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Effect Of Electrolyte Type On The Hydrogen Production Using A Plate Electrolyzer

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ABSTRACT

In this work, a plate electrolyzer was designed and built to evaluate the hydrogen production by varying parameters such as voltage, amperage, connection setup and electrolyte concentration. The electrolytes used were NaOH and KOH, due to low corrosion on the stainless steel. The electrochemical cell was designed based on physicochemical and thermodynamic fundamentals obtaining an electrolyzer of 7 plates, each with dimensions of 20 cm by 10 cm. High hydrogen production was obtained using a configuration of the plates in parallel and KOH as electrolyte, for a maximum production of 0,682 l/min.

Keywords: plate electrolyzer, electrolyte, Faraday's law, electrodes.

1. Introduction

Currently, the use of fossil fuels has caused serious problems for our ecosystem, this due to the large increase in greenhouse gas emissions that contribute to global warming, melting of the poles and sea level rise, which in turn brings uncontrollable natural phenomena as tsunamis and storms, for these reasons it is necessary find quick alternatives to help reduce all these events, and that the degree of contamination be less. Rising oil demand has made decrease these raw material reserves, increasing costs increasingly used in automotive gasoline [1]. One way to reduce fuel consumption in cars is by implementing an electrolyzer to produce hydrogen from water, the hydrogen will be produced by electrochemical and thermodynamic principles of electrolysis, which decomposes water in hydrogen and oxygen. Hydrogen is a fuel which is fed to the combustion engine in a similar way as is currently done with natural gas. The electrical energy needed for electrolysis is supplied by the same car through the alternator which converts mechanical energy into electrical whose original purpose is to ignite radio, lights, air conditioning and other electrical devices and also be used to perform the process electrolysis [2, 3].

The Earth's climate has been constantly evolving from its point of origin, but in recent times have witnessed drastic changes, caused mainly by the increase of CO_2 emissions which create a dense layer in the atmosphere that prevents sunlight refracted by the earth naturally dig out , causing you land area increasingly increase its temperature [4]. Approximately 18% of CO_2, comes from the combustion of fossil fuel filed in automobiles [5]. According to data released by Ecopetrol in 2011, gasoline consumption in the country had an increase of 13.6% over the previous year, this combined with the price increase which was recorded in January 2012 around 150 pesos per gallon have become unsustainable for these fuels, thus encouraging a constant search for new technologies to reduce consumption in cars [6], so, as hydrogen becomes an option for the future to replace oil as a primary energy source, as this is the most abundant element in the universe, is clean and long-term contamination risks are almost nonexistent, since the energy of hydrogen is given without radioactivity, and their contribution to the greenhouse effect is very small, although it is noteworthy that storage techniques are a bit expensive and might present some risks, and the production of this usually has purity levels not very optimal [7]. Other form to obtain hydrogen is from alternative energy sources like wind and solar, which can be harnessed to provide clean energy to an electrolyzer for hydrogen production [8-11].

The objective of this project is to design, built and evaluation of plate electrolyzer, which will be based on the thermodynamic and electrochemical analysis. The electrolyzer allows to study the variation of parameters such as electrolyte, electrolyte concentration, voltage, amperage and connection settings between plates, in order to determine the best conditions for hydrogen production. Initially, the material will be selected taking into account parameters such as corrosion, electrical conductivity and thermal conductivity, then calculate the required area considering that the configuration of the device will be in slabs, thereby the electrodes are of the same configuration, then proceed to test the device based on each of the variables, whose ultimate purpose, will determine the hydrogen production in each of these conditions to determine the point of higher production and lower power consumption. As another alternative for optimizing the electrolytic cells, the plates are arranged from one another at a distance of 3mm in order to reduce resistance and to ensure a more efficient design [12].

