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Research Article

Influence of Hydrogen Humidity on the Performance of a PEMFC

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ABSTRACT

The utilization of hydrogen, particularly green hydrogen, is rapidly assuming a central role across a myriad of societal domains, spanning applications from space exploration, rocketry, and submarine propulsion to terrestrial transportation and residential energy needs. Among the exemplars of high efficiency in this domain stands the proton exchange membrane fuel cell. Effective management and control of the intricate reactions transpiring within the cell constitute paramount determinants of its performance. Notably, the interplay between the humidity of reactant gases and the moisture content within operational components exerts profound influence on the outcomes of generation processes, thereby modulating characteristic parameters including electrical voltage, current density, and power yield. This study rigorously investigates the operational performance of a commercial fuel cell under diverse environmental conditions, encompassing variations in humidity levels, pressure dynamics, and flow kinetics. Through meticulous analysis and discourse, the acquired results illuminate the multifaceted intricacies of fuel cell operation and elucidate their responsiveness to environmental variables, thereby contributing to the advancement of sustainable energy technologies.

Keywords: lorem ipsum Hydrogen PEMFC, Humidity, Operating conditions, Characteristic curve.

INTRODUCTION

Proton Exchange Membrane (PEM) hydrogen fuel cells represent a leading edge in sustainable energy technology, offering promising prospects for addressing the pressing challenges of energy sustainability and environmental conservation [1]. These fuel cells operate through an electrochemical process wherein hydrogen and oxygen combine to produce electricity, with water and heat as the only byproducts, rendering them inherently clean and environmentally friendly [2]. One of the key advantages of PEM fuel cells lies in their high efficiency and relatively low operating temperatures, making them suitable for a wide array of applications ranging from automotive propulsion to stationary power generation [3].

Their compact size, rapid start-up times, and ability to operate under variable loads further enhance their appeal for diverse deployment scenarios [4]. However, despite their numerous advantages, PEM fuel cells are not without limitations [5]. Chief among these are their reliance on expensive catalyst materials, particularly platinum, which can significantly elevate production costs [6]. Moreover, the sensitivity of PEM fuel cells to impurities in hydrogen fuel and the requirement for precise water management pose ongoing challenges in their widespread adoption [7]. To address these issues and unlock the full potential of PEM fuel cells, researchers have conducted extensive studies aimed at optimizing their performance, enhancing durability, and reducing costs [8].

These studies encompass a wide spectrum of research areas, including catalyst development, membrane materials engineering, water management strategies, and system integration [9]. Numerous research papers and scholarly

articles have contributed to advancing the understanding and development of PEM fuel cells [10]. For instance, studies by H. Wang et al. have focused on catalyst design and synthesis to improve the efficiency and durability of PEM fuel cells [11].

Similarly, research conducted by S. Mukerjee and J. McBreen has explored novel approaches to mitigate catalyst degradation and enhance the long-term stability of PEM fuel cell systems [12]. In summary, PEM hydrogen fuel cells represent a transformative technology with the potential to revolutionize energy systems and mitigate environmental impacts [13]. While they offer significant advantages in terms of efficiency, cleanliness, and versatility, ongoing research efforts are essential to address their limitations and accelerate their widespread adoption [14] [15] [16] [17].

For a long time, the Fuel Cell Unit and Systems Integration at CIEMAT have been working with various commercial polymer electrolyte fuel cells (PEMFC) from different manufacturers and origins. It has become evident in all cases that their properties are altered by operating conditions, fuel and oxidant composition, operating temperature and pressure of the fuel cell, and also influenced by the degree of ambient humidity.

Various tests have been conducted on a commercial fuel cell with the intention of studying the influence of operating conditions, particularly the humidity of the supplied gases, on its behavior under different operating conditions.

EXPERIMENTAL PART

The fuel cell studied is a Horizon H-300, supplied by H2Planet, and consists of 60 cells, capable of delivering up to 300 W of power. This fuel cell has a controller that regulates the air supply to the cathode and adjusts the speed of the fans to maintain the cell temperature below the maximum operating temperature of the membranes. In addition to temperature control, the controller periodically opens a purge valve for a very short time to expel any accompanying components with the hydrogen, and also, with the same period, causes a short circuit to keep the components in perfect condition. These two actions lead to the appearance of some data in the records corresponding to these moments, which have been removed from the overall data to minimize the noise produced in the signals

The trials have been conducted at a testing station capable of operating PEMFCs up to 1 kW of power, with the ability to supply the devices and control the flow rates of pure hydrogen or a gas mixture, and to work under different pressure conditions. The station is controlled by a program developed in Labview in our laboratory, allowing the setting of different operating variables and the storage of data for all of them and their evolution throughout the trials. These trials did not employ mixtures, and only hydrogen was used as fuel, supplied from a bottle (grade N48) provided by Air Liquide, with the flow rate measured using a flow meter (Bronkhorst), and ambient air as the oxidant, automatically supplied by the fuel cell stack's fans. To regulate the fuel cell's consumption, an electronic load HH PL1000 was used, also controlled by the program. The trials conducted were of two types. The first was obtaining the I-V characteristic curves through steps where the current intensity is first set at increasing values and then decreasing ones, with the data for stack voltage and generated energy, along with station parameters, being stored. In different trials, the humidity of the supplied hydrogen was varied by bubbling it through a humidifier with water at different temperatures.

