Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Influence of operational parameters on the performance of PEMFCs with serpentine flow field channels having different (rectangular and trapezoidal) cross-section shape

Luciana S. Freire [a], *Ermete Antolini* [b], *Marcelo Linardi* [c], *Elisabete I. Santiago* [c], *Raimundo R. Passos* [a,*]

[a] *Laboratório de Eletroquímica e Energia — LEEN, Departamento de Química, Universidade Federal do Amazonas, Av. Gal Rodrigo Octávio, 6200, 69077-000, Manaus, AM, Brazil*

[b] *Scuola di Scienza dei Materiali, Via 25 Aprile 22, 16016, Cogoleto, Genova, Italy*

[c] *Instituto de Pesquisas Energéticas e Nucleares, IPEN-CNEN/SP, São Paulo, SP, 05508-000, Brazil*

ARTICLE INFO

Article history:
Received 27 March 2014
Received in revised form
29 May 2014
Accepted 8 June 2014
Available online 1 July 2014

Keywords:
PEMFC
Bipolar plate
Serpentine channel
Cross-section shape
Water management

ABSTRACT

The effect of operational parameters on the performance of PEMFCs by using serpentine flow field channels with different (rectangular and trapezoidal) cross-section shape has been investigated. More than cell temperature and pressure, reactant humidification temperature ($T_{ha,c}$) has a significant influence on the effect of serpentine channels with trapezoidal cross-section on cell performance. The high capability of water removal by serpentine channels with trapezoidal cross-section positively affects the fuel cell performance when the water content in the system is high, as in the case of the reactant humidification temperature higher than cell temperature (T_c). On the contrary, when the water content in the cell is low, as in the case of $T_{ha,c} = T_c$, the high ability of water removal of serpentine channels with trapezoidal cross-section results in a less effective membrane/cathode hydration. Conversely, the effect of $T_{ha,c}$ on the performance of the cell with serpentine channels with rectangular cross-section is negligible.

Copyright © 2014, Hydrogen Energy Publications, LLC. Published by Elsevier Ltd. All rights reserved.

Introduction

Polymer electrolyte membrane fuel cells (PEMFC's) are commonly formed by a membrane electrode assembly (MEA) sandwiched between two bipolar plates, with machined channels for distributing fuel and oxidant to the anode and the cathode, respectively. The electrodes usually comprise a gas diffusion layer (GDL) and a catalyst layer (CL). The GDL consists of a micro-porous layer (MPL) formed by carbon particles and polytetrafluoroethylene (PTFE), coated on a porous carbon material backing layer (GDM). The CL is formed by a carbon supported platinum-based catalyst and an ionomer [1]. At the cathode, water is formed by reaction of O_2 with protons and electrons. Due to the low cell temperature, in gas channels water is present in liquid form. Water

* *Corresponding author*. Tel.: +55 92 3305 2875.
E-mail addresses: rrpassos@ufam.edu.br, rdopassos@gmail.com (R.R. Passos).

http://dx.doi.org/10.1016/j.ijhydene.2014.06.041

0360-3199/Copyright © 2014, Hydrogen Energy Publications, LLC. Published by Elsevier Ltd. All rights reserved.

management is a key topic for a suitable fuel cell operation. Indeed, the membrane has to be fully hydrated and, on the other hand, cathode flooding by liquid water has to be avoided. The use of humidified reactant gas stream for both electrodes allows a satisfactory membrane hydration [2,3]. A way to obtain a suitable water balance in low temperature fuel cells is a right design of flow channels on the bipolar plates [4]. The bipolar plate acts as electron and heat conductor and allows flow passages for reactant gases and water. Manso et al. [4] reviewed the most important results regarding the effect of flow channel geometric characteristics on PEMFC performance. Among the different bipolar plate topologies, the serpentine flow channel layout is the most widely used, due to the high performance of PEMFCs with this type of flow channels [4,5]. The larger pressure drop across the serpentine configuration presents both challenges and opportunities for cell designers. A disadvantage of such a design is the increase of pumping requirements, which adversely affects both system cost and volume. The larger pressure drop, however, can give rise to positive effects. Indeed, it can remove blockages due to liquid water produced on PEMFC cathode side and enhance cell performance by increasing convective mass transport into the GDL [6].

The cross-section of flow channels is commonly rectangular, but other shapes such as trapezoidal, triangular and semi-circular have been investigated. There is not a general consensus, however, regarding the more suitable shape. Flow channel geometry significantly affects water removal efficiency and fuel cell performance. Many experimental and theoretical works reported the effect of rectangular channel dimensions on cell performances [7–15]. Only few theoretical works, instead, reported the effect of channel shape on the cell performance [7,16,17]. By a computational analysis, triangular and hemispherical shaped cross-section showed an enhancement in hydrogen consumption at the anode than rectangular shaped cross-section, which should result in a better PEMFC performance [7]. Ahmed and Sung [16] investigated the performance of a PEMFC with different channel cross-section but the same boundary conditions by a computational fluid dynamics analysis. High cell voltages were attained by the channels with rectangular cross-section, but a more uniform reactant and local current density distributions at the membrane–cathode GDL interface was showed by the channels with trapezoidal cross-section. Sun et al. [17] found that the trapezoidal shape of the channel cross-section can decrease the pressure drop and enhance fuel cell performance.

The effect of flow channel shape on the efficiency of water removal in PEMFC cathode was also evaluated [18,19]. Owejan et al. [18] investigated liquid water accumulation in the GDL and reactant distribution channels of PEMFCs by the neutron radiography method. They found that channels with triangular geometry retain less water than rectangular channels with the same cross-sectional area. Models of microchannels with various cross-sections were compared, and the detachment and removal times of the water droplet were in following order: triangle < trapezoid < rectangle [19].

