid vehicles on land. The PEMFC has several advantages compared to other fuel cells as operation at low temperature (< 120°C) and low pressure (< 6 bar), high efficiency (+/- 75%), low volume/weight rate, etc. These advantages allow the PEMFC is considered an appropriate power generator system primarily maritime and land transport, but it were recently reported aerial applications. Furthermore, the PEMFC electrochemical device also promises to include smaller scale portable applications, for example, in laptop computers, mobile phones, audio systems and portable video. The development of PEMFC has shown progress; however an agile and vigorous commercial market introduction still requires a significant technological advance, particularly requires that the fuel cells to achieve high performance in varying environmental conditions at lower cost, thus the PEMFC system should be simplified and miniaturized. The application of atmospheric oxygen as oxidizer and water management must be based on an appropriate cell geometry and materials suitable for portable applications. A PEM fuel cell conventional type (Figure 1) consists primarily of: i) a thermal-pressure assembly to membrane-electrode-electrode, ii) gas distribution plates with transport channels (polar plates) and iii) plates mechanical support [1-6].

Figure 1. Conventional PEMFC used in this study.

The water balance and its management is a factor key in the operation and high performance of a PEMFC due to the polymer electrolyte membrane applied (usually Nafion), that must be hydrated to obtain an optimum proton conductivity at the point of maximum efficiency PEMFC, simultaneously the excess water must be removed to prevent the partial or total flooding within the pores in the electrodes used for the PEMFC technology. The water balance in a fuel cell at operation condition is determined by the water production rate at the cathode and two water transport processes in the membrane electrolyte; (i) the electro-osmotic drag from anode to cathode current effect of the proton carried by the potential difference in the PEMFC and (ii) back diffusion by concentration gradients from the cathode to the anode. Both streams are distributed heterogeneously on the electrode active area where the direction and magnitude of water flux varied by this effect, becoming able to affect the operation of the PEMFC. Additionally, water transport between the membrane and the reagent flow also depends on the level reactants humidification, cell temperature, and pressure in the reactant feeding, also geometry and materials affects the fuel cell performance. On the other hand, the flood at the cathode by water is commonly described as follows; assuming that the oxygen fed to the cell is not saturated, the difference in the partial pressure of water coming from the electro-reaction generates condensate water, this must be transported out of the reaction sites through the pores in the electrode to the distributor channels and later out of the PEMFC [5-7]. On other hand, some studies have been reported about transport phenomena in Nafion membrane, polymer electrolyte normally used by the

PEMFC technology. Thus, the Costamagna’s model [8] proposes humidity gradients in the Nafion membrane between 50 and 76% in the anode side while the cathode side gradients are between 66 and 100% during operation in a PEMFC. Also, Bautista and colleagues have also suggested the presence of gradients of electrical resistance on the surface of Nafion membrane, being the origin of current density gradients and temperature gradients during operation in a PEMFC [9-10]. These observations are confirmed by Costamagna's model, estimating a temperature gradient between 76 and 88 °C with current density gradients between 445 and 843 mA/cm^2. On the other hand, Mennola and colleagues have estimated the fraction of water generated in the cathode through the anode in values between 0 and 58% depending on operating conditions in the PEMFC. Additional results show variability in the value for the water transport coefficient through the active area on the cathode electrode [5].

The PEMFC functionality is typically characterized by a potential current polarization curve (I-E), which comprises 4 areas classified as: i) irreversibility losses zone, characterizing the electrochemical reaction applied, ii) activation losses zone, due at activation energy required by the electrocatalyst used, iii) ohmic losses zone, due at the interfacial phenomena in the triple contact zone (Platinum-Carbon-electrolyte) and iv) diffusion losses zone (mass transport phenomena) [1-4]. In a PEMFC operating, the mass transport phenomena have origin in the distribution channels of polar plates (mass conduction) and in the diffusion layer of porous electrodes (mass diffusion). Mass conduction phenomena currently consider: i) pressure drops, ii) variability in the velocity profiles of gas flow, iii) variability in flow profiles and distribution of reagents iv) variability in the density of gases, the effect of water vapor pressure of product diffusion into the cathode and the anode, v) dilution of the concentration of the reactants along the distribution channels for consumption, vi) flood water (still the leading cause of falls in the functionality of the PEMFC at high current densities due to transport barriers resulting liquid water trapped in the pores of electrodes, these barriers can cause dead zones reach the area active electrode reducing the effective reaction area), vii) Mass flow direction within distribution channels, viii) variability in the concentration and density of gases by pressure changes (reagents consumption and products generation), ix) non-uniform distribution of reagents on the active layer of the electrodes due to the mechanical conditions between distribution channels and the diffuse layer, x) the use of oxygen in the air as fuel represents a dilution in the concentration of oxygen gas flow (developing a low partial pressure of oxygen, which reduces the oxygen reduction reaction and impacts the efficiency and power delivered by the PEMFC). Dutta and colleagues confirmed the presence of reagent concentration gradients along the distribution channels and the active layer of electrodes, including the presence of dead zones (no reaction), its mathematical models also suggest the presence of different profiles flow depending on the distance between the bottom of the channel and the electrode surface, including vortices. The direction of water transport channels disrupts the current density in the local, mainly at the cathode where water is generated reaction product. The distribution of reactive gas flow is affected by consumption patterns in the areas closest to the electrode surface [4, 6, 11-20].

