PEM Fuel Cell Performance at Sub-zero Temperatures

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Abstract

In this work a study of the performance of a low power fuel cell at sub-freezing temperatures has been undertaken. Knowledge in this area is still scarce. After global characterization of the stack on a wide range of temperatures and relative humidity's the behaviour at negative temperatures (-5ºC -10ºC, -15ºC) has been established. Furthermore, performance was evaluated after the cell was submitted to cycles from -25ºC to + 25ºC. At the end of 10 cycles only marginal loss in performance was registered, when testing at + 2.5ºC and + 25ºC. On the basis of the obtained results a strategy for start-up and shut-down has been designed in order to be implemented for operation at low temperatures. A failure analysis of the membrane and catalyst layers and GDLs is under way in order to evaluate material degradation.

Keywords: *PEM fuel cells, sub-zero temperatures, degradation, performance*

1 Introduction

The Proton Exchange Membrane Fuel Cell (PEM FC), has shown rapid development in the last few years, with great increase in the ratio power density to specific power and demonstrated viable options for a variety of applications. Maturity of the technology demands increased stability and reliability in performance as well as a significant reduction in cost before full implementation.

PEM fuel cells usually operate at temperatures between 60 and 80ºC but in recent years, due to the interest in automotive, residential and portable applications, the question related to performance and durability of PEM fuel cells at low negative temperature has arisen great interest [1,2]. Non-freezing, freezing bound and free water are the states of water known to be present in the porous materials constituting the MEA fuel cell. Water initially generated at the cathode will freeze and block the path and transport of reactants in the catalyst and gas diffusion layers preventing cold start and sub-zero operation of the fuel cell. Furthermore, the properties of the proton exchange membrane electrolyte, typically Nafion, may be considerably altered at freezing temperatures.

In this work, performance of a low power fuel cell at sub-freezing temperatures has been studied with the objective of identifying the critical issues for operation in cold climates. Knowledge in this area is still scarce, but considered paramount in fuel cell design optimization and in the strategies for start-up and shut-down in the context of water removal in order to minimize the effects of phase transformations and volume changes of water during ample thermal cycles.

2 Experimental

The fuel cell used in this work, a PEM technology low power FC developed by SRE with the support of LNEG, has the following main characteristics:

- Passive management of water and heat for reliable performance (external humidification and system for temperature control are not required)
- Reduced system complexity
- Minimised power consumption of auxiliary components
- Optimised cell geometry and materials

Stack polarization curves were registered for a full characterization using a purpose-built test station described elsewhere. In a first approach, tests at temperatures between 5 and 55ºC were undertaken, integrating a range of variation for relative humidity from 29 to 80%. In a second phase the testing included negative temperatures down to -15ºC. Finally, tests were conducted using a temperature cycle between -25ºC and + 25ºC with polarization curves registered at + 2.5 ºC and + 25ºC, with the objective of evaluating the relationship between water management and the freeze/thaw cycles and the implications on cell performance in cold climates.

The stack used in this work was composed by 4 cells connected in series operating with pure hydrogen, and an air cathode which was designed to contribute to water removal and stack cooling. An air fan located at the edge of the cathode manifolds was used to provide an excess air stoichiometry condition. The stack uses own design flow field drawn on graphite plates from Schunk. The MEA uses a catalyst coated membrane from 3M and a gas diffusion layer (GDL/GDE) from Johnson Matthey. The geometrical active area was 3.8 cm^2.

Tests were conducted in a climatic chamber BINDER, at the various temperature and relative humidity's.

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3 Results

Results indicated that 60% relative humidity is associated to maximum performance on the fuel cell under study.
Figure 1 shows typical stack performance at 60% relative humidity over a wide temperature range covering from 55 to 5ºC.
Water management is done in a passive fashion; heat management is done on the basis of the injection of air at the cathode with the fuel cell showing good performances at relatively low currents where back diffusion towards the anode is favored.

The loss of performance with temperature increase is related to an increase in the membrane resistance which may correspond to loss of water on the anode side. Performances at temperatures lower that room temperature showed only slight decrease in power.

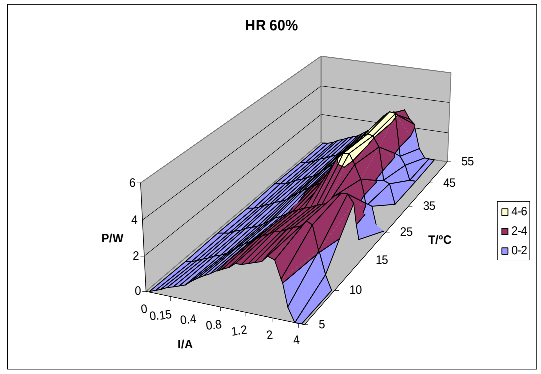


Fig. 1 Power vs current curves for PEM low power stack fed with hydrogen at 0.25 bar, 0.5 Lmin^{-1}, for a relative humidity of 60%. Cathode under excess air stoichiometry condition. Temperature varied from 55 to 5ºC.