The goal of this work is to evaluate the influence of operational parameters on the performance of PEMFCs with bipolar plates having different cross-section shape of serpentine channels. At the best of our knowledge, this is the first experimental work addressed to the effect of the cross-section shape of serpentine channels on fuel cell performance. Two different shapes of cathode flow channels were compared, that is, rectangular and trapezoidal, at fixed anode flow channel rectangular shape, since that the cathode side is the most critical side of the fuel cell, due to the management of water produced at the cathode as well as to the mass transport, being oxygen diffusion rate lower than hydrogen diffusion rate. In addition to bipolar plate geometric parameters, operational parameters such as temperature and pressure, and GDL components such as PTFE have a strong influence on water management and fuel cell performance.

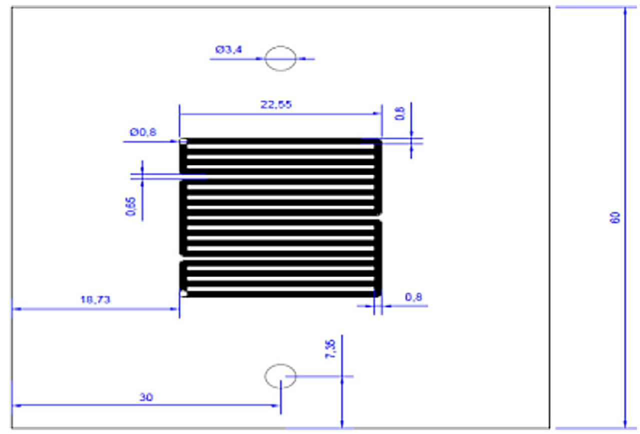

Fig. 1 – Serpentine flow field pattern.

Experimental

Bipolar plates

Bipolar plates with serpentine configuration have been utilized in this work for both the electrodes, as shown in Fig. 1. Two different cross-sectional geometries that is, rectangular and trapezoidal, were tested at the cathode side (Fig. 2). The

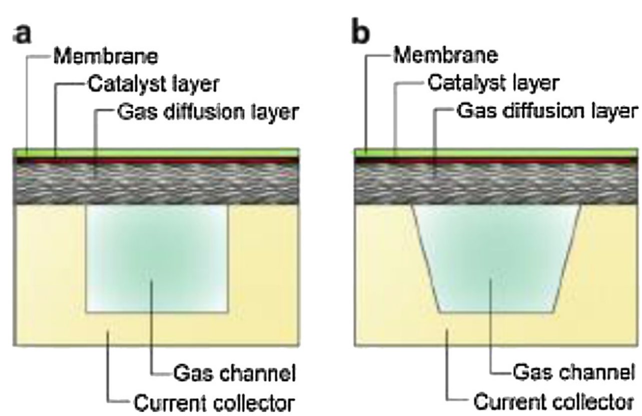

Fig. 2 – Cross-sectional views of flow channel geometries. (a): rectangular; (b): trapezoidal.

geometrical characteristics of gas flow plates with different cross-section shape were similar and are reported in Table 1.

Electrode preparation

The electrodes were prepared by a combined deposition/painting procedure using carbon supported Pt (20% Pt/C by E-TEK), carbon powder (Vulcan XC-72, Cabot), a carbon cloth substrate, a PTFE suspension, a Nafion solution and isopropanol.

Diffusion layer preparation

The diffusion layer was prepared by deposition of a homogeneous water suspension of carbon and PTFE onto both the faces of the carbon cloth. The composite structure was dried, then baked for 30 min at 280 °C, and finally sintered at 350 °C for 30 min. For all measurements, PTFE content in the diffusion layer of the anode was 15 wt% on both carbon cloth sides. For measurements of the effect of temperature and pressure on cell performance, PTFE content in the cathode was kept in 15 wt%. In order to evaluate the effect of PTFE in the diffusion layer on cell performance, PEMFC with different PTFE contents (15, 30 and 50 wt%) were also prepared. The total mass loading for the diffusion layers of the electrodes was 3 mg cm^{-2} with 15% PTFE in all cases.

Catalyst layer preparation

A homogeneous suspension was formed by the Pt/C catalyst and the Nafion solution with isopropanol as solvent. The resulting ink was deposited onto one of the faces of the diffusion layer by a painting procedure. As a final step, the sample was cured at 80 °C for 1 h. Pt loading was 0.4 mg cm^{-2}, and the Nafion loading was 1.1 mg cm^{-2} for all the electrodes investigated.

MEA preparation

A Nafion membrane N115 was used. The anode and cathode were hot pressed onto the Nafion membrane at 125 °C under a pressure of 5 MPa for 5 min. Cell tests were carried out in H_2/O_2 at 85 °C, a hydrogen pressure of 2 atm and at different oxygen pressures (1, 2, 3 and 5 atm).

Tests in single PEMFCs

PEMFC tests were carried out in H_2/O_2 at cell temperatures (T_c) of 80 and 85 °C; considering that, when fuel cell operating temperature is higher than the gas stream humidification temperatures, the performance of the fuel cell can decrease [2], cathode and anode reactant humidification temperatures (T_{hc} and T_{ha}, respectively) were the same or higher than T_c; each test was expressed as $T_c/T_{hc}/T_{ha}$, and the temperature tested were: 80/80/80, 80/85/95, 85/85/85, and 85/90/100. Cell tests were performed at hydrogen and oxygen pressures of 1 bar. Tests at 80/85/95 °C were also carried out at H_2 pressure of 2 bar and O_2 pressure of 2 and 3 bar. H_2 and O_2 gas flow was 148 and 200 mL min^{-1}, respectively.