Currently there are 4 strategies reported for the humidification of the gases fed to a PEMFC: i) the conventional method, which involves passing the gas through a humidifier based on temperature, ii) injecting steam to the flow of reagents, iii) recirculation by the humidifier and iv) injection of liquid water. Wood and colleagues [2] have reported results for a flow system interdigitations design, the purpose is forcing the wet gas to flow through the pores of the electrode. In contrast to conventional systems (serpentine), the mass transport mechanisms in place increase by the diffusive convective mechanisms and shear gas flow, as result; increase the remosion of liquid water trapped in the inner layers of the electrode and reducing the flood problem. The Wood's results (PEMFC system: H_2 / O_2) indicate an optimal humidification in the anode provides a greater benefit to the functionality of the PEMFC; however, if gas humidification is not applied at the cathode the impact is negligible and the electrodes are more susceptible to flooding. In PEMFC H_2 / Air system, MEA is more susceptible to dehydration in the cathode by the increase in the gas flow to maintain the oxygen ratio fed which requires greater liquid water supply. In both cases, interdigitated flow system applied was favorable for the functionality of the PEMFC. By contrast, there are 3 strategies reported for the water remosion from the anode in order to avoid dehydration of the polymer electrolyte and cathode flooding, these are: i) controlling the relative humidity in the anode compartment, ii) generate a thermal gradient at the anode to increase the vapor pressure to the saturation of flow out of the PEMFC and iii) reducing the pressure of gas flow along the anode channel flow by increasing the purpose of increasing the mole fraction of water carryover. Voss and colleagues [21] have applied the water remosion from the anode to generate an optimal pressure drop in the anode flow channel, inducing increased transport of water from the cathode and the electrolyte membrane. The results have been observed in favor of the functionality of the PEMFC, the first effect has been to reduce the overpotential of cathode electrode without a substantial reduction in the ionic conductivity of the membrane.

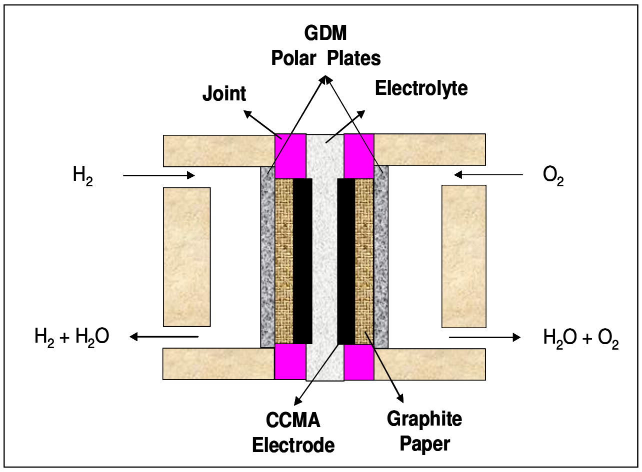
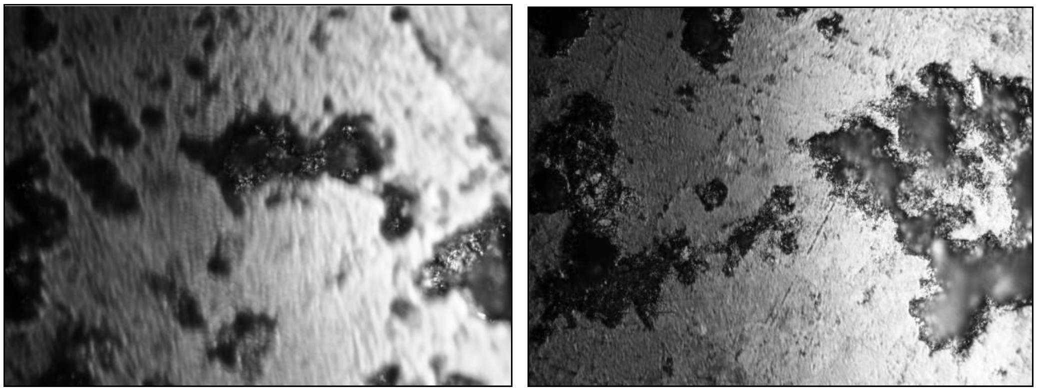


Figure 2. PEMFC scheme modified for the modification of transport phenomena, using graphite plates as porous media distribution reagents.

In a conventional PEMFC system, micro and mesopores of the diffusion layer can feed the reactive gases, for its part; the macropores allow drainage of liquid water into the distribution channels of reagents. At high current densities, micro and mesopores are saturated with liquid water product of the reaction at the cathode, then the macropores develop both functions (supply and drainage), which is why the typical constraints are generated by mass transport in the porous electrodes [11]. This study focuses on the combined effect of rigid gas diffusion media (RGDM) in graphite used as a gas distributor and graphite paper (Toray) as diffusive layer on the active layer area. This condition has been applied to forming a Coated Catalytic Membrane Assembly (CCMA) as an electrode. The aim is to increase the effective area of reaction and reduce resistance to the diffusion of gases and products in the diffusion layer using RGDM a structure mainly composed of meso and macropores. Figure 2 shows a sketch about PEMFC design used for this study, the effects on the functionality of a PEMFC: H_2 / O_2 in wet conditions, these results will be compared and discussed with dry gases condition.

