Study of the behavior of electrodes with corrugated channels for alkaline electrolysis of water (P-18H)

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1. Introduction

Hydrogen, as a clean energy carrier, is presented as one of the main candidates to replace fossil fuels, mitigating greenhouse gases and their implications for climate change. It can, in turn, be one of the tools to achieve the sustainable development goal 7 of the United Nations, which proposes "ensure access to affordable, reliable, sustainable and modern energy". It could be said that it is a vital component to achieve zero emission economies, attaining the sustainable development of the residential and industrial sectors.

A wide variety of processes are available for the production of hydrogen, which depending on the raw material used, can be divided into two main categories: fossil fuels and biomass or water. Among the methods that use only water as raw material, are electrolysis, thermolysis and photoelectrolysis. Electrolysis, however, is a very efficient technique for splitting the water molecule as a well-established and well-known method. The main types of water electrolyzers are: alkaline, proton exchange membrane and solid oxide, they differ mainly in terms of the type of electrolyte used in the electrolytic cells.

Currently, research and development activities are focused on increasing the operating current density as well as improving efficiency of electrolyzers. Alkaline water electrolysis remains a promising option for commercial applications and further development. Research is currently being carried out on electrodes, electrolytes, ionic transport, formation and detachment of bubbles.

Since it is in the interest of industry to lower the production costs of these equipments, researchers are studying the behavior of other materials. Along that line are the works mentioned below.

Olivarez – Ramirez et al., studied the hydrogen evolution reaction (HER) on stainless steels 304, 316 and 430 looking for a more economic material with nickel in its chemical composition. Based on the results obtained, it is concluded that stainless steel 316 is the best material due to its high nickel content of 12%. [1]

In order to find the optimal operating conditions for hydrogen production, Nassar et al., evaluated electrodes of stainless steels 316, 409, 410 and 430 at working temperatures between 60 and 90ºC and its corrosion rate. Stainless steel 410, due to its high nickel content of 25%, presented a better performance in hydrogen generation rate and corrosion resistance, throughout the range of tested temperatures. The increase in temperature favors the hydrogen production in all types of stainless steel analyzed. [2]

D'Arc de Fatima Palhares et al., evaluated a cylindrical electrolytic cell to produce green hydrogen, which was connected to a photovoltaic panel of 20 W. The electrodes were of 304 stainless steel and the electrolyte was sodium hydroxide. Certain voltajes (2; 2.7 and 3.4) and electrolyte concentrations (2; 3.5 and 5 [mol/L]) were studied. It was observed that at the highest values, both variables increased the flow of hydrogen production. The content of air in the sample of hydrogen obtained, under the operating conditions of 3.4 V and NaOH 5 [M] is 0.85%. [3]

This work proposes studying two different geometries that involve corrugated channels. It is based on two different manufacturing methods and the behavior of both electrodes at three different distances is analyzed with the ultimate goal of being able to compare them and determine which one has the best performance for hydrogen production.

2. Experimental

2.1 Methods used for the manufacture of electrodes

2.1.1 Electrode A:

It was formed starting from a one-millimeter-thick AISI 316L stainless steel sheet, placing a 130 x 110-millimeter cutout resting on a support that houses two 4-mm-diameter brass rods ten millimeters apart (see Fig. 1 a).

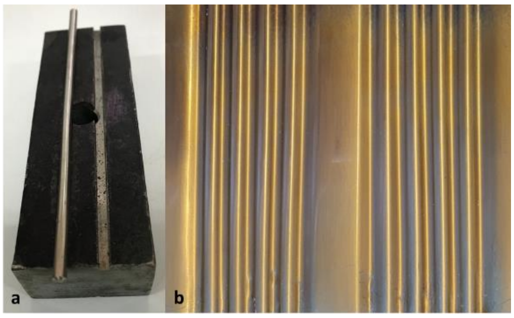

Fig. 1. a) Construction devise for electrode A anb b) electrode A.

Placing a rod of the same diameter on the plate and between the two lower rods and pressing the assembly, the deformation of the plate is produced, generating a gutter. This procedure is repeated producing an electrode with eight channels wtih flat areas in the middle and at both sides. With subsequent machining, the pair of electrodes reached dimensions of 109 x 110 x 1 [mm], which show an increase in the exposed area of the order of 9.2% compared to a flat electrode. Fig. 1.b*,* shows the finished electrode.