2. Experimental

A series of steps was necessary to carry out this project. This project is both, experimental and descriptive, as they perform a series of tests on computer to get the right conditions and analyze each of the variables to manipulate

2.1. Electrolyzer Design

The minimum expansion work (Wrev) that is necessary to provide for a process that does not occur spontaneously at temperature and constant pressure is equal to the increase in Gibbs free energy of the process (ΔG_T):

$$W_{REV} = \Delta G_T \tag{1}$$

The electrolyzer only has ability to exchange work (other than expansion work) as electrical energy in our case is satisfied:

$$W_{ELE} = \Delta G_R \tag{2}$$

where ΔG_R is the increase in Gibbs free energy of reaction of water electrolysis. On the other hand, Faraday's law relates the electrical work and the conversion rate in terms of molar quantities. The expression of Faraday's law is:

$$W_{ELE} = n * F * U \tag{3}$$

where *n*, is the number of electrons transferred in the electrolysis of water, U is the applied voltage to the electrolytic cell terminals and F is the Faraday constant, the value is 96485,34 C/mol. Finally, equations indicated above are combined and taking into account a reversible process, is obtained the relation:

$$U_{rev} = \frac{\Delta G_r}{2 * F} \tag{4}$$

where U_{rev} is the reversible voltage and it is defined as the minimum voltage required to produce the electrolysis. If the process is not carried out reversibly, the electrical work required for electrolysis is now:

$$W_{ELE} = \Delta H_R \tag{5}$$

where ΔH_R, is the reaction enthalpy given . This equation is combined with Faraday's law to obtain:

$$U_{tn} = \frac{\Delta H_r}{2 * F} \tag{6}$$

where U_{tn}, is thermoneutral voltage, which is the minimum voltage which ensures that water electrolysis occurs. Note that $Utn \geq Urev$ because:

$$\Delta H_R = \Delta G_R + T\Delta S_R \tag{7}$$

where $\Delta S_{R,}$ is the entropy of electrolysis reaction of water. To calculate the free energy of reaction is necessary to have the value of the enthalpy and entropy formation (see Table1) of each of the compounds involved in the reaction at a reference temperature and pressure (T = 25 ° C, P = 1 bar).

Table 1. Reaction enthalpy values.

Reaction enthalpy values.		
Molecule	ΔH° (j/mol)	Δs°(j/mol K)
Water	-285800	69,9
Hydrogen	0	130,6
Oxygen	0	205

The reaction enthalpy at another temperature than the reference is calculated with equations 8 and 9, and the constants values are shown in Table 2.

$$H(T) = a_jT + \frac{4}{5}b_jT^{5/4} + \frac{2}{3}c_jT^{3/2} + \frac{4}{7}d_jT^{7/4} \tag{8}$$

$$S(T,P) = a_jlnT + 4b_jT^{1/4} + 2c_jT^{1/2} + \frac{4}{3}d_jT^{3/4} - RlnP \tag{9}$$

Table 2. Enthalpy and entropy coefficients

Enthalpy and entropy coefficients				
Molecule	*aj*	*bj*	*cj*	*dj*
Water	180	-85,4	15,6	-0,858
Hydrogen	79,5	-26,3	4,23	-0,197
Oxygen	10,3	5,4	-0,18	0

The enthalpy and entropy values allow to calculate the change of the reference temperature to the working temperature of the cell for each molecule in the reaction.

$$\Delta H_J = H_j(T) - H_j(T_{ref}) \tag{10}$$

$$\Delta S_J = S_j(T) - S_j(T_{ref}) \tag{11}$$

The reaction entropy and enthalpy at the temperature and operating pressure are calculated.

$$\Delta H_R = \Delta H_{products} - \Delta H_{reagents} = \Delta H_{H_2} + \frac{1}{2}\Delta H_{O_2} - \Delta H_{H_2o} \tag{12}$$

$$\Delta S_R = \Delta S_{products} - \Delta S_{reagents} = \Delta S_{H_2} + \frac{1}{2}\Delta S_{O_2} - \Delta S_{H_2O} \tag{13}$$

The resistance is calculated with the measured voltage and Ohm's law.

$$V = IR \tag{14}$$

The dimensions of electrolyzer are calculated using the material resistivity (ρ):

$$R = \frac{\rho L}{S} \tag{15}$$

2.2. Electrolyzer construction

The following materials were used to construct the plate electrolyzer shown in Figure 1.

- Two small sheets of transparent acrylic, 15cm by 25cm.
- 7 sheets of 316L stainless steel, 12cm by 22cm
- 10 screws of 3/8 with nut and washer.
- 10 hose gaskets of 3/4 with 5 cm long to avoid contact of the boards with screws
- 5 plastic hose connectors.
- A meter of hose and 3/8 transparent.
- 9 clamps of ½ and 4 elbows of 1/2.
- Two plastic containers for washing gases and the water supplier
- One meter of bipolar cable

2.3. Experimental Design

Voltage change, different electrolyte concentration (KOH) and configuration in parallel and series of plates were studied by measure of hydrogen flow. The experiments were repeated using NaOH as electrolyte.