2. EXPERIMENTAL PART

PEMFC structural design was reported in a previous paper [21], this have monopolar plates (Figure 1) with serpentine distribution channels and support plates in Cu. The polar plate applied to the conventional PEMFC used in this study is also the distributor of reagents. The channels dimensions were 30 x 3 x 2 mm while the dimensions for the graphite plate were 50 x 50 x 10 mm. The new structural design of the experimental PEMFC used in this study, consists of a metal frame manufactured in two Cu plates with dimensions of 50 x 50 x 10 mm with hole housing for commercial graphite stiff as gas diffusion media (Helwing Carbon Co; originally used in electric furnaces) as reactive gas distributor and electrons collector (electrical current), its dimensions are 30 x 30 x 3 mm. A sample of this commercial graphite is analyzed by XPS technique on a JEOL JPS-9200, the result is discussed later (Figure 13). Among the Cu plate and graphite plate (RGDM) there is an empty chamber of 2 mm in order to allow the entry of reactive gases to cover the surface of porous graphite and distributing to the reaction zone. Figure 3 shows optical microscopy images (Nikon Eclipse MA-100) on both sides of RGDM used for gasses distribution. These images show a greater diameter and major number of pores in the diffusion layer compared with that seen in those presented by Kong and colleagues [11].



(a) **(b)**

Figure 3. Optical microscopy in porous graphite plates surfaces on both sides to 50 x 0.8 increases.

At opposite side at CCMA, two threaded holes 9 mm in diameter are located. The upper hole was used for gas feeding and the lower hole as purge for residual reactants and products. A piece of commercial graphite paper (Toray) with equivalent surface dimensions (14 x 14 mm) was used as a diffusion layer on the reaction area. Figure 4 shows the structure of graphite paper, observing paper layers and carbon fibers. This structure forms porosity (in to paper layers) which allow the diffusion of gases while the carbon fibers have openings through which reactants are transported by conduction. Viton joints were used to avoid leakage of the reactants; a square hole has been cutted at the center of the gasket surface with area equivalent to the RGDM for the free passage of reactants and products. The CCMA used in this paper has been developed by the Department of Chemistry, CINVESTAV [22], the main features of preparation are: using an ink prepared with 2.5 mg of platinum (E-Tek), mixed with 1 mg of coal in powder (Vulcan XC-72, Cabot) in a 5% ethanol in Nafion ®, the solution is applied by spraying compressed air on surface of Nafion membrane, evenly distributed over the area. These features are applied as electrodes on both sides (anode and cathode), thus CCMA and graphite paper undergoing at thermal pressurized conditions according to the literature [20, 22]. Figure 5 shows the CCMA surface characteristics after its use in this study.

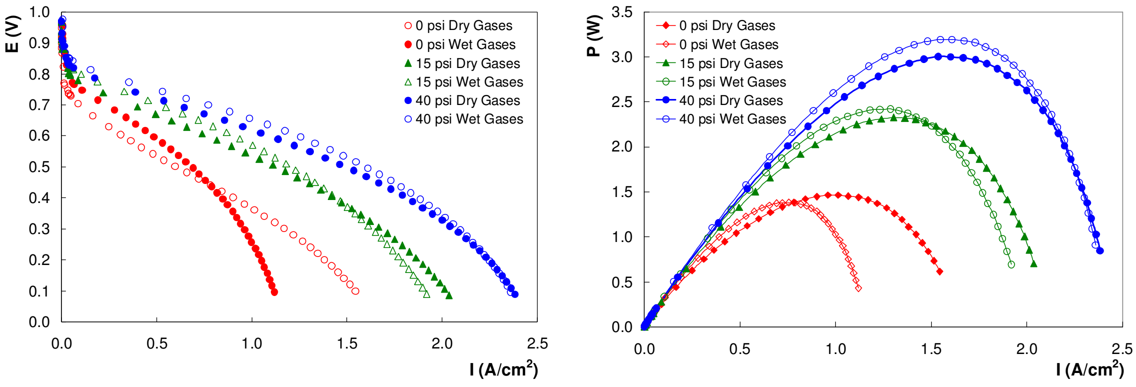
Figure 4. Optical microscopy for graphite paper surface at 50 x 0.8 increases.

Figure 5. Optical microscopy for CCMA surface at 50 x 0.8 increases.

The electrolyte membrane is Nafion ® 112 used with a thickness of approximately 50.8 µm [1-4]. The electrolyte used had an equivalent area of 35 x 35 mm. The fuel gas fed to the PEMFC was high purity (H2, 99% Infra) and oxidizer (O2, 99% Infra). The characterization of PEMFC was conducted in a test model Globe Fuel Cell Test System Tech Compu-Cell GT-890-B. The experimental conditions imposed on the PEMFC for this study were: gas flow 50 cc / min, cell temperature was 23 ° C and humidification temperature was 30°C while the pressure in the reactants compartment was variable for each case. This study was conducted using an experimental design 2k, combining two distributor types for reactive gases and varying levels of pressure in the reactive gas flow (from 0 to 40 psig) for the purpose of analyzing the effects on the functionality of the PEMFC.