Figure 1. PEMFC Horizon and test station used in the tests.

RESULTS AND DISCUSSION

Curves were obtained operating under different conditions, the first of which were those indicated by the manufacturer: dry hydrogen supplied to the anode at constant pressure (0.5 bar), and automatic ambient air supply

to the cathode. As in other curves, the effect of humidity is most noticeable in the initial stage. The stack had been inactive for several days, causing the membrane's humidity to decrease with ambient temperature and humidity. Upon starting the measurements to obtain the curve and increasing the current intensity, there is a sudden drop to lower voltages due to the increase in current-dependent polarizations, mainly activation polarization. Subsequently, the voltage gradually recovers as the components (the membrane) become saturated with generated water and optimize their properties. As the water content increases, the internal resistance of the MEA slightly decreases, leading to a decrease in ohmic polarization and an increase in stack voltage. In the following stages, the starting point finds the membrane saturated, thus maintaining or slightly increasing the voltage at each intensity where a measurement is taken.

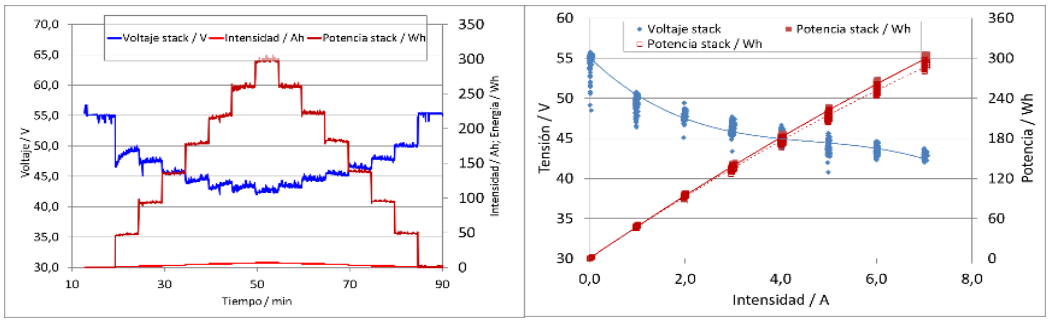

Figure 2. I-V curve data. Left: depending on the operation time. Right: I-V curve (all data)

In the figure, data has been collected over time, showing the characteristic curve with stack voltage data and energy generated based on current intensity. There's a clear difference between the data obtained in the first part of the curve and those obtained in the second part (decreasing intensity). There's a clear reason for this, which is the progressive humidification of the membrane during the increase in intensity, especially in the first step, where the current intensity is fixed at 1 A, and where reactions and water generation begin, which is absorbed into the membrane. To test the influence of hydrogen humidity on the performance of the cell, several tests were conducted by feeding saturated hydrogen at various temperatures (60, 70, and 80 ºC). In the tests where a characteristic curve was obtained, as shown in the following figure, no differences were observed between the data obtained with dry hydrogen and saturated hydrogen. The first curve was obtained without saturating the hydrogen, and the second one with gas saturated at 60ºC. The curves obtained only show a slight difference in the final points.

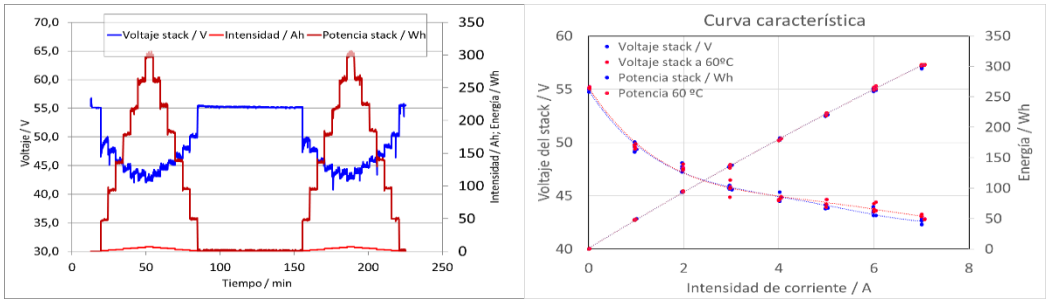

Figure 3. I-V curve data. Left: depending on the operation time. Right: I-V curve (all data)

In both cases, there is an increase in voltage at each current step's initial points, while during the descent, there is a slight decrease in voltage during the stabilization of the points. This variation is due to membrane humidification. On one hand, the amount of water produced is proportional to the current generated in the cell, while the airflow passing through the cathode depends on the cell's temperature. If the airflow is very high, water carry-over increases, causing a decrease in membrane water content, hence a slight increase in internal resistance, thereby increasing the cell voltage.