2.1.2 Electrode B:

In order to increase the rigidity, another pair of electrodes was made of a metal sheet of the same material but with a thickness equal to 2 [mm]. For the purpose of the gutters to be better finished and parallel to each other, it was decided to build a device (see Fig. 2.a) made up of two pieces, one with four lower slots and another upper one with three slots that couple with the lower one, leaving a gap of 2 [mm].

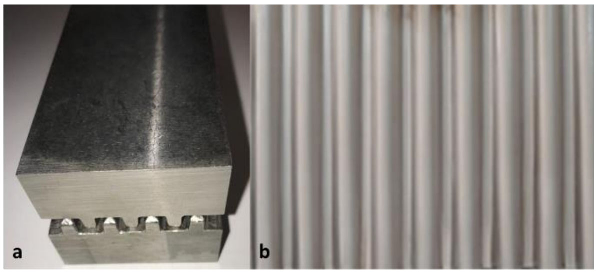

Fig. 2. a) Matrix for machining electrodes and b) electrode B.

To facilitate the machining of the sheet metal, some perforations were made at the beginning of each channel. By placing the sheet metal cutout between the two pieces and pressing them, three gutters are formed at the same time. By moving it, an additional channel can be formed by pressing. For pressing, a Carver Laboratory brand press with a maximum capacity of 20 tons was used. Fig. 2.b, shows electrode B. The pair of electrodes were left with dimensions of 106 x 110 x 2 [mm], which show an increase in the exposed area of the order of 21% compared to flat electrodes.

2.2 Performance evaluation at different distances between electrodes

The analysis of electrodes for alkaline electrolysis of water was carried out in a cristal acrylic electrolytic container, which allows the distance, to be established, by means of gages. The device consists of a cubic contanier, in the center of which, there is a channel for the parallel positioning of the separator. In the upper part and in solidarity with the electrolytic container, the pair of gages and the guide brackets are placed. The gages, built in pairs and of different sizes, allow establishing the positioning of the electrodes supported from the guide brackets. The guide brackets had the specific function of holding the electrodes in a vertical position, perfectly parallel to each other and to the separator as well. The position of these two pieces: gages and guide brackets are fixed with another that receives the name of mobile lock. The distance between electrodes then depends on the pair of gages used and the geometry of the electrodes. The material used as separator is Zirfon Perl UTP 500, which is composed of an open mesh polyphenylene sulfide fabric coated with a mixture of particules of zirconium oxide and a mixture of a polymer, giving the properties to act as a gas separation diaphragm.

Experiments were carried out using an electrolytic solution of potassium hydroxide (KOH) 30% w/w (Biopack, Pro-Analysis A.C.S., 85.0%), prepared with distilled water. Once the electrolytic solution was incorporated to the cubic container, one drop of a colloidal dispersion of Triton X-100 (Biopack) added with the purpose of reducing the superficial tension of the solution. Electrical connectors were switched to a power source Fullenergy System DC Power Supply HY3020. Current measurements were made at a certain potential between 0.0 and 2.7 V, changing the applied voltage differences 0.1 V every 30 s. The analysis of each distance generated by the gages and the electrodes, is performed at least four times. Standard deviation and standard error were calculated to obtain the error bars that were included in the graphical representations presented in the results section. Working conditions were atmospheric pressure and initial temperature of the electrolytic solution at 20 °C.

3. Results

3.1 Efect of the distance between electrodes

3.1.1 Electrode A

Three pairs of gages were used, obtaining the following distances between electrodes: 7.70; 7.00 and 5.65 [mm]. Fig. 3 shows the polarization curves obtained for each of them, including the standard error.

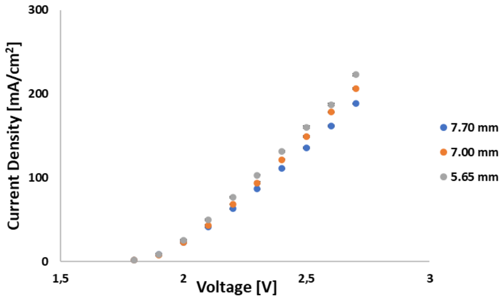

Fig. 3. Polarization curves at different distances between eletrodes A.

The results show that as the distance decreases (considering those that were the object of study in this work), the performance of the system improves.