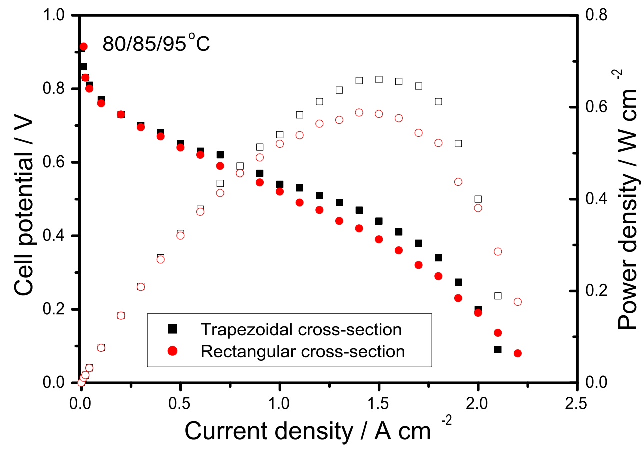

Fig. 3 – Polarization and power density curves of single PEMFCs with serpentine channels having rectangular and trapezoidal cross-section. T_c: 80 °C; T_{hc}: 85 °C; T_{ha}: 95 °C; O_2 pressure: 1 bar; H_2 pressure: 1 bar; PTFE content in both anode and cathode MPL: 15 wt%. Anode and cathode catalyst: 20 wt% Pt/C, Pt loading 0.4 mg cm^{-2}. Full symbols: polarization curves; open symbols: power density curves.

Results and discussion

The optimal operating temperature of a PEMFC is the highest temperature in which the cell can operate preserving a suitable membrane hydration. A PEMFC commonly operates at 80 °C, but the optimal value depends on other operational parameters, such as humidification and pressure of the inlet gases, which have a remarkable influence in the membrane hydration. Paganin et al. [20] showed that the best performance was obtained at a cell temperature of 80 °C and oxygen and hydrogen humidification temperatures of 85 and 95 °C, respectively. On this basis, we took as basic operating conditions of a PEMFC $T_c/T_{hc}/T_{ha}$ = 80/85/90 °C, and hydrogen pressure = oxygen pressure = 1 bar, with a PTFE content in the MPL of 15 wt%.

Effect of cell and reactant humidification temperature

The polarization and power density curves of PEMFCs with serpentine channels having rectangular and trapezoidal

Table 1 – Geometrical data of serpentine channels with different cross-section shape.

Cross-section shape	Channel height (mm)	Channel width (mm)	Distance between channels (mm)	Channel number (mm)	Channels/electrode contact area (mm^2)
Rectangular	0.8	0.8	0.65	16	302.08
Trapezoidal	0.8	0.8	0.65	16	297.98

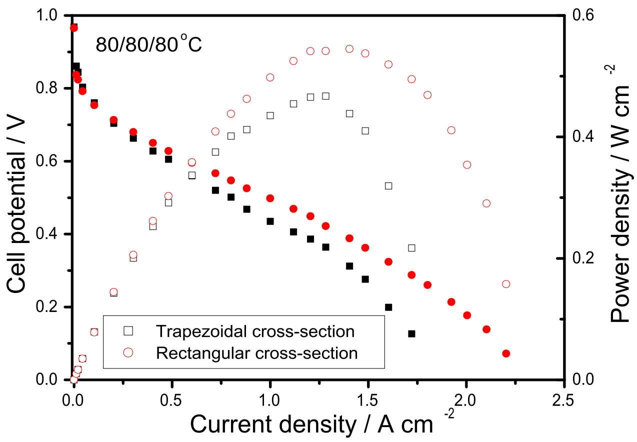

Fig. 4 – Polarization and power density curves of single PEMFCs with serpentine channels having rectangular and trapezoidal cross-section. T_c: 80 °C; T_{hc}: 80 °C; T_{ha}: 80 °C; O_2 pressure: 1 bar; H_2 pressure: 1 bar; PTFE content in both anode and cathode MPL: 15 wt%. Anode and cathode catalyst: 20 wt% Pt/C, Pt loading 0.4 mg cm^{-2}. Full symbols: polarization curves; open symbols: power density curves.

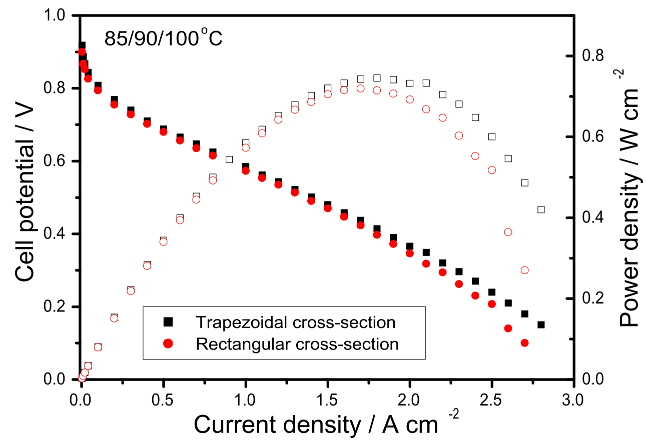

Fig. 6 – Polarization and power density curves of single PEMFCs with serpentine channels having rectangular and trapezoidal cross-section. T_c: 85 °C; T_{hc}: 90 °C; T_{ha}: 100 °C; O_2 pressure: 1 bar; H_2 pressure: 1 bar; PTFE content in both anode and cathode MPL: 15 wt%. Anode and cathode catalyst: 20 wt% Pt/C, Pt loading 0.4 mg cm^{-2}. Full symbols: polarization curves; open symbols: power density curves.

cross-section operating at 80/85/95 °C are shown in Fig. 3. The polarization behaviour of a fuel cell results from three types of phenomena: electrode kinetics (at low current density), ohmic losses (at low/intermediate current density), and mass transport limitations (at high current density). We focused on the effect of cross-section shape of serpentine channels on the ohmic losses, mainly due to a poor hydration of membrane/electrodes and/or electrode flooding. If the membrane and/or electrodes are not fully hydrated, the decay of performance starts at low current densities. As can be seen in Fig. 3, up to *ca.* 1.0 A cm^{-2}, the performance of the cell with serpentine channels having trapezoidal cross-section was similar to that of the cell with serpentine channels having rectangular cross-section. This means that in these operational conditions the cross-section shape affects the membrane and electrode hydration in the same way. In the range of current density from 1.0 to 2.0 A cm^{-2}, instead, the performance of the cell with serpentine channels having trapezoidal cross-section was higher to that with serpentine channels having rectangular cross-section. In this current density range, where a high amount of water is present in the cathode, due to the electrochemical reaction and to the electro-osmotic drag, the improved performance of the cell with serpentine channels having trapezoidal cross-section has to be ascribed to a more effective water removal from the cathode. At high current density, a fast decay of cell potential with increasing current