3. RESULTS AND DISCUSSION

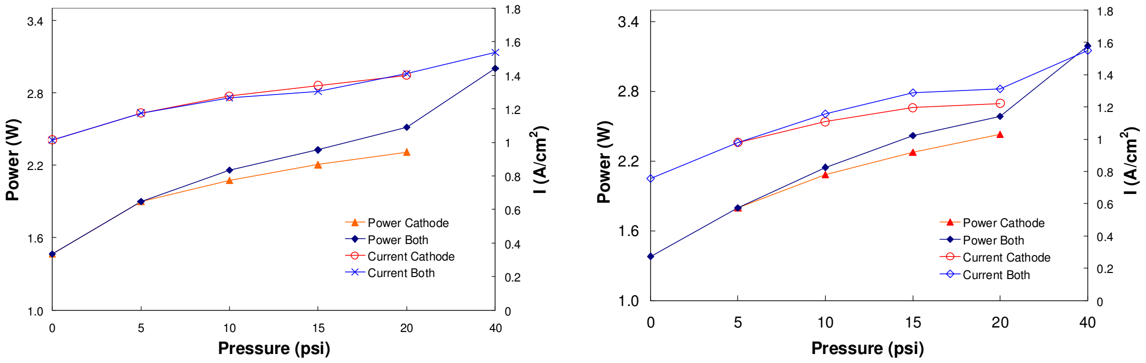
The effect of water in the flow of the reactants fed to a PEMFC in a conventional system (humidifier + temperature) is shown in Figure 6a. This shows polarization curves of PEMFC using two gas distribution plates with serpentine channels at different pressure levels on the cathode while the anodic pressure was fixed at 5 psig. Some curves correspond to dry gases fed and the others at wet gases fed (reactive gases humidified at 30°C). The curves at wet conditions shows a reduction in ohmic resistance that is attributable to an increase in the ionic conductivity of the Nafion membrane, however an adverse effect was observed on the diffusion region on the curves at wet conditions with the greatest impact at low pressure levels, i.e. reduces transport limitations of reactants and products in the diffusion layer used (graphite paper) in according to increasing pressure applied to the cathode electrode. Figure 6.b represents the electric power developed by the PEMFC to the experimental conditions used in the collection of curves in Figure 6.a. At low pressure in the cathodic compartment, the effect generated by gas humidification is not significant for the power value but this value is expressed at lowest current densities in comparison with values for dry gases. On the other hand, the electric power value increase in function of pressure level for wet conditions until values higher than those obtained in dry conditions, also moving to higher current densities, being particularly noted to 40 psig of pressure with an equivalent cathode to 3.2 W at a current density of 1.55 A/cm^2.



(a) **(b)**

Figure 6. Polarization curves (a) and electric power curves (b) generated by a PEMFC operating with serpentine channels at 5 psig in the anode and different experimental conditions.

The electrical characteristics PEMFC developed by the values of maximum power with conventional design to the experimental conditions described, are presented in Figure 7a for dry reactive flows [24] and Figure 7.b for wet conditions. The curves correspond to current density and electric power in pressure function (see part I) [24]. In general, we see similar behavior in the electrical characteristics at maximum power delivered by the PEMFC for dry and wet conditions. In general, we see similar behavior in the electrical characteristics at maximum power delivered by the PEMFC with dry and wet conditions. However it is noticeable the increase in current density values and electrical power for wet condition at pressures greater than 10 psig, i.e., the combined effect of pressure and humidity favor the functionality in the conventional PEMFC design at pressures greater than 10 psig.



(a) **(b)**

Figure 7. Electrical characteristics at maximum electrical power in a PEMFC operating with serpentine distribution plate and different humidity conditions: (a) dry gases, (b) humidification temperature at 30°C.

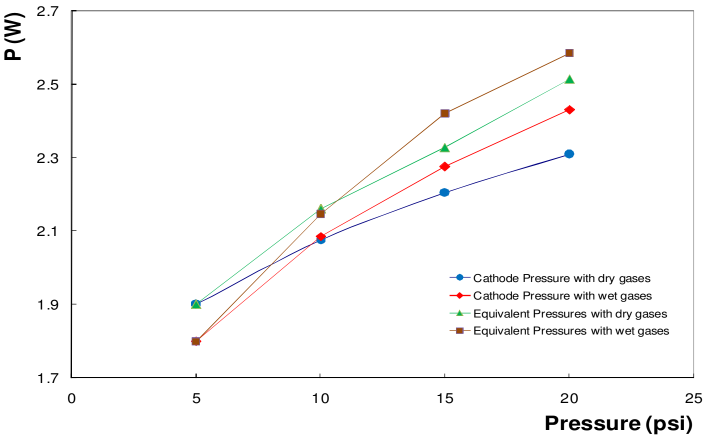
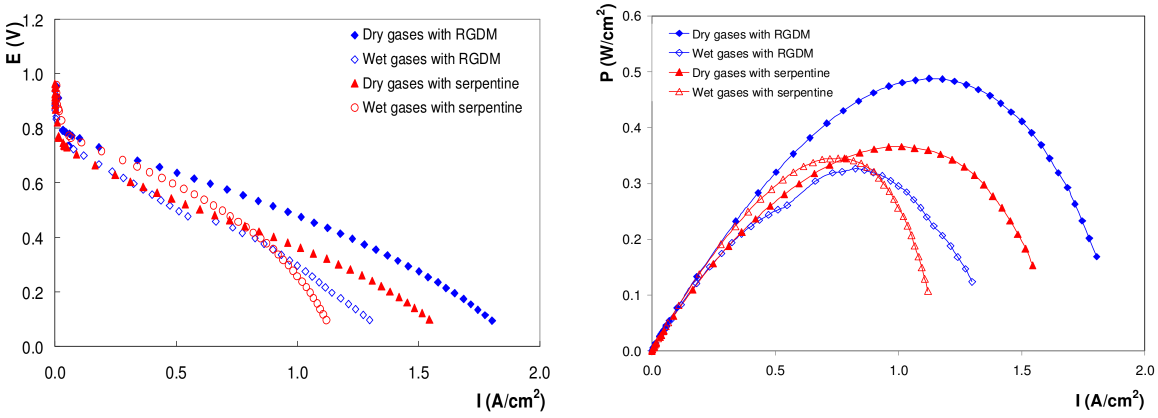


Figure 8. Electric power generated by the PEMFC at different levels of pressure using a serpentine gas distributor and two humidity conditions in reactive gases.