3.1.2 Electrode B

Three sets of gages were also used to analyze this type of electrode, reaching the following distances between them: 8.21; 6.97 and 6.16 [mm]. Fig. 4 shows the polarization curves obtained for each of them, including the standard error.

Analyzing the results obtained from electrodes B, it is also observed that by reducing the distance between electrodes (for the values studied) the efficiency of the system is enhanced.

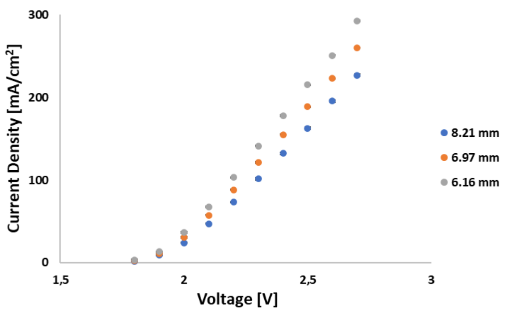

Fig. 4. Polarization curves at different distances between eletrodes B.

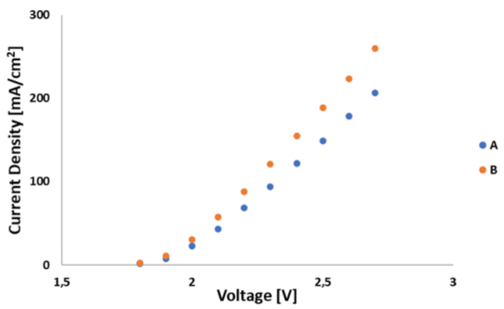

Fig. 5. Polarization curves of electrode A at 7.00 [mm] and electrode B at 6.97 [mm].

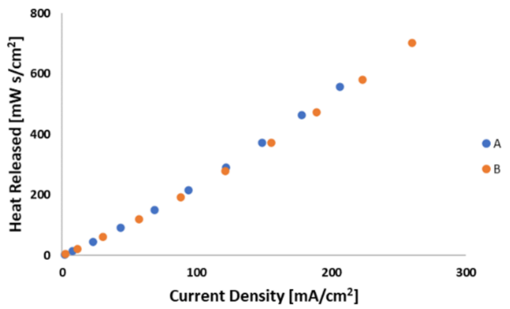

Fig. 6. Energy released in the production of hydrogen and oxygen at the same current density for electrode A and B.

4. Discussion

4.1 Manufacturing methods of the electrodes

Of the two methods used to manufacture electrodes with corrugated channels, it can be said that the one used in electrodes B is more precise and reproducible. The manufacture of this type of electrodes will depend on the size of the piece and the matrix. The first method is more traditional and requires training and care on the part of the operator.

4.2 Distance between electrodes

The results presented in the previous section show that both types of electrodes improve the performance of the system as the distance between them, decreases. This result can be justified given that the electrical resistance is directly proportional to the resistivity and length of the current and inversely proportional to the cross-sectional area; therefore, if the space between electrodes is smaller, electrical resistance will be reduced.

At the distances studied, the resistance of the hydrogen and oxygen bubbles that form and detach from the cathode and anode, respectively, do not seem to affect the performance of the system.

4.3 Comparing performance between of electrodes A and B

In order to carry out this analysis, the evaluated distances that are most similar in value were taken from both types of electrodes: 7.00 [mm] for electrodes A and 6.97 [mm] for electrodes B. Given that the electrolytic cell used establishes the distance by means of gages and that can be modified by the type of electrode's geometry, the same distances are not possible for both types of electrodes.

Fig. 5 shows the polarization curves of both electrodes, with electrode B presenting a higher current density than electrode A, under the same operating conditions. The average current density increase is approximately 28%.

If heat released was calculated as the voltage difference applied to the systems by the current density for these electrodes in these operating conditions, it could be observed that for an equal amount of generated hydrogen the system with lower performance released more heat (Fig. 6).

5. Conclusions

The performance of two types of electrodes with corrugated channels at different distances between electrodes has been evaluated. Electrode A presented a higher current density at 5.65 [mm] and electrode B at 6.16 [mm], caused by a decrease in electrical resistance. At the distances studied no effects caused by the formation of bubbles were evidenced, an analysis should be carried out at smaller distances. Electrode B presented higher efficiency than A (28%), which may be due to the shape of the channel that favors the detachment of bubbles. Of the two methods used for the construction of the electrodes, the method that uses the matrix is more precise and reproducible.

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