The gases flow was measured using an inverted beaker on a larger container as show in the Figure 1c, the produced gas enter to the beaker by the bottom, and a chronometer is used to determinate the filling time of system, the internal pressure will be kept manually with help of the levels.

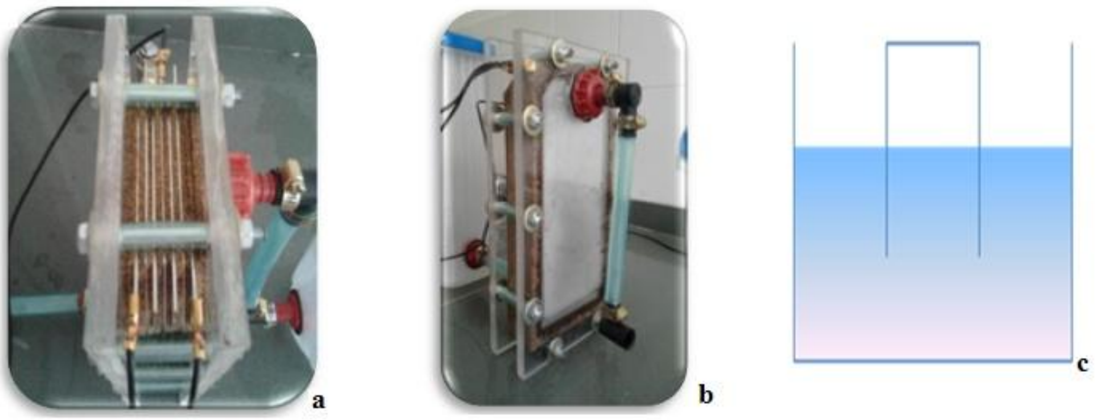

Fig.1. a) top view of electrolyzer, b) side view of electrolyzer and c) inverted beaker

3. Results

3.1 Electrolyzer design and assembly

The thermoneutral potential calculated was 1.48 V, and this is the minimum voltage required to produce the electrolysis. From this value is calculated the electrolyzer dimensions as shown in Table 3.

Table 3. Electrolyzer dimensions

Nominate	Value
Plates number	7
Potency	36 watts (12 volts y 3 amperes)
Area on each plate	200 cm^2
Plate wide	10 cm
High on the plate	20 cm
Thickness	0,3 cm
Space between the plates	3 mm

Figure 1a shows the top view of the electrolyzer used in this investigation, where distribution between plates and gaskets can be observed. Furthermore, Figure 1b shows a side view, where is observed the gas outlet tube, and Figure 2 shows the all components of system including supply tank and safety systems such as the bubbler.