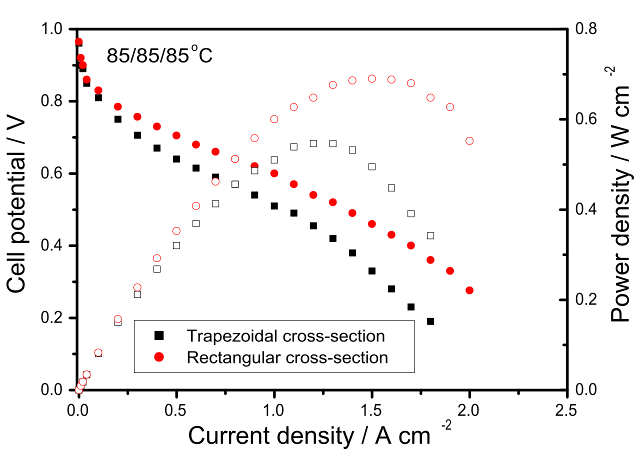

Fig. 5 – Polarization and power density curves of single PEMFCs with serpentine channels having rectangular and trapezoidal cross-section. T_c: 85 °C; T_{hc}: 85 °C; T_{ha}: 85 °C; O_2 pressure: 1 bar; H_2 pressure: 1 bar; PTFE content in both anode and cathode MPL: 15 wt%. Anode and cathode catalyst: 20 wt% Pt/C, Pt loading 0.4 mg cm^{-2}. Full symbols: polarization curves; open symbols: power density curves.

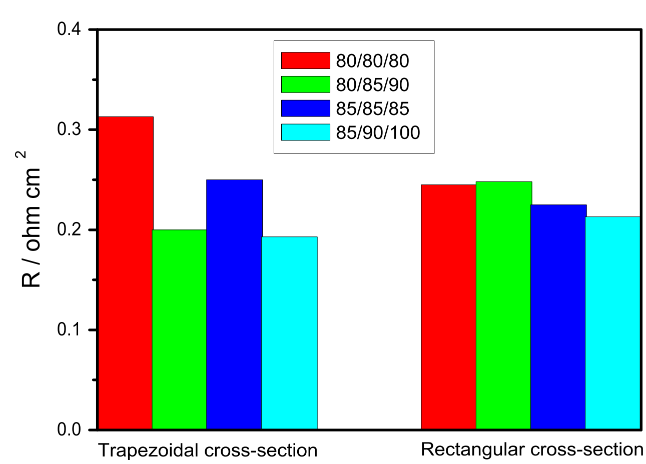

Fig. 7 – Histogram of the ohmic resistance of PEMFCs with serpentine channels having rectangular and trapezoidal cross-section at various $T_c/T_{hc}/T_{ha}$ conditions. $P_{O_2} = P_{H_2} = 1$ bar. PTFE content in the cathode MPL: 15 wt%.

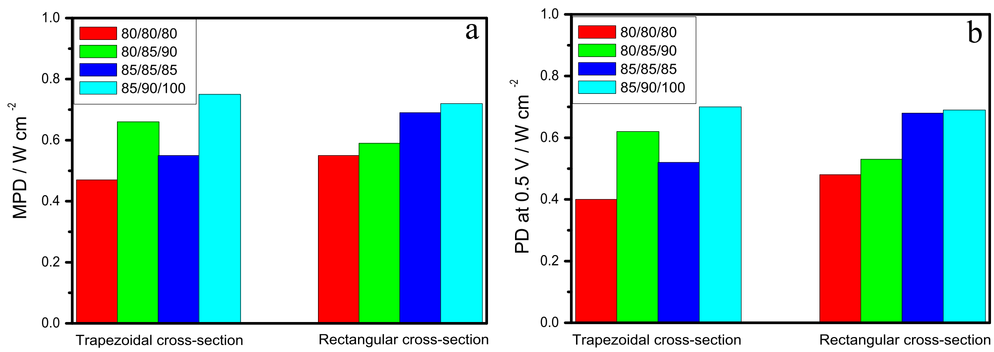

Fig. 8 – Histogram of the maximum power density (a) and power density at 0.5 V (b) of PEMFCs with serpentine channels having rectangular and trapezoidal cross-section at various $T_c/T_{hc}/T_{ha}$ conditions. $P_{O_2} = P_{H_2} = 1$ bar. PTFE content in the cathode MPL: 15 wt%.

density for the cell with serpentine channels having trapezoidal cross-section than that of the cell with serpentine channels having rectangular cross-section was observed, likely due to decrease of pressure drop in serpentine channels with trapezoidal cross-section [17]. Indeed, as reported in Section Introduction, a decrease in pressure drop can be adverse for mass transport [6]. By decreasing gas humidification temperature to cell temperature (80 °C), the relative humidity of the system decreases. Fig. 4 shows the polarization and power density curves of PEMFCs with serpentine channels having different cross-section shape operating at 80/80/80 °C. From 0.2 A cm^{-2}, the performance of the cell with serpentine channels having rectangular cross-section was higher to that of the cell with channels having trapezoidal cross-section. This indicates that, when the cross-section shape of serpentine channels in the cathode side is rectangular, the membrane and electrodes are better hydrated than when the cross-section shape is trapezoidal. This result has to be ascribed to the high capability of water removal of the flow channels with trapezoidal cross-section, which in this case produces a negative effect, that is, a less effective membrane/cathode hydration. By decreasing reactant humidification temperature, the hydration of the cathode and, particularly, the anode decreases. At low current density, for a low anode

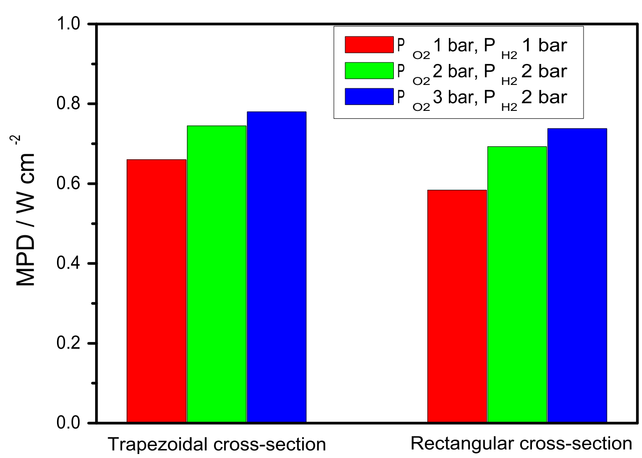

Fig. 10 – Histogram of the maximum power density of PEMFCs with serpentine channels having rectangular and trapezoidal cross-section at various oxygen and hydrogen pressures. $T_c/T_{hc}/T_{ha} = 80/85/95$ °C. PTFE content in the cathode MPL: 15 wt%.

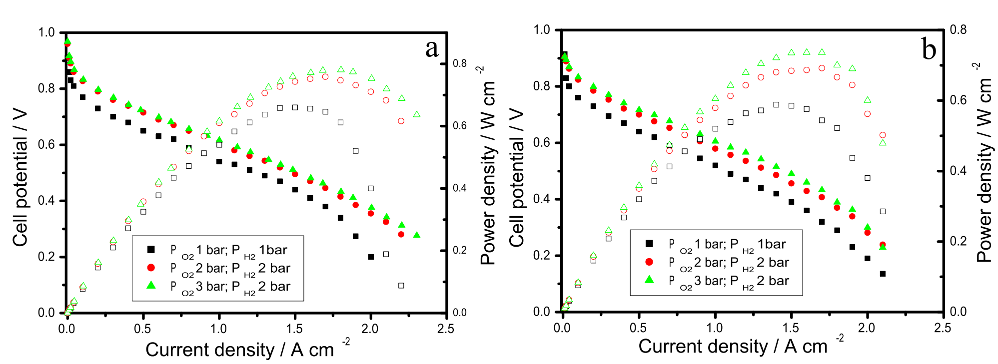

Fig. 9 – Polarization and power density curves of single PEMFCs with serpentine channels having trapezoidal (a) and rectangular (b) cross-section at different oxygen and hydrogen pressures. T_c: 80 °C; T_{hc}: 85 °C; T_{ha}: 95 °C; PTFE content in both anode and cathode MPL: 15 wt%. Anode and cathode catalyst: 20 wt% Pt/C, Pt loading 0.4 mg cm^{-2}. Full symbols: polarization curves; open symbols: power density curves.

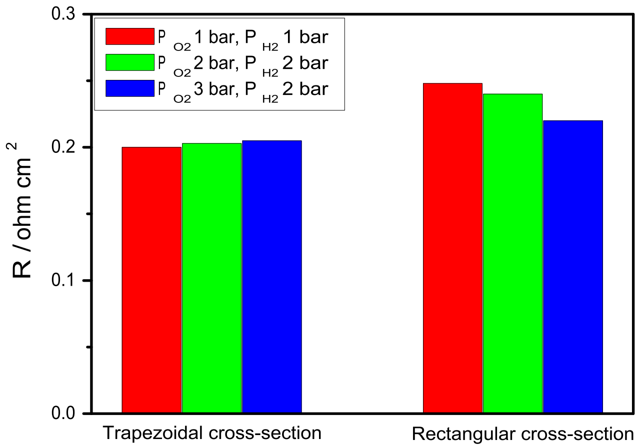

Fig. 11 – Histogram of the ohmic resistance of PEMFCs with serpentine channels having rectangular and trapezoidal cross-section at various oxygen and hydrogen pressures. $T_c/T_{hc}/T_{ha}$ = 80/85/95 °C. PTFE content in the cathode MPL: 15 wt%.

hydration, the water transfer through the membrane from the cathode to the anode by back-diffusion is high. The water transfer from the cathode to the anode is more pronounced in trapezoidal cross-section channels, resulting in a water deficiency in the cathode and in the membrane, which results in a low performance of the cell with this channel cross-section shape. As observed in the previous operating conditions (80/85/95 °C), at high current density a remarkable decrease of performance and the limiting current of the cell with serpentine channels having trapezoidal cross-section was observed, due to the negative effect of the decrease in pressure drop. By increasing cell temperature from 80 °C to 85 °C, which results in a higher water evaporation rate, and/or for gas humidification temperatures equal to cell temperature (85/85/85 °C), by using serpentine channels having trapezoidal cross-section, the sum of the water introduced and produced into the cathode could be not enough for an effective membrane and cathode hydration. As expected, as the effect of the higher water evaporation, due to cell temperature increase, has to be added to the higher water removal rate from the cathode through the serpentine channels with trapezoidal cross-section, the negative effect of the trapezoidal cross-section is more pronounced, as can be seen in Fig. 5. Finally, oxygen and hydrogen humidification temperatures were increased to 90 and 100 °C, respectively, maintaining cell temperature at 85 °C. As can be seen in Fig. 6, the performance of the cell with channels having trapezoidal cross-section shape was slightly higher to that with rectangular cross-section for current densities higher than 1.0 A cm^{-2}. In this case, the degree of membrane/electrode hydration was the same for both types of cells, with a slightly better water management in the cathode for the cell with channels having trapezoidal cross-section shape for current densities higher than 1.0 A cm^{-2}.

