Design, Construction and Performance Evaluation of a Solid Polymeric Electrolyzer

S. Citalán-Cigarroa, A. Rodríguez-Castellanos, C. Castro-Morales, O. Solorza-Feria.

Centro de investigación y de Estudios Avanzados del I.P.N., Av. IPN 2508, D.F., México, 07360.
Tel: 57473800 ext. 4473, e-mail: scitalan@cinvestav.mx

ABSTRACT

In this paper the design, construction and characterization of a Solid Polymer Electrolyte (SPE) as water electrolyzer is presented. As anode, titanium grade 2 with geometric surface area of 12 cm^2 impregnated with a mixture of oxides of RuO-IrO2/Ti was used. This material offer advantages in terms of stability, resistance to extreme corrosion and good electrical conductivity, determined by chronoamperometry experiments. Commercial carbon black supported Pt (Pt/C 20wt%) was used as a cathode electrode. The electrolyzer uses DC power which was supplied by a 30W solar panel. The hydrogen produced was fed to a 5W PEM fuel cell.

Keywords: Design; Electrolyzer; Stack Fuel Cell;

1. Introduction.

Hydrogen has been considered as an ideal energy carrier to support sustainable energy development, which can be effectively produced through fossil-fuel-based process. However, the development of renewable hydrogen production technologies to replace fossil fuel-based hydrogen production methods is an important step towards a sustainable hydrogen economy [1,2].

Up to now, most of the research and development on water electrolysis related to renewable hydrogen production projects have focused on alkaline electrolysis systems and PEM electrolysers. The PEM electrolyzers are more advantageous due to their ecological cleanness, easy maintenance, compactness. Recently, most studies on PEM electrolysis emphasize on the development of new catalysts. However, the development of technologies for renewable hydrogen production methods to replace hydrogen production based on fossil fuels is an important step towards sustainable hydrogen [3-5].

2. Experimental conditions.

2.1 *Preparation of surface titanium.*

The current collectors are made of titanium foil grade 2. These were polished using mechanical and electrochemical methods for removal of oxides. The RuO_2 ink was prepared with Hexane (Aldrich), it was painted with brushed over a titanium foil and was heating in an oven at 250 ºC for 15 minutes and repeating 10 times until catalysts loading was reached of about 0.5 mg cm^{-2}.

2.1 *Preparation of membrane electrode*

The Nafion 117 (SPE electrolyzer) and 112 (fuel cell) membranes were treated before being used in order to clean and improve ions transfer. The membrane was first preheated in pure water at 80 ºC and then transferred to a solution of 3% H_2O_2 at 80 ºC for 1 h to remove organic impurities. After these step, the membrane was vigorous washed by deionized water. The membrane was boiled at 80 ºC for 1 h using 2M H_2SO_4 solution, for ion exchange the membrane completely with protons and removes the inorganic impurities. After these steps, the membrane was washed by deionized water and stored in deionized water, the membrane became active and ready to be used [6-8].

2.3 *Preparation of membrane electrode assemblies for the electrolyzer.*

The catalytic inks were prepared by mixing the corresponding catalysts, $70RuO_2$-$30IrO_2$ (Aldrich 99.99%) and PtC 40 wt%, as anode and cathode respectively, with 2-propanol (Aldrich) and 5% Nafion solution (Aldrich). The corresponding ink was then brushed over a stainless steel mesh with geometrical surface area of 12 cm^2, which was used as gas diffusion medium. The anode and cathode were then hot-pressed using Nafion 117 as solid electrolyte at 120 °C during 90 seconds at 16 kg cm^2. The electrolizer was feed with deionized water and the performance evaluated trough galvanostatic polarization in a PARSTAT 2273 and 2273 Power Booster system (KEPCO BOP 20-10M). A schematic representation of the SPE electrolyzer and their components are shown in Figure 1. The cell was made of acrylic pieces with flow fields machined using a computer numerical control (CNC) milling and CNC laser cutter. Titanium sheet acted as current collector in both cases (i.e., anode-Ti/RuO2, and cathode –Ti/Pt/C).

Figure 2. Stainless steel mesh / RuO2 and IrO2.

Figure 3 shows the components of an experimental electrolyzer cell. The MEA was inserted into the electrolyzer cell for testing. An electrolyzer cell is shown in Figure 4. The performance of electrolyzer was determined by galvanostatic polarization in a PARSTAT 2273 and 2273 Power Booster system (KEPCO BOP 20-10M). The electrolyzer was fed with deionized water.