Stability of the stack in terms of voltage decay was found to be minimal with periods of break-in of about 1 minute.

Drastic potential falls were registered for relatively low currents for operation at negative temperatures between – 5 and -15ºC. Typical polarization and power curve is shown in figure 2 for -15ºC.

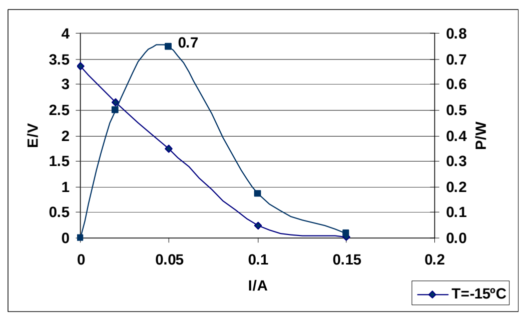
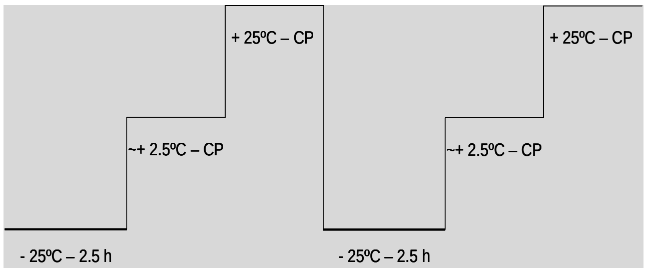
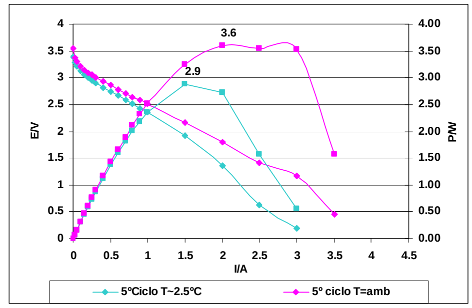


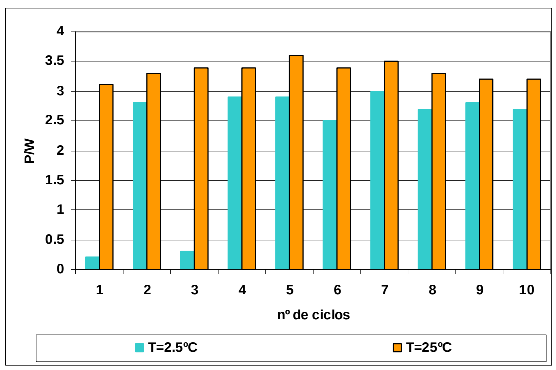
Fig. 2 Polarization and power curve a for PEM low power stack fed with hydrogen at 0.25 bar, 0.5 Lmin^{-1}. Cathode under excess air stoichiometry condition. Temperature -15ºC.

Taking into account the results obtained at negative temperatures and also those obtained at temperatures between 5 at 25ºC, a test cycle was defined in order to evaluate the performance of the cell.
The cycle is presented in figure 3a). The cell is kept at -25ºC for a residence time of 2.5 h, being taken afterwards to stages where the temperature was + 2.5ºC and + 25ºC. Polarization curves were performed at both temperature stages before the cycle was implemented again, for a total number of 10 cycles.





(a) (b)



(c)

Fig. 3 Temperature cycle from -25 to + 25ºC (a); polarization and power curves for the 5th cycle (b); maximum fuel cell power display by the fuel cell stack after stage at - 25ºC according to the temperature cycle (c).

4 Concluding Remarks

- It was verified that it was possible to "start-up" the stack at negative temperatures but current densities to demand depend on the temperature, being smaller the more negative the imposed temperature.
- After 10 cycles of residence at -25ºC for 2.5 h the fuel cell did not present significant loss of performance when tested at + 2.5ºC and then at + 25ºC.
- On the basis of the obtained results a star-up and shut-down procedure was designed for operation at low temperatures.
- A failure analysis of the membrane and catalyst layers and GDLs is under way in order to evaluate degradation of the various materials and components of the cell.

References

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