The fuel cell voltage losses can be broken up into three different types of losses. These are activation, ohmic, and mass transport/concentration losses [21]. Each loss has a different effect on the theoretical fuel cell voltage. The activation loss is associated to the kinetic rate limitation caused, mainly, by oxygen reduction reaction (ORR). Such loss occurs at low current densities and depends on the type of catalyst. The second source of loss is the ohmic drop, which is related, majority, to the membrane conductivity. The ohmic drop polarization occurs at intermediate current densities. It might appear as a major source of loss in fuel cells. The third type of loss is the mass transport/concentration polarization. Such loss is resulting from the diffusional limitation of the reactants (H_2 and O_2) at high current densities, where the consumption of the gases is faster than the diffusion rate [21]. The measurement of ohmic losses gives important information on water management. The ohmic losses, E_Ω, comprise electronic and ionic contributions from the anode (R_a), the cathode (R_c), and the membrane (R_m). The total electronic resistance comprises contact and bulk components ($R_{contact}$, and $R_{electronic}$, respectively), resulting from the overall assembly, and is expressed by the following equation [22]:

$$E_\Omega = iR = i(R_a + R_c + R_m) + i(R_{contact} + R_{electronic}) \quad (1)$$

In this work, the contact and bulk resistances were assumed constant and negligible. The slope of the linear portion of the polarization curves (ohmic region) was utilized

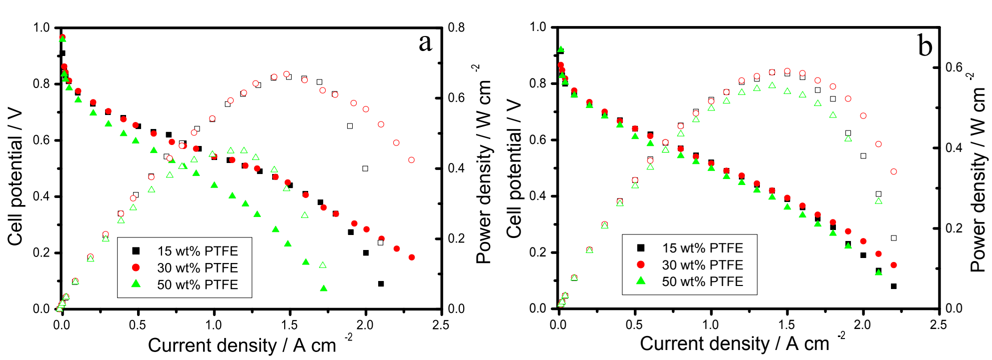

Fig. 12 – Polarization and power density curves of single PEMFCs with serpentine channels having trapezoidal (a) and rectangular (b) cross-section with different PTFE content in the cathode MPL. T_c: 80 °C; T_{hc}: 85 °C; T_{ha}: 95 °C; PTFE content in both anode and cathode MPL: 15 wt%. Anode and cathode catalyst: 20 wt% Pt/C, Pt loading 0.4 mg cm^{-2}. Full symbols: polarization curves; open symbols: power density curves.

to calculate R. The ohmic resistances of PEMFC with trapezoidal (R_t) and rectangular (R_r) cross-section shape of serpentine channels at various operating temperatures $T_c/T_{hc}/T_{ha}$ are reported in the histogram in Fig. 7. Both R_t and R_r decreased with increasing T_c. At fixed T_c, with increasing gas humidification temperature R_t decreased (better membrane/electrode hydration), whereas R_r was nearly constant, in agreement with the previous considerations. Independently of T_c, for $T_{ha,c} > T_c$ it follows that $R_t < R_r$, but for $T_c = T_{ha,c}$ the values of R_r are considerably lower than those of R_t: when more water is present in the cell ($T_{ha,c} > T_c$), the high capability of serpentine channels with trapezoidal cross-section to remove water decreases the ohmic losses, reducing the excess of water in the cathode. The opposite effect, that is, an increase of the ohmic losses, occurs when less water is present in the system ($T_{ha,c} = T_c$), due to an inappropriate membrane/electrode hydration.

For both PEMFC types, independently of reactant humidification temperature, a positive effect of T_c increase on cell performance, expressed as the maximum power density (MPD), was found, as can be seen in the histogram in Fig. 8(a). The increase of the fuel cell performance and limiting currents with the increase of the cell temperature can be explained by the increase of the diffusivity and the decrease of both mass transport and Nafion membrane resistances. The exchange current density also increases with the increase of fuel cell temperature, reducing activation losses. At fixed T_c, whereas $T_{ha,c}$ affects the performance of the cell with rectangular cross-section of the serpentine channels in a negligible way, the effect of $T_{ha,c}$ on the performance was pronounced on the cells with trapezoidal cross-section of the channels, positive for $T_{ha,c} > T_c$ and negative for $T_{ha,c} = T_c$, due to the higher ability of channels with trapezoidal cross-section to remove water. Summarizing, trapezoidal cross-section shape was more effective for $T_{ha,c} > T_c$, whereas rectangular cross-section shape was more suitable for $T_{ha,c} = T_c$. The potential at the MPD, however, is not constant. From the histogram in Fig. 8(b), which shows the power density (PD) at 0.5 V of PEMFCs operating at different operating temperature, it is more evident that the power density of the cells with rectangular cross-section shape of channels mostly depends on T_c and is near independent of $T_{ha,c}$. The PD at 0.5 V of the cells with trapezoidal cross-section shape of channels, instead, depends on both T_c and, particularly, on $T_{ha,c}$, at fixed T_c.

Effect of pressure

The effect of the operating pressure of the anode and the cathode sides on polarization and power density curves of PEMFCs with serpentine channels having trapezoidal and rectangular cross-section shape operating at 80/85/95 °C are presented in Fig. 9(a) and (b), respectively. By increasing the pressure of anode and cathode to 2 bar, the performance of both types of cells increases, and by increasing the cathode pressure to 3 bar, maintaining the anode pressure at 2 bar, a further slight increase of the performance can be observed. An increase of the limiting current with increasing pressure was observed for the cell with serpentine channels having trapezoidal cross-section. The open circuit voltage increases with increasing pressure, according to the Nernst equation. A reason for the enhanced performance is the increase of reactant gas partial pressure with increasing operating pressure, improving hydrogen oxidation and oxygen reduction reactions. Another reason for the improvement in the cell performance is the increase of the diffusivity of the reactant gases, which results in a decrease of the mass transport resistance problem. As can be seen in the histogram in Fig. 10, the effect of pressure on cell performance was nearly independent of the cross-section shape, only slightly higher for the cell with channels having trapezoidal and rectangular shape, due to the slight decrease of R_r with increasing pressure (see histogram in Fig. 11). The decrease of R_r has to be ascribed to a better water removal from the cathode at high pressure. R_t, instead, was nearly independent of pressure (Fig. 11). Indeed, at this operating temperatures (80/85/95) a satisfactory water management is obtained by the channels with trapezoidal shape, thus the pressure effect on R_t is not relevant.