Figure 3. SPE electrolyzer Components

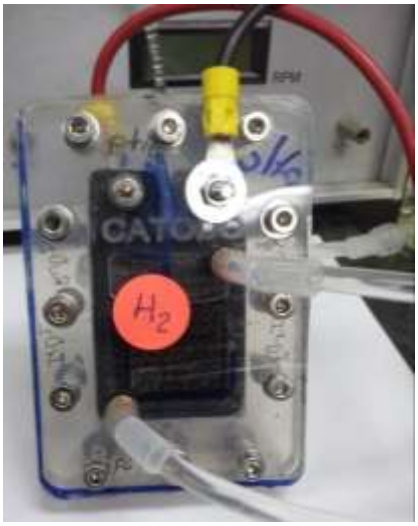

Figure 4. Electrolyzer cell

2.2 *Preparation of membrane electrode assemblies for the fuel cell stack*

The MEAs of fuel cell stack were prepared using a commercial carbon cloth as gas diffusion catalysts (GDC) with geometrical surface of 9 cm^2. Previously to assembled, the GDC was covered with a thin layer of Nafion 5 % solution (Aldrich). Each single MEA was prepared by hot-pressing of the catalysts GDC, in order to prevent ohmic resistance and to form good contact between the electrodes and the polymer membrane. The MEAs were inserted into the fuel cell testing system. A fuel cell stack is shown in Figure 5. The performance of fuel cell was determined by potentiostatic polarization in a fuel cell stack test system (electrochem 890e). The anode was feed with H_2 and air at the cathode side, without pressure.

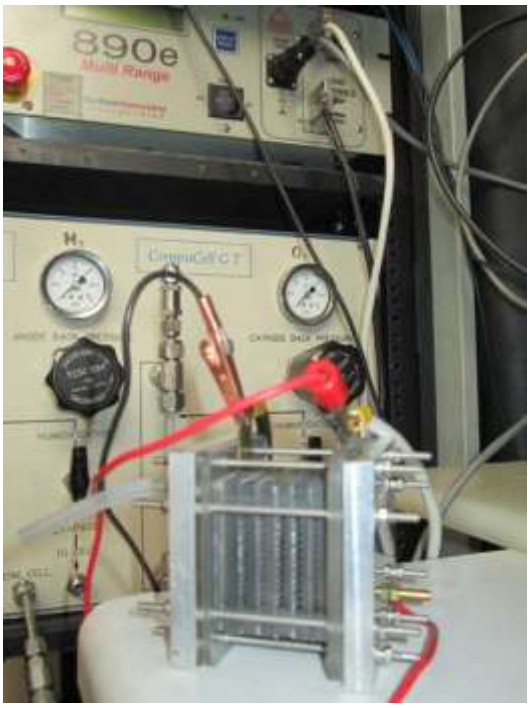

Figure 5. A fuel cell Stack

3. Results and discussion

Figure 6 shows chronopotentiometric curves obtained when current pulses are applied during 180 sec. The constant voltages are suggesting the reproducibility of electrochemical processes occurring on its surface. Carbon supported platinum nanoparticles was used at the cathode of PEM electrolyzer for the hydrogen evolution reaction. At the anode mixed oxides RuO_2 and IrO2 was used for the Oxygen evolution reaction. Current-voltage polarization curve measured at 30 °C on PEM water electrolysis cell is illustrated in Figure 7.

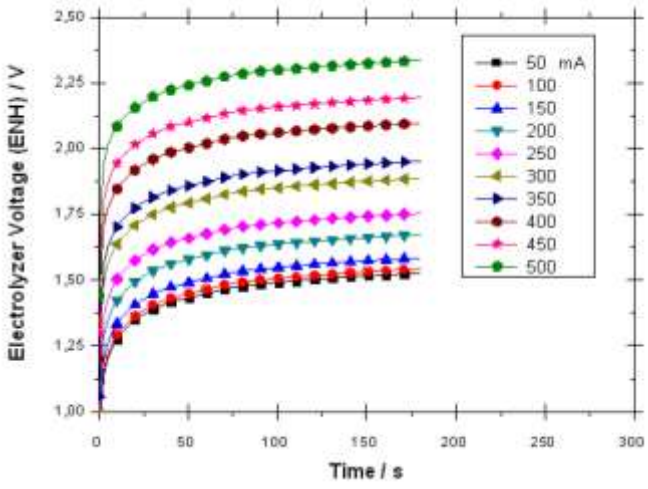

Figure 6. Electrode potential response during the application of pulses of different current at 25°C.

The hydrogen produced during the electrolysis operation is collected in glasses containers. The theoretical yield of hydrogen is calculated using Faraday laws equation given by [9].

$$W_{H2} = \frac{ItM}{FM_e}$$

Where w is the weight of the hydrogen produced at the cathode, I the applied current intensity (A), t the time (s), M the molecular weight of hydrogen (g mol^{-1}), F the Faraday's constant (96485 C mol-1) and N_e the number of electrons involved in the reaction.