Figure 8 illustrates the double interaction on the maximum electrical power developed by the conventional PEMFC at experimental conditions of pressure and humidity. It's presents a favorable mechanism to change the power of the PEMFC by interaction of humidity and pressure applied to the over than 10 psig. This behavior allows at authors to assume: first, the adhesion of molecules of feed flow (water and reagent) at the walls of the pores in the diffusion layers and/or catalytic layer. This attachment blocks the free diffusion of the reactants when the pressure applied is less than 10 psig. However at higher pressures, the gas flow rate feed increase into the diffusion and active layers so the shear force is capable of removing the molecules attached to the wall of the pores and a greater concentration of reactants deposited at reaction sites in the electrode increased the catalytic activity.

Second, it should be noted that the moisture in the gas flow generates a higher ionic conductivity in polymer electrolyte. Third, the diameter of pores in the graphite paper allows an increased on dragging water molecules at the channels of gas distributors (polar plates), favoring the functionality of the PEMFC at higher current densities.

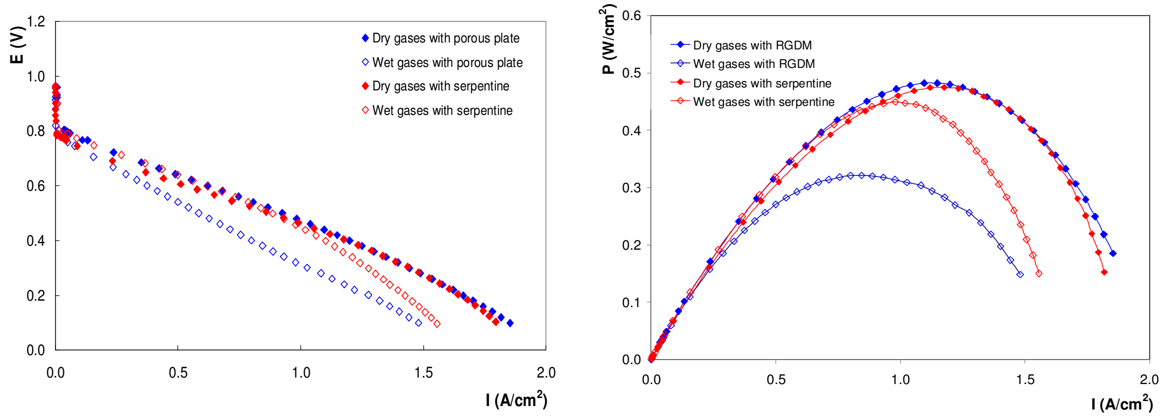
The effect of humidity on the reaction gas with RGDM as a gas distributor at 0 psig on the PEMFC functionality, it is observed in polarization curves on Figure 9a and compared versus the corresponding curve using a conventional design (serpentine flux) at dry conditions. In other hand, their electric power curves are presented in Figure 9.b. The best PEMFC functionality was observed by using of RGDM with dry reagents (1.8 A/cm^2 at 0.1 V) and confirmed by their respective power curve, having a maximum of 0.49 W/cm^2 at 1.13 A/cm^2. In other way, the activation losses (0-0.1 A/cm^2) were highest at wet gas flow versus dry gas flow when using RGDM that is attributable to a possible interaction of water content in the feeding of reagents with the activation energy of the CCMA electrode.



(a) **(b)**

Figure 9. Polarization curves (a) and electric power curves (b) for conventional and experimental PEMFC at 0 psig on both electrodes (anode and cathode) and different humidity conditions.

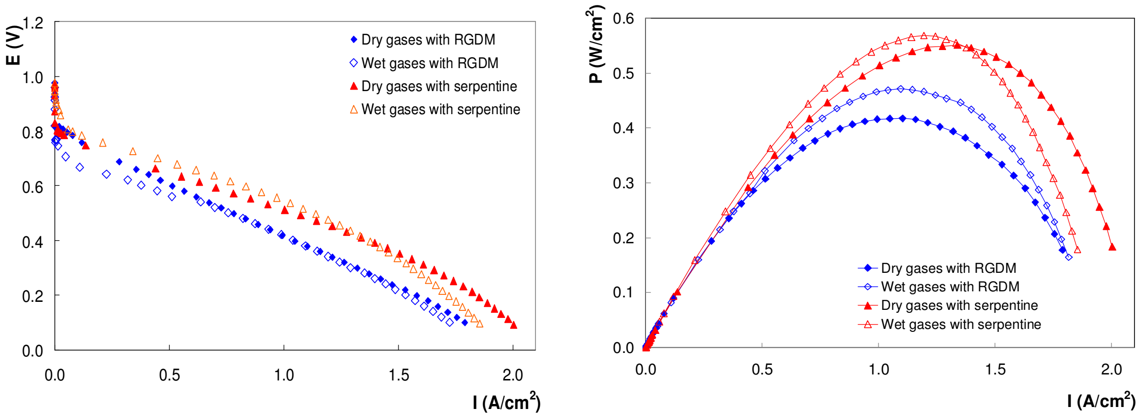
Subsequently, a second effect was observed in the region of ohmic losses where the polarization curve shows a linear behavior between 0.1 to 0.5 A/cm^2, this linearity suggests a limitation due to a low electrical conductivity of the porous matrix RGDM related to the Ohm's Law, where: V = I / R where V show a linear behavior if R is constant. Additionally a change of mechanism is observed from 0.6 A/cm^2 to 0.85 A/cm^2, being attributable to an interaction of water contained in the flow of reagents and the reaction product moisture on the membrane electrolyte, enhancing conductivity, the effect is also observed in the corresponding power curve between 0.52 - 1.2 A/cm^2 with a maximum of 0.33 W/cm^2 to 0.83 A/cm^2, respectively. In other hand, the transport limitations on the E-I curve were observed lowest using the RGDM in comparison with same case using a serpentine gas distributor, indicating a better diffusion characteristic for RGDM as a distributor of reagents in the PEMFC. Moreover, the functionality of the conventional PEMFC with dry reagents at 0 psig shows a similar trajectory to that of a wet gases flow but the values are below at the curve for the RGDM. This behavior can be attributed to a saturation of reagents on the catalytic surface of the electrode as a result of better reactant distribution and favorable transport conditions in the RGDM. Finally, the polarization curve using the serpentine distributor with wet gases and 0 psig have observed some lower ohmic limitations as result of improvement of Nafion membrane conductivity, however the resistance to mass transport were increased, reaching impact on the amplitude of the electric power curve.