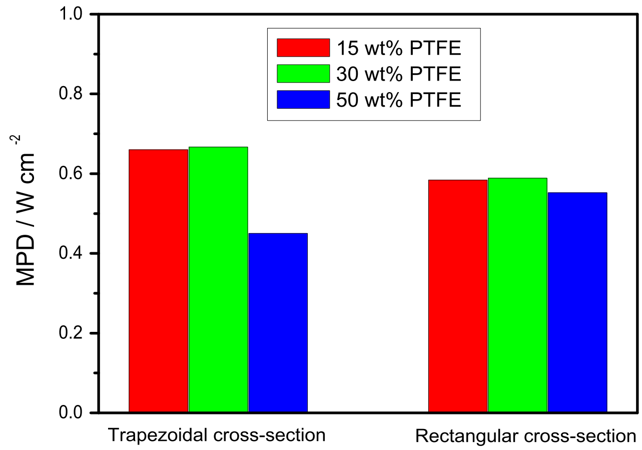

Fig. 13 – Histogram of the maximum power density of PEMFCs with serpentine channels having rectangular and trapezoidal cross-section at various PTFE content in the cathode MPL. $P_{O_2} = P_{H_2} = 1$ bar. $T_c/T_{hc}/T_{ha} = 80/85/95$ °C.

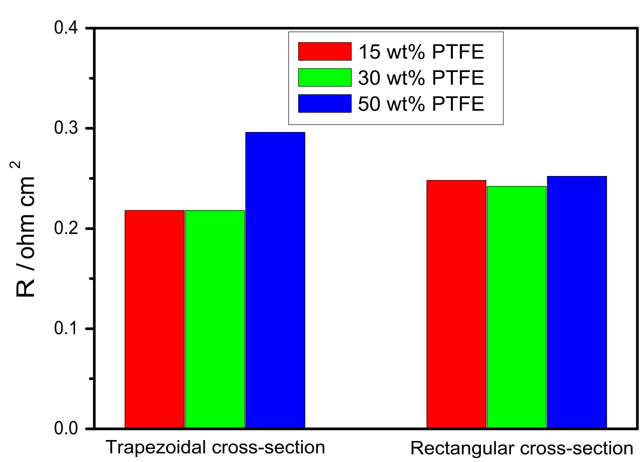

Fig. 14 – Histogram of the ohmic resistance of PEMFCs with serpentine channels having rectangular and trapezoidal cross-section at various PTFE content in the cathode MPL. $P_{O_2} = P_{H_2} = 1$ bar. $T_c/T_{hc}/T_{ha} = 80/85/95$ °C.

Effect of PTFE content in the MPL

The main role of the micro-porous layer is to improve water removal from the CL and to avoid the penetration of the catalyst ink through the GDM [23]. Although PTFE in the MPL mainly affects the water behaviour within the cell, its impacts on other parameters should also be considered for an appropriate cell design. Indeed, the increase of the PTFE content within the MPL decreases electrical conductivity, thermal conductivity, permeability and porosity of the MPL. The polarization and power density curves of PEMFCs with serpentine channels having trapezoidal and rectangular cross-section shape operating at 80/85/95 °C with various PTFE content (15, 30 and 50 wt%) in the MPL are shown in Fig. 12(a) and (b), respectively. For both the PEMFCs with different serpentine channel cross-section shapes the performance of the cells with a PTFE content of 30 wt% was similar to that of the cell with 15 wt% PTFE. This results can be due to a balance of the increase of positive (water removal) and negative (conductivity, porosity, etc) effect of the PTFE increase from 15 to 30 wt%. At high current density, however, both the cells with 30 wt% PTFE better performed than that with 15% PTFE. For a higher amount of PTFE in the MPL (50 wt%), instead, both the PEMFCs showed a decrease in the performance, which is more pronounced for the cell with serpentine channels having trapezoidal cross-section. For the cell with serpentine channels having rectangular cross-section, a slight decrease in the performance is related to negative effects of PTFE on the conductivity and porosity, overcoming the positive effect on water removal. For the cell with serpentine channels having trapezoidal cross-section water removal by PTFE turns on a negative effect (excess of water removal from the cathode due by both trapezoidal cross-section and PTFE), and has to be added to the other negative effects of PTFE, resulting in a remarkable worsening of cell performance. As can be seen in Fig. 13, the histogram of MPD of both types of cells showed similar performance for the cells with 15 and 30 wt% PTFE, but for the cells with 50 wt% PTFE a lower MPD was observed, particularly for the cell with serpentine channels having trapezoidal cross-section. The histogram of the ohmic resistance of the cells with different cross-section shape and different PTFE content (Fig. 14) is in good agreement with the results of cell performance, that is, a negligible effect of the increase of PTFE content from 15 to 30 wt% on R_r and R_t, a slight increase of R_r and a large increase of R_t for the cells with 50 wt% PTFE.

Conclusions

The effect of operational parameters and PTFE content in the MPL on the performance of PEMFCs with serpentine channels having different cross-section shape was investigated. Independently of the cross-section shape of serpentine channels, for both $T_{ha,c} = T_c$ and $T_{ha,c} > T_c$ a positive effect of T_c increase on cell performance was observed. At fixed T_c, for the cell with serpentine channels having trapezoidal cross-section a remarkable effect of $T_{ha,c}$ on cell performance was observed, positive for $T_{ha,c} > T_c$ and negative for $T_{ha,c} = T_c$, due to the high ability of serpentine channels with trapezoidal cross-section to remove water. For the cell with serpentine channels having rectangular cross-section, instead, the effect of $T_{ha,c}$ on cell performance was not significant. The use of serpentine channels with rectangular cross-section shape was more effective when $T_{ha,c} = T_c$, while the trapezoidal cross-section shape was more suitable when $T_{ha,c} > T_c$. At fixed T_c and $T_{ha,c}$ the cell performance increased with increasing anode and cathode pressures. The effect of pressure on cell performance was near independent of the cross-section shape of serpentine channels. At an operation temperature of 80 °C and high current density a fast decay of cell voltage was evident in the polarization curve of the cell with serpentine channels having trapezoidal cross-section, due to the negative effect of the decrease in pressure drop in the serpentine channels with this cross-section shape, decreasing the mass transport. By increasing T_c or pressure, the negative effect of decrease of the pressure drop in the serpentine channels on mass transport is attenuated by the increase of gas transport rate. For both the cells with different cross-section shape, the effect of the increase of the PTFE content from 15 to 30 wt% on cell performance was negligible; an increase of the limiting current for the cells with 30 wt% PTFE, however, was observed. When the amount of PTFE in the MPL was increased to 50 wt%, a slight negative effect on the performance of the cell with serpentine channels having rectangular cross-section was observed. The cell with serpentine channels having trapezoidal cross-section, instead, showed a considerably lower performance, due to an excessive water removal. These results clearly indicate that the cross-section shape of bipolar plate serpentine channels has to be take into account in the design of fuel cell systems.

Acknowledgements

The authors acknowledge financial assistance from Conselho Nacional de Desenvolvimento Científico e Tecnológico (Grants #553988/2006-2 and #554613/2010-7), FAPEAM and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior.

REFERENCES

[1] Antolini E. Recent developments in polymer electrolyte fuel cell electrodes. J Appl Electrochem 2004;34:563–76.
[2] Wang L, Husar A, Zhou T, Liu H. A parametric study of PEM fuel cell performance. Int J Hydrogen Energy 2003;28:1263–72.
[3] Amirinejad M, Rowshanzamir S, Eikani MH. Effects of operating parameters on performance of a proton exchange membrane fuel cell. J Power Sources 2006;161:872–5.
[4] Manso AP, Marzo FF, Barranco J, Garikano X, Garmendia Mujika M. Influence of geometric parameters of the flow fields on the performance of a PEM fuel cell. A review. Int J Hydrogen Energy 2012;37:15256–87.
[5] Li X, Sabir I. Review of bipolar plates in PEM fuel cells: flow-field designs. Int J Hydrogen Energy 2005;30:359–71.
[6] Feser JP, Prasad AK, Advani SG. On the relative influence of convection in serpentine flow fields of PEM fuel cells. J Power Sources 2006;161:404–12.

[7] Kumar A, Reddy RG. Effect of channel dimensions and shape in the flow-field distributor on the performance of polymer electrolyte membrane fuel cells. J Power Sources 2003;113:11–8.

[8] Yoon YG, Lee WY, Park GG, Yang TH, Kim CS. Effects of channel and rib widths of flow field plates on the performance of a PEMFC. Int J Hydrogen Energy 2005;30:1363–6.

[9] Sun W, Peppley BA, Karan K. Modeling the influence of GDL and flow-field plate parameters on the reaction distribution in the PEMFC cathode catalyst layer. J Power Sources 2005;144:42–53.

[10] Ferng YM, Su A. A three-dimensional full-cell CFD model used to investigate the effects of different flow channel designs on PEMFC performance. Int J Hydrogen Energy 2005;30:4466–76.

[11] Scholta J, Häussler F, Zhang W, Küppers L, Jörissen L, Lehnert W. Development of a stack having an optimized flow field structure with low cross transport effects. J Power Sources 2006;155:60–5.

[12] Scholta J, Escher G, Zhang W, Küppers L, Jörissen L, Lehnert W. Investigation on the influence of channel geometries on PEMFC performance. J Power Sources 2006;155:66–71.

[13] Shimpalee S, Greenway S, Van Zee JW. The impact of channel path length on PEMFC flow-field design. J Power Sources 2006;160:398–406.

[14] Lee S, Jeong H, Ahn B, Lim T, Son Y. Int J Hydrogen Energy 2008;33:5691–6.

[15] Manso AP, Marzo FF, Garmendia Mujika M, Barranco J, Lorenzo A. Numerical analysis of the influence of the channel cross-section aspect ratio on the performance of a PEM fuel cell with serpentine flow field design. Int J Hydrogen Energy 2011;36:6795–808.

[16] Ahmed DH, Sung HJ. Effects of channel geometrical configuration and shoulder width on PEMFC performance at high current density. J Power Sources 2006;162:327–39.

[17] Sun L, Oosthuizen PH, McAuley KB. A numerical study of channel-to-channel flow cross-over through the gas diffusion layer in a PEM-fuel-cell flow system using a serpentine channel with a trapezoidal cross-sectional shape. Int J Therm Sci 2006;45:1021–6.

[18] Owejan JP, Trabold TA, Jacobson DL, Arif M, Kandlikar SG. Effects of flow field and diffusion layer properties on water accumulation in a PEM fuel cell. Int J Hydrogen Energy 2007;32:4489–502.

[19] Zhu X, Liao Q, Sui PC, Djilali N. Numerical investigation of water droplet dynamics in a low-temperature fuel cell microchannel: effect of channel geometry. J Power Sources 2010;195:801–12.

[20] Paganin VA, Ticianelli EA, Gonzalez ER. Development and electrochemical studies of gas diffusion electrodes for polymer electrolyte fuel cells. J Appl Electrochem 1996;26:297–304.

[21] Rayment C, Scott S. Introduction to fuel cell technology; 2003.

[22] Herrera OE, Wilkinson DP, Mérida W. Anode and cathode overpotentials and temperature profiles in a PEMFC. J Power Sources 2012;198:132–42.

[23] Li H, Tang Y, Wang Z, Shi Z, Wu S, Song D, et al. A review of water flooding issues in the proton exchange membrane fuel cell. J Power Sources 2008;178:103–17.