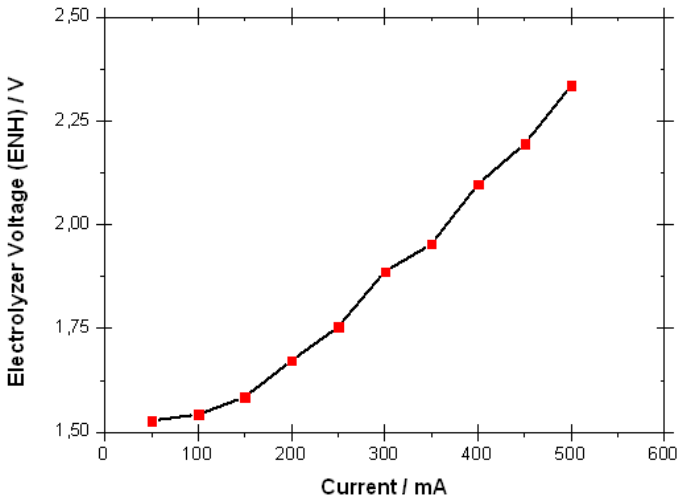

Figure 7. Polarization curve measured using 117 Nafion membrane at 30 °C.

The experiments were performed for 180 s at currents of 50, 100, 150, 200, 250, 300, 350, 400, 450, 500 mA at temperature 30 °C, and the produced hydrogen and oxygen gases were collected in separate containers. The yield of the hydrogen was calculated for a production of 25.8 ml h^{-1} at 50 mA.

3.1 Fuel cell Performance.

The polarization and power density curves for a PEMFC stack using a Nafion 112 membrane are presented in Figure 8. A power output closed to 3.42 W was determined.

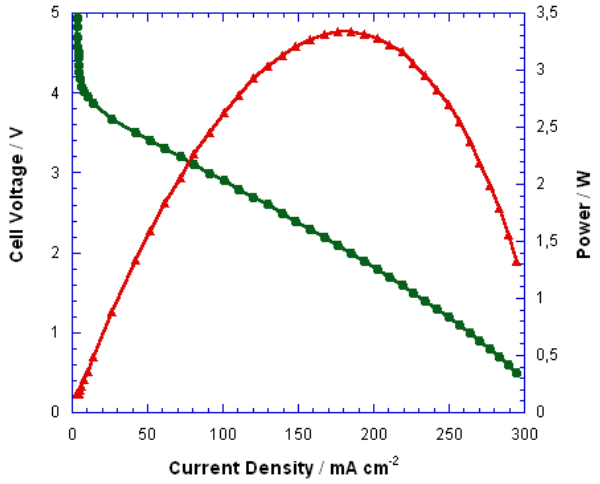

Figure 8. PEMFC performance polarization curves and power density evaluated at 30°C.

4. Conclusions

In this work, we have tested various electrocatalysts materials that were integrated in the membrane-electrode assemblies as part of an electrolyzer which allow us to build a demonstrative and efficient solar-hydrogen prototype.

5. Acknowledgements

The authors acknowledge the financial supports from the National Council of Science and Technology of Mexico, Conacyt (FOINS/75/2012). Also acknowledges The University of Texas TAMU-Conacyt for providing help and support in the design and development (Alloy nanocatalysts for fuel cell electrodes).

6. Referentes

[1] O. Fakuk Selemet, Fatih Becerikli, Mahmut d. Mat, Yuksel Kaplan, *Int.J. Hydrogen Energy*, 36, 11480, (2011).

[2] Luis M. Gandia, Gurutze Arzamendi and Pedro M. Dieguez. *Renewable Hydrogen and Technologies, Production, Purification, Storage, Application and Safety*,Elsevier, pp. 6-10, ISBN:978-0-444-56352-1(2013)

[3] H. Zhang, Shanhe Su, Guoxing Lin, Jincan Chen, *Int. J. Electrochem. Sci*., 7, 4143, (2012).

[4] D. Webb, S. Mùller-Hols, *Journal of Power Sources* 103, 54,(2001)

[5] M. Carmo. David l. Fritz, Jurgen Mergel and Detlef Stolen, *I. J. Hydrogen Energy* 38, 4901, (2013).

[6] J. B. Benzinger, M. B. Satterfield, W. H.J. Hogarth, J. P. Nehlsen, I. g. Kevrekidis, *J. Power Sources*, 155, 272, (2006).

[7] N. Monoranjan, K. Chandra-Sarma and N. Gopil-Singh., *I. J. Computer Application*, 48, 975, (2012).

[8] L.G. Arriagaa, W. Martínez, U. Cano, H. Bluda, *Int. J. Hydrogen Energy*, 32, 2247, (2007).

[9] K. Mazloomi1,*, Nasri b. Sulaiman1, H.Moayedi2, *Int. J. Electrochem. Sci.*, 7, 3314, (2012).

[9] Andrés Rodríguez Castellanos, Ernesto López Torres, Omar Solorza Feria, *J. Mex. Chem. Soc*., 51, 55, (2007).