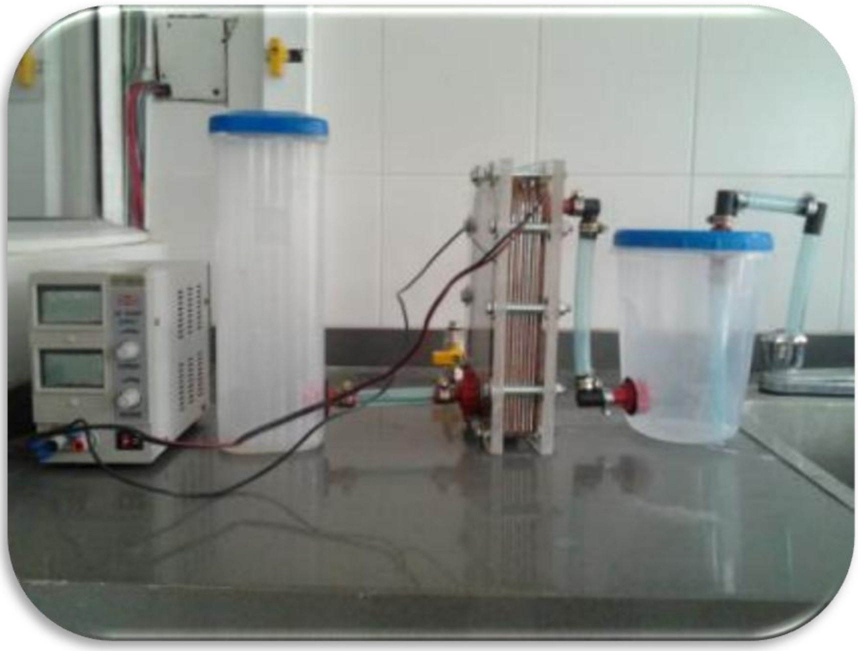

Fig. 2. Complete system of plate electrolyzer

3.2. Hydrogen Flow

Figure 3 shows the relationship between voltage and amperage at 3mm spacing between electrodes, taking into account the electrolyte type, the electrolyte concentration and configuration of the plates. The configurations used were parallel plates (+ n –) and plates in series (+ n – n +). This describes a linear behavior as expressed in Ohm's law, the slope at the beginning is lower because the voltage used was not sufficient for the electrolysis was carried out, but when it came to about 3V, the slope increased, and with she amperage consumed. On the other hand, the electrolyte used, got the best result with NaOH and so, to higher concentration increases the electrical conductivity, allowing a lower voltage electrolysis and low consumption.

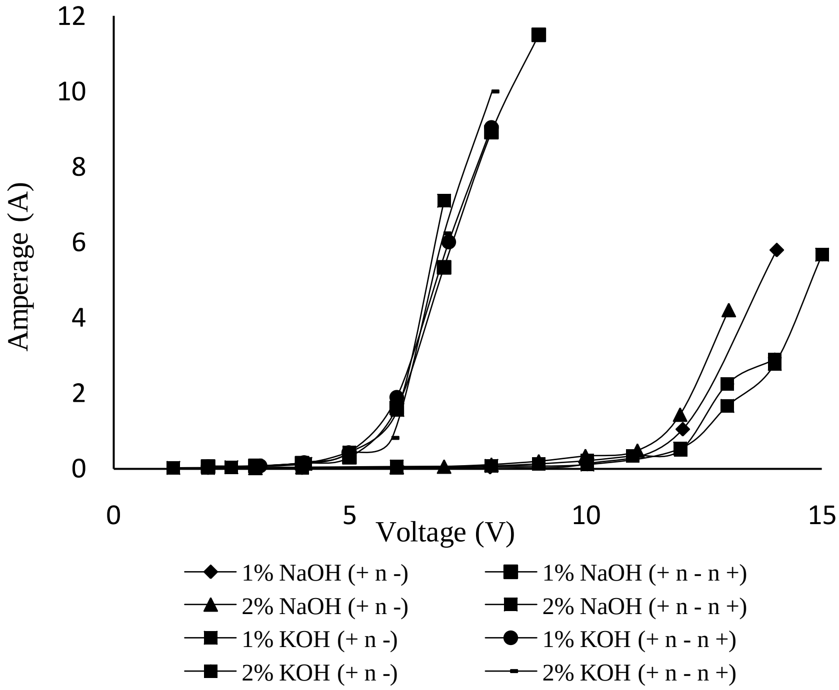

Fig. 3. Relation between voltage and amperage at different connection setup, electrolyte type and electrolyte concentration.

The Figure 4 shows the relation between the voltage and the volumetric flow of hydrogen in different plate configurations (series and parallel) and electrolyte concentration. The hydrogen flow in parallel configuration is higher than series configuration. Furthermore, the hydrogen flow increases with increasing the electrolyte concentration. On the other hand, the hydrogen flow using KOH as electrolyte is higher than those using NaOH as electrolyte, due to highest conductivity of KOH. Although, this generated many bubbles that diminish the transfer of gases between the plates.