(a) **(b)**

Figure 10. Polarization curves (a) and electric power curves (b) for conventional and experimental PEMFC at 5 psig on both electrodes (anode and cathode) and different humidity conditions.

Figure 10 show the E-I and power curves respectively for experimental conditions increasing pressure to 5 psig on both PEMFC systems. Under conditions of dry-reagent flow with both types of distributors developed PEMFC functionality were observed similar curves (Figure 10.a), but the RGDM design shows slight advantages over ohmic and difussion losses regions on the polarization curves, this behavior is attributable to a more efficient reagents distribution by porous structure in the RGDM allowing a higher saturation on the active sites on both electrodes, therefore a larger amount of water is generated, improving the conductivity of the Nafion membrane and reducing ohmic limitations . On the other hand, the improvement on the mass transport conditions promotes PEMFC power at high current densities. Both considerations allow that the experimental PEMFC reach an electrical power of 0.49 W/cm^2 at a density of electric current of 1.15 A/cm^2 using dry reagents flows, those values were the highest obtained in the experimental series while at the same conditions on conventional PEMFC operating had have a maximum power slightly smaller and slightly moved to higher densities of electric current. In other hand, the case with serpentine distributor and humidified reactants, its corresponding polarization curve shows a reduction in ohmic resistance, the effect being equivalent to the case with RGDM and dry gases flows, however a sharp increase in the resistance of mass diffusion was observed on the polarization curve, in consequence the electrical power developed is less than the previous cases. Finally, the E-I curve for the wet conditions and RGDM distributor had the highest voltage drop and power in the experimental series, being primarily attributable to: an increase in mass transport resistance due to possible accumulation of liquid water in the pores of RGDM. The second drop in tension with the linear behavior in the corresponding polarization curve is attributed to limitations in the electronic conductivity of RGDM (discussed in Part I) [24] and possibly interact with the presence of water in the RGDM. Moreover, additional water may absorb heat energy by reducing the scope of the PEMFC in electrical power.

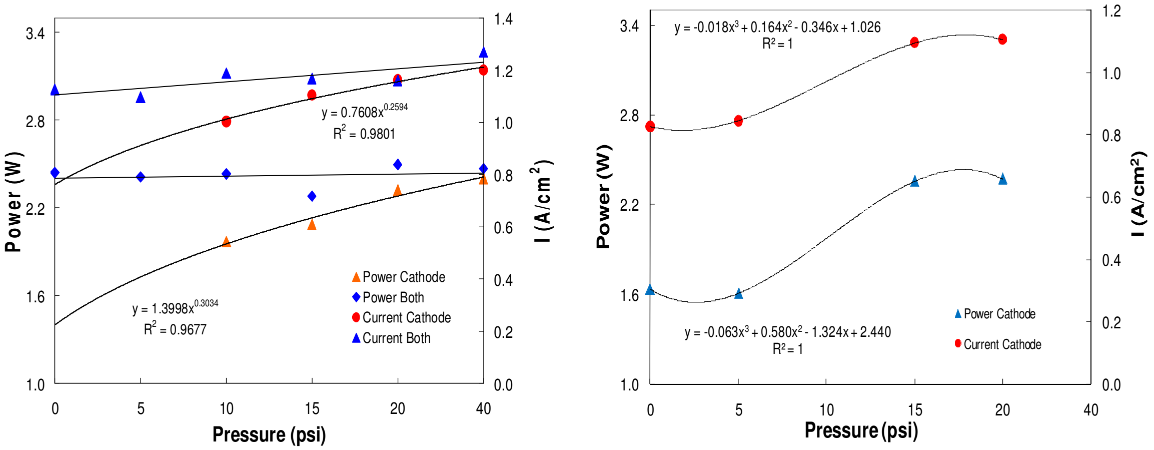


(a) **(b)**

Figure 11. Polarization curves (a) and electric power curves (b) for conventional and experimental PEMFC at 15 psig on both electrodes (anode and cathode) and different humidity conditions.

Figure 11 show the E-I (a) and power curves (b) respectively for both PEMFC systems in study, now increasing the pressure at 15 psig. The combined effect of pressure-humidity was observed on both cases on the PEMFC functionality curves showed in Figure 11.a. First, the E-I curves for the PEMFC with serpentine distributor are higher in both wet conditions with those corresponding at RGDM. Secondly, it's observed a noticeable contrast between the behavior of polarization curves with wet gases: for conventional PEMFC, the humidity conditions favors the conductivity of the Nafion membrane at low and medium densities of electric current allowing maximum power (0.45 W/cm^2 0.98 A/cm^2) in the experimental series, however it's observed an increase in the mass transport resistance, shifting the curve to lower current densities. In contrast, an effect in activation zone was observed on the E-I curve for experimental PEMFC at wet gases conditions, however at medium current density (0.6 A/cm^2), the curve shows a change in the phenomena mechanism similar to case of Figure 9, allowing to reach values of the curve to dry gases conditions at high current densities, where the values decrease slightly by an increase in diffusion resistance. The corresponding electrical power curve shows values above the curve to reagents at dry conditions.

The behavior in the curves of conventional PEMFC can be attributed on one hand the increased concentration of reactants at the catalytic surface of the electrodes, the effect of the imposed pressure, to significantly increase the flow velocity in the gas stream, allowing greater removal by entrainment of water in excess of the catalyst surface compared to the cases at lower pressure levels, should be understood as favoring wet gas conductivity of the Nafion membrane at low and medium current densities. In contrast, the polarization curve of the experimental system and wet gases shows a significant decrease in the area of activation with respect to the E-I curves at dry gases, showing an interaction of liquid water in the activation processes of active sites, additionally, the resistance to mass transport show a slight increase and ohmic limitations in this case show a significant reduction until 0.38 A/cm^2 to achieve a higher maximum value of electric power for case at wet gases (0.47 W/cm^2 to 1.09 A/cm^2) compared with the case at dry gases (0.41 W/cm^2 to 1.10 A/cm^2).



(a) **(b)**

Figure 12. Electrical characteristics at maximum electrical power in an operating PEMFC with GDRM distributor plate and different humidity conditions: (a) dry gases, (b) humidification temperature at 30 °C.

A comparison between the behavior of electrical characteristics to the maximum conditions of electric power PEMFC developed by applying a distributor RGDM reagents as a function of pressure is presented in Figure 12. The power behaviors at dry conditions is showed in Figure 12.a (being discussed in Part I of this study)[24] while the behaviors at reactive gases humidified conditions are observed in Figure 12.b. Remarkably different behavior in all cases in the study presented when using the RGDM as gas distributor. First, PEMFC power has a quasi-linear behavior in function of equal pressure level at both sides in the cell. Second, cell power has an exponential behavior in function of different pressure levels in cathode compartment. Third, PEMFC power has a third order mathematical behavior by effect of water content in gases flow and pressure level at the cathode comportment where a stepwise increase is observed at pressures greater than 10 psig.

A sample of commercial H grade graphite used in this study was analyzed by XPS technique, the resulting spectrum is shown in Figure 13. The peak shape and position are characteristic of carbon, oxygen and magnesium (NIST values). The shift of the signals provides important information as: the band associated with the O_2 has a shift to 531 eV which is interpreted as a bound to C forming CO_2 while the shift towards higher values at 532 eV is interpreted as oxygen bound to Mg to forming MgO. The H graphite sample observes a signal typical of amorphous carbon and shows a slight formation of the carbon signal for the type diamond. These results allow the authors to assume that the presence of MgO and liquid water in reactive gases can generate significant changes in the overpotential of the electrode when RGDM is used as gas distributor, having a directly contact with the active layer of CCMA, similar behavior has been reported by Kong [11]. Thus, functionality and electric power generated by the PEMFC is affected differently depending on the pressure level applied to values below 10 psig when cathodic pressure increase to values higher than 10 psig where PEMFC functionality increase.

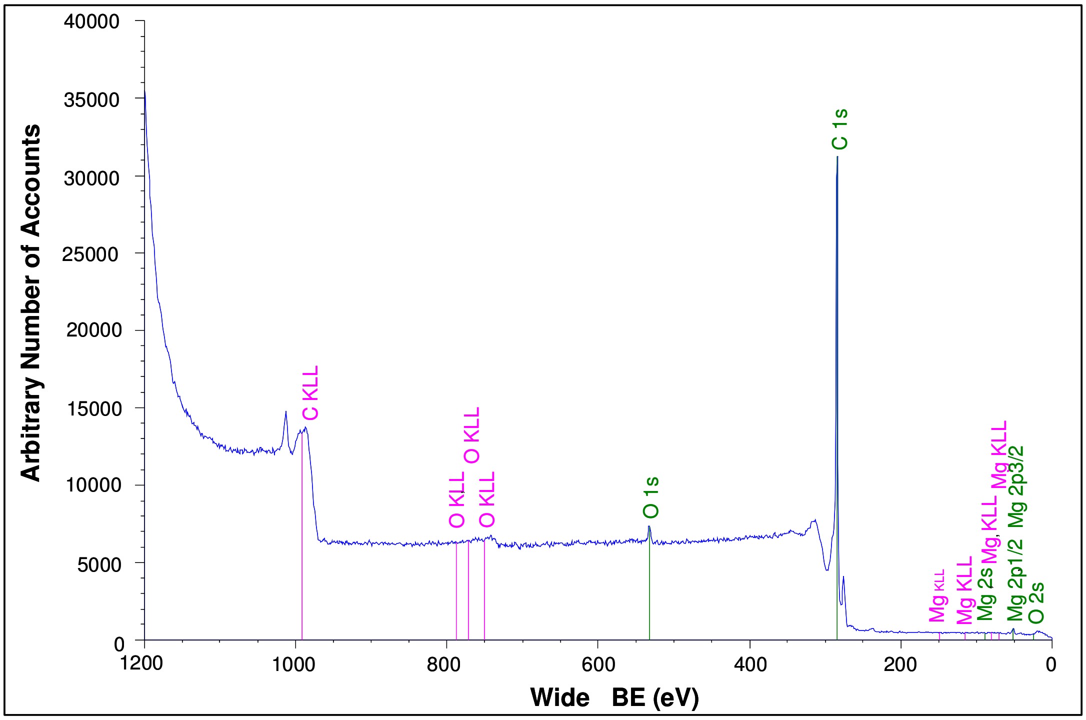


Figure 13. Spectroscopy RXP for commercial graphite H grade (Helwing Carbon Co).

4. CONCLUSIONS

This work includes a comparison of functionality and electrical power developed by a conventional PEMFC with a distributor of reagents with serpentine-shaped channels and a diffusive experimental half rigid graphite using wet reagent at different levels of pressure, comparing the results with dry gases. In both PEMFC structural designs, the results show an unfavorable effect for the functionality of the PEMFC with wet reactive gases at lower pressures to 10 psig, but the effect is reversed at higher pressures favorably to that level of pressure. In the conventional PEMFC, water reduces the effect of power levels depending on the pressure but retains the general behavior of the curves while in the experimental model, humidity significantly modifies the behavior of electric power as a function of level pressure applied on reactive gas flow, attributable to the conditions of flow rate and residual water drained into the pores of the medium stiff diffusive and water management trend is more complex in the RGDM used in the PEMFC. In the experimental PEMFC, the effect of humidity reactant gases is observed generally unfavorable, reaching lower values of electric power, transport of reactants through the pores poorly diffusive rigid environmental humidity conditions. However, the PEMFC functionality increase at pressures greater than 10 psig where the flow of reactive gases promotes functionality in both fuel cell designs, this promotion is due to increased flow velocity, allowing more drag moisture outside the PEMFC and reducing the transport limitations. Finally, the presence of heavy metals such as Mg electrodes in the structure of trade can generate significant changes in the overpotential of the cell in the presence of moisture in the reactants, which affects the functionality developed by the PEMFC.

ACKNOWLEDGMENTS

The authors are grateful to Alter Energias Grupo for partial financial support to this study and Professor Octavio Olivares Xómetl of Chemical Engineering Faculty in BUAP for Optical Microscopy.

References

1. Fuell Cell Hanbook. EG&G Services, Parsons Inc. 5th Edition, USA, 2000.
2. P. Costamagna, S. Srinivasan. *Journal of Power Sources*, 102 (2001) 242
3. P. Costamagna, S. Srinivasan. *Journal of Power Sources*, 102 (2001) 253
4. D. L. Wood III, J. S. Yi and T. V. Nguyen. *Electroquímica Acta*, V. 43, No. 24 (1998) 3795
5. T. Mennola, M. Noponen, T. Kallio, M. Mikkola and T. Hottinen. *Journal of Applied Electrochemistry*, 34 (2004) 31
6. K-H Choi, D-H Peck, Ch-S Kim, D-R Shin, T-H Lee. *Journal of Power Sources* 86 (2000) 197
7. T. V. Nguyen. *J. Electrochem. Soc.*Vol. 143, No. 5 (1996) L103
8. Paola Costamagna. *Chemical Engineering Science* 56 (2001) 323
9. C. Moisés Bautista-Rodríguez, Araceli Rosas-Paleta, J. Antonio Rivera-Márquez, Omar Solorza-Feria. *International Journal of Electrochemical Science* 4 (2009) 43
10. C. Moisés Bautista-Rodríguez, Araceli Rosas-Paleta, J. Antonio Rivera-Márquez, Omar Solorza-Feria. *International Journal of Electrochemical Science* 4 (2009) 60
11. Ch. S. Kong, D-Y Kim, H-K Lee, Y-G Shul, T-H Lee. *Journal of Power Sources*, 4725 (2002) 1
12. C. Boyer, S. Gamburzev and A. J. Appleby. *Journal of Applied Electrochemistry*, 29 (1999) 1095
13. J. J. Baschuk, Xianguo Li. *Journal of Power Sources*, 86 (2000) 181
14. V. A. Paganin, E. A. Ticianelli, E. R. Gonzalez. *Journal of Power Sources*, 70 (1998) 55
15. D. R. Sena, E.A. Ticianelli, V.A. Paganin, E. R. Gonzalez. *Journal of Electroanalytical Chemistry*, 477 (1999) 164
16. S. A. Grigor'ev. *Rusian Journal of Elecrochemistry*, V 40, 11 (2004) 1188
17. Zhigang Qi. *Journal of Power Sources*, 109 (2002) 469
18. S. Dutta, S. Shimpale and J. W. Van Zee. *Journal of Applied Electrochemistry*, 30 (2000) 135
19. S. Dutta, S. Shimpale and J. W. Van Zee. *International Journal of Heat and Mass Transfer*, 44 (2001) 2029
20. C. Moisés Bautista-Rodríguez, Araceli Rosas-Paleta, Andrés Rodríguez-Castellanos, J. Antonio Rivera-Márquez, Omar Solorza-Feria, J. Antonio Guevara-Garcia, J. Ignacio Castillo-Velázquez. *International Journal of Electrochemical Science*, 2 (2007) 820

21. H. H. Voss, D. P. Wilkinson, P. G. Pickup, M. C. Johnson and V. Basura. *Electrochimica Acta* V. 40, No. 3 (1995) 323
22. K. Suárez-Alcántara, A. Rodríguez-Castellanos, S. Durón-Torres, O. Solorza-Feria, *J. Power Sources* 171 (2007) 381
23. I. A. Maslii, N.P. Poddubnyi and A. Zh. Medvedev. *Russian Journal of Electrochemistry*, Vol 40, No.2 (2004) 218
24. C. Moisés Bautista-Rodríguez, Araceli Rosas-Paleta, J. Antonio Rivera-Márquez, J. Roberto Garcia de la Vega. *International Journal of Electrochemical Science* 4 (2009) 1754.