The evolution of stack voltage under stable conditions over a longer period of time has been studied. The cell has been kept operating at a constant current intensity of 5 A, first under the cell's operating conditions, i.e., closed anode, feeding dry hydrogen to the anode at an inlet pressure of 0.5 bar, with temperature controlled automatically by the cell. And then, feeding saturated hydrogen at 80°C.

The behavior is similar to that of characteristic curves: when fixing the intensity at 5 A, there is a sharp decrease in voltage due to activation polarization and ohmic polarization, which partially recovers due to the progressive absorption of water generated in the membrane and the decrease in internal resistance. After this initial step at constant intensity, the fuel cell is kept on pause without fixing any intensity.

During this period, with no water generation but maintaining an airflow, part of the water from the components is carried away by the operating air, causing a slight increase in internal resistance and a very slight decrease in stack voltage. Finally, in the third part of the test, the same intensity of 5 A is applied to the cell again, but this time the fed hydrogen is passed through a saturator at 80°C to increase its humidity.

The cell's behavior is similar to the first section, although humidification occurs more quickly, and the voltage increase is somewhat higher than in the first case, indicating that membrane saturation occurs more rapidly thanks to the excess water introduced into the anode, and it seems that saturation is also more complete as the voltage increases slightly more than with dry hydrogen. In the final part of the test, an effect derived from this excess fed water is observed, as a few minutes later, the cell voltage begins to decrease, counteracting the previously mentioned effect.

This variation is explained due to the accumulation, on the anodic side, of the excess fed water, leading to membrane oversaturation on that side and water deposition on the reaction surface, causing an increase in internal resistance and a decrease in stack voltage.

Another test has been conducted by reversing the order of the previous test; the cell has been kept operating with saturated hydrogen at 80°C for about 50 minutes, and then switched to dry hydrogen supply.

The evolution is similar to the previous case, but in this instance, there is no noticeable decrease in voltage due to water oversaturation on the anodic side. During the operation time, the voltage was maintained once stabilized. When the water supply to the hydrogen ceases, only a small difference is observed, manifested by a slight increase in stack voltage, indicating that there is some oversaturation and that when the water supply to the anode ceases, this excess disappears, and the internal resistance decreases slightly, causing the stack voltage to rise slightly

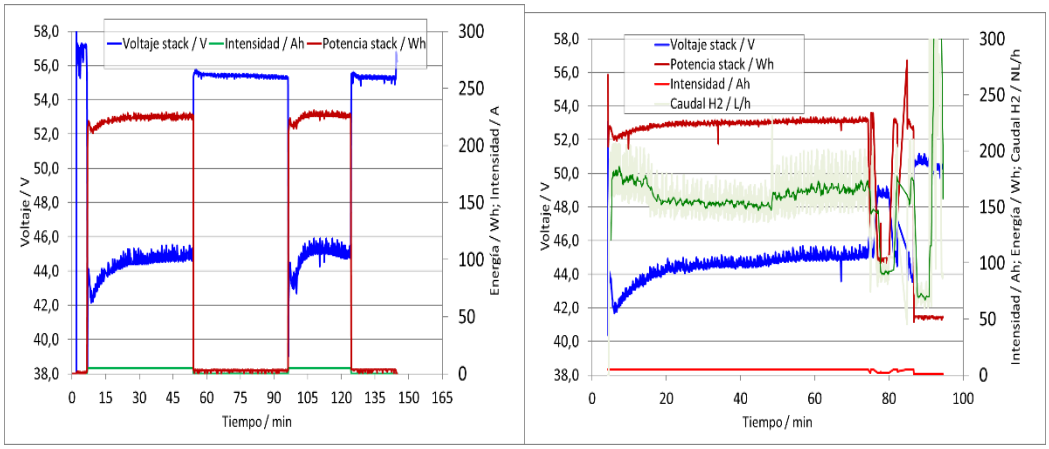

Figure 4. Operation data. Left: Feed first dry and then saturated. Right: Feed first saturated and then dry

Several additional tests have been conducted aimed at determining the influence of humidity on the performance of this fuel cell. Calculations have also been performed to determine the values of the polarizations and their dependence on the humidity of the supplied hydrogen.

CONCLUSIONS

Different tests have been conducted to verify the influence of humidity on the performance of a commercial polymer fuel cell. Dry hydrogen is supplied, and the ambient air is used, maintaining the relative humidity of the air at all times.

During normal operation, the generated water is absorbed into the membrane until it reaches a maximum value, corresponding to its saturation. The supply of cathodic air, besides providing the reaction oxygen, removes the excess heat generated in the reaction and the water formed at the cathode, maintaining the cell at an appropriate humidity

level for its operation. The ambient air humidity does not influence this balance due to the small variation it may undergo compared to the large amount of water formed during the reaction.

Additional humidity to the anodic hydrogen has a small influence on the cell's operation, which is only observed at high saturation temperatures, as it increases the membrane's water content, increasing its internal resistance and therefore decreasing the voltage and energy generated in the stack.

REFRENCES

[1] MADHESWARAN, Dinesh Kumar, et al. Powering the future: progress and hurdles in developing proton exchange membrane fuel cell components to achieve department of energy goals—a systematic review. Sustainability, 2023, 15.22: 15923.

[2] STAMBOULI, A. Boudghene. Fuel cells: The expectations for an environmental-friendly and sustainable source of energy. Renewable and Sustainable Energy Reviews, 2011, 15.9: 4507-4520.

[3] ERDINC, Ozan; UZUNOGLU, Mehmet. Recent trends in PEM fuel cell-powered hybrid systems: Investigation of application areas, design architectures and energy management approaches. Renewable and Sustainable Energy Reviews, 2010, 14.9: 2874-2884.

[4] ALIZADEH, Mohammed I., et al. Flexibility in future power systems with high renewable penetration: A review. Renewable and Sustainable Energy Reviews, 2016, 57: 1186-1193.

[5] DAUD, W. R. W., et al. PEM fuel cell system control: A review. Renewable Energy, 2017, 113: 620-638.

[6] AGYEKUM, Ephraim Bonah, et al. Research progress, trends, and current state of development on PEMFC-new insights from a bibliometric analysis and characteristics of two decades of research output. Membranes, 2022, 12.11: 1103.

[7] MAO, Jiahao, et al. A review of control strategies for proton exchange membrane (PEM) fuel cells and water electrolysers: From automation to autonomy. Energy and AI, 2024, 17: 100406.

[8] ABOKHALIL, Ahmed G.; ALOBAID, Mohammad; MAKKY, Ahmed Al. Innovative approaches to enhance the performance and durability of proton exchange membrane fuel cells. Energies, 2023, 16.14: 5572.

[9] LEE, Anna; ELAM, Jeffrey W.; DARLING, Seth B. Membrane materials for water purification: design, development, and application. Environmental Science: Water Research & Technology, 2016, 2.1: 17-42.

[10] OJEMAYE, Mike O.; OKOH, Anthony I. Global research direction on Pt and Pt based electro-catalysts for fuel cells application between 1990 and 2019: A bibliometric analysis. International Journal of Energy Research, 2021, 45.11: 15783-15796.

[11] H. Wang, Yanghua, et al. Atomically dispersed metal–nitrogen–carbon catalysts for fuel cells: advances in catalyst design, electrode performance, and durability improvement. Chemical Society Reviews, 2020, 49.11: 3484-3524.

[12] MUKERJEE, Sanjeev. Fundamental investigations of durability at a polymer electrolyte-electrode Interface. 2008.

[13] WANG, Yun, et al. PEM Fuel cell and electrolysis cell technologies and hydrogen infrastructure development–a review. Energy & Environmental Science, 2022, 15.6: 2288-2328.

[14] ATEIA, Mohamed; WEI, Haoran; ANDREESCU, Silvana. Sensors for emerging water contaminants: overcoming roadblocks to innovation. Environmental Science & Technology, 2024, 58.6: 2636-2651.

[15] CIGOLOTTI, Viviana; GENOVESE, Matteo; FRAGIACOMO, Petronilla. Comprehensive review on fuel cell technology for stationary applications as sustainable and efficient poly-generation energy systems. Energies, 2021, 14.16: 4963.

[16] SCHMITTINGER, Wolfgang; VAHIDI, Ardalan. A review of the main parameters influencing long-term performance and durability of PEM fuel cells. Journal of power sources, 2008, 180.1: 1-14.

[17] OZEN, Dilek Nur; TIMURKUTLUK, Bora; ALTINISIK, Kemal. Effects of operation temperature and reactant gas humidity levels on performance of PEM fuel cells. Renewable and Sustainable Energy Reviews, 2016, 59: 1298-1306.