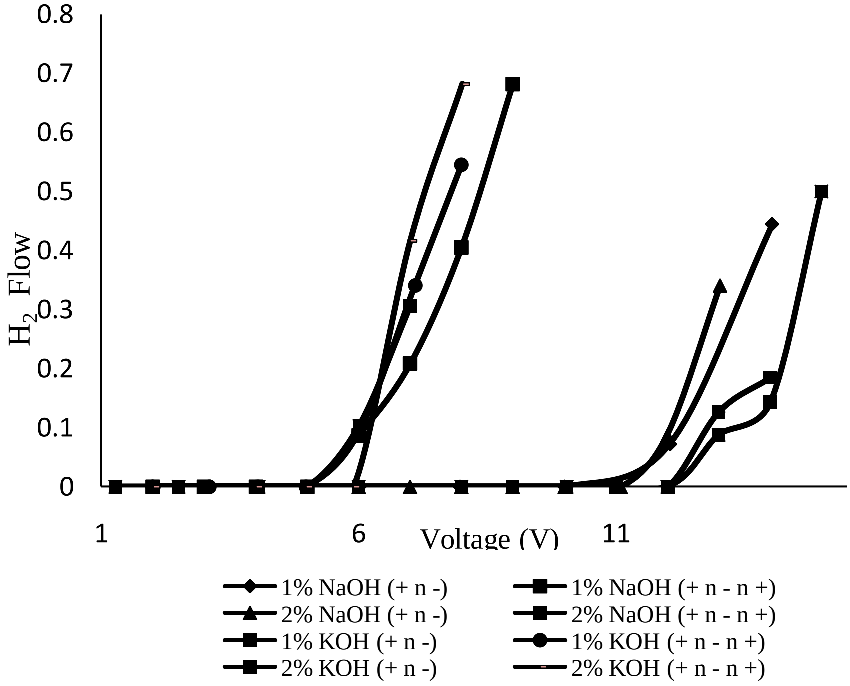

Fig. 4. Effect of voltage on the hydrogen flow at different connection setup, electrolyte type and electrolyte concentration.

4. Conclusions

An electrolyzer of stainless steel plate was designed, built and evaluated for hydrogen production. The highest hydrogen flow (0.682 l/min) was obtained using as electrolyte, KOH, with a concentration of 2% (w/w) at parallel configuration. Furthermore, the electrolyzer in this configuration could operate at lower voltages, giving the possibility of working at high currents to generate more hydrogen. The electrolyzer operates very efficient and stable, it could easily measure the volumetric flow, and the acrylic material allows to observe the process internally. It is recommended in future research evaluate electrolyte concentrations more highest and to use electrolyzer with more number of plates, to evaluate its effect on the production of hydrogen.

References

[1] Kelly, N., T. Gibson, M. Cai, S. James A and D. B. Ouwerkerk, "Development of a renewable hydrogen economy: Optimization of existing technologies", International Journal of energy, 35(3), pp. 892-899, 2010.

[2] Martinez, F., P. Ai Quoc and A. Salvador, "A natural gas- assisted steam electrolyzer for high- efficiency production of Hidrogen," Revista Internacional de Hidrogeno Energia, 28(5), pp. 483-490, 2003.

[3] Realpe, A., J. Orozco, and M. Acevedo, "Wind Power For Hydrogen Production Using A Spiral Electrolyzer", International Journal of Applied Engineering Research, 10(4) pp. 9175-9183, 2015.

[4] Juan D. and Z. Wenping, "The Analysis to the Influence of Carbon Dioxide Emissions in Different Countries", Energy Procedia, 5, pp. 2426-2431, 2011.

[5] Veziroglu, T., I. Gürkan and M. Padki, "Remediation of greenhouse problem through replacement of fossil fuels by hydrogen", International Journal of Hydrogen Energy, 14(4), pp. 257-266, 1989.

[6] Sabine J., "Fuel price and technological uncertainty in a real options model for electricity planning," in Energy, 2010, pp. 2938-2944.

[7] Carl W., and Jochen, "Hydrogen energy — Abundant, efficient, clean: A debate over the energy-system-of-change", International Journal of Hydrogen Energy, 34(14), pp. 51-52, 2009.

[8] Verhelst S., P. Maesschalck, N. Rombaut, R. Sieren “Efficiency comparison between hydrogen and gasoline, on a bi-fuel hydrogen/gasoline engine”, 2009.

[9] Andrews J., Shabani Bahman, “Re-envisioning the role of hydrogen in a sustainable energy Economy, Fuel and Energy Abstract, 37(2), 2012

[10] Realpe, A., J. Diazgranados, M. Acevedo, Electricity generation and wind potential assessment in regions of Colombia, DYNA, 79(171), 2012.

[11] Da Silva, E., Marin, A., Ferreira, P., Camargo, J., Apolinario, F., Pinto, C. Analysis of hydrogen production from combined photovoltaics, wