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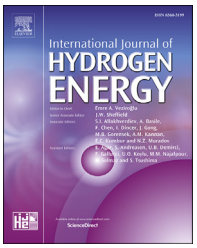

Operando current mapping on PEM water electrolysis cells. Influence of mechanical stress

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ABSTRACT

Proton Exchange Membrane Water Electrolysis (PEM WE) is considered as a key technology for large scale storage of renewable electricity, using hydrogen as an energy vector. To achieve economically viable MW-scale storage units, there is a strong trend to increase both current density and electrode surface area. Such upscaling raises concerns regarding the homogeneity of compression forces and current lines distribution throughout the electrolysis stack. Mechanical and thermal stresses resulting from any heterogeneity can result in faster local ageing and accelerated degradation. Thus, there is a major interest to measure and understand the nature of such coupled heterogeneities. We report here on results obtained with a non-disturbing tool for the current and the temperature mapping of PEM WE electrodes. A complete description of the setup is discussed in order to avoid some mapping artefacts that could come from the measurement device. Measurements made on 250 cm^2 surface area cells show that the clamping pressure homogeneity over the entire geometrical surface area of the cell is one of the first mandatory requirement for an appropriate operation of electrolysis cells. In particular, it was found that even homogeneous pressure distribution could lead to excessive current maldistribution in some cases, due to overriding inhomogeneous electric contacts. This situation has been corrected by using non-flat end plates and/or an accurate thickness of the gaskets. Current mapping has been performed. Results are discussed.

Introduction

Hydrogen is considered as an appropriate energy vector to implement a carbon-neutral economy and to face to the demand for increasing amounts of clean primary energy sources [1]. Hydrogen can be used under various forms and for a wide panel of applications. However, today, hydrogen production is not sustainable and compatible with this perspective of a carbon free energy society. Approximately 96% of the global hydrogen demand is satisfied by fossil fuel transformation, mainly Steam Methane Reforming (SMR) of oil and natural gas, and coal gasification. These processes are from far the main techniques used, but also the most polluting ones [2]. On the contrary, water electrolysis offers a sustainable and efficient way to produce hydrogen from abundant liquid water

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and clean energy sources. Accounting for the major part of hydrogen produced by water electrolysis, alkaline technology is the most mature, and commercially advanced [3], whereas Solid Oxide technology is mostly under development. But PEM (Proton Exchange Membrane) electrolysis is now on the way to become cost-competitive. The technical advances achieved up to now enable to reduce the system cost and to consider optimistic perspectives [4,5]. However, one of the critical point is related to system costs compared to life expectancy [6]. On one hand, the use of an acidic electrolyte and the high operating potential of the anode and temperature, and on the other hand, material optimization, especially membrane thickness, are now coming to a harsh point where a lot of efforts are required for small improvements.

To optimize PEM water electrolysis technology and extend the lifetime of the cells, there is a need to better understand the ageing of individual cell components. First of all is the MEA (Membrane Electrode Assembly), in the closest conditions from the real stack operation. Then focusing on the R&D effort within the resulting conclusion to finally implement the more fundamental breakthroughs in terms of coatings, porous transport layers, membranes and catalysts accordingly. That is the way to make those advances significantly efficient.

Having this in mind, we investigated the current distribution on a large surface area (250 cm^2, circular shape) PEM water electrolysis single cell, a surface sufficiently large to analyze mechanical, thermal and fluidic management constraints that could be encountered on a large commercial stack [7–9], and subjects of intense developments from industrials.

As explained above, particular focus will be made on ageing and degrading conditions.

An important preliminary work has been done on the experimental set-up in order to implement the current distribution visualization device in the cell. The internal segmentation of the components has been first considered as the path that the electrons should follow. Quite inspiring work was done for fuel cells and we have found some correlations with our application. Various methods have been previously studied for PEM FC [10] (very few on PEM electrolyzers): MEA segmentation [11,12], flow field segmentation [13,14], shunt resistance [15], segmented PCB-based Bipolar Plates (BPP) [16–18], S++® current measurement plates [19,20]. Especially a technique derived from the one of Ghosh et al. [15] has been considered to be adapted for our electrolysis purpose for its flexibility and easy evolution. But finally, given uncertainties of implementation, the most viable approach to stick as close as possible to real stack operation appears to be by using commercialized S++® current measurement card.

As far as we know this communication is the first to establish and use such a current and temperature mapping device for PEM WE. This communication will detail the experimental set-up used, and then describe an application of the tool for a local *operando* study of the cell dysfunction.

Experimental

Cell specifications

In order to perform reliable *in-situ* and *operando* measurements, we used a fragmented cell. Several specifications must be fulfilled to perform not too intrusive measurements. From the mechanical viewpoint, the fragmented cell should be robust and rigid enough to support 1.8 MPa mechanical clamping pressure and also to transfer this compression constraint completely to the MEA, without absorbing any substantial part of the mechanical force. To perform testing under pressure, we fixed a minimum of 5 bars internal pressure at the cathode. From the fluidic viewpoint, the device must first be watertight with the ambient and internally: the introduced measurement device must not affect water- and gas-tightness at the risk of creating hazardous leakage and mixtures. Lastly, electrically speaking, it is needed to drain out the voltage for each segment independently of the running cell power.

Experimental set-up

The single cell used to perform our measurements was initially designed for MEA characterization at low current densities ($j < 0.5$ A/cm^2). Consequently, some mechanical optimizations were required to obtain a satisfying electrochemical behavior at higher current densities. The cell is 250 cm^2 active area, and composed of various elements detailed in Fig. 1. End plates, current collectors and sealant gaskets have been resized and redesigned. Design is circular as in most cases for PEM WE mainly due to its robustness towards high gas pressures and potential leaks. Porous Transport Layers (PTLs) are made of two main pieces, eg meshed titanium wires layers and porous titanium sinters.

A gold-plated electronic Printed Circuit Board from S++® Simulation Services Company has been used for current density measurements. A specific circular design of the S++® Current Scan Shunt measurement device was developed. This type of measurement relies on the measurement of the voltage drop over calibrated micro-resistances. The cell shown in Fig. 2 contains 64 electrically independent segments of equal surface area (3.89 cm^2 each) positioned radially from the center. The interest of this design is that comparative measurement can be performed between inlet and outlet, center and edges, along different radii.

In a stack configuration, current propagation is supposed to be isotropic along the stack and on the whole active area, thus current lines are supposed to be perpendicular to the plan of the assembly. This is not true at both stack ends, where we must consider a recombination of the current lines within the plan of the last Gas Diffusion Layer (GDL) and the last Bipolar Plate (BPP): because of current lines convergence in one particular point of the current collector. Comparatively, in a single cell, this recombination is likely to happen at both sides of the MEA, and may lead to inhomogeneous current lines distribution. To avoid this artefact while we effectively measure this distribution, 4 mm thick graphite plates, tailored by Fraunhofer ISE, are added on both sides of the S++® device (Fig. 3). They are segmented with the same pattern than the S++® card (cf Fig. 4), and are supposed to simulate upstream and downstream cells, without affecting the current lines distribution caused by the upstream part of the system, mostly the first MEA. Because of the elevated working potential of the anode during electrolysis, this set-up can be implemented only on the cathode side to avoid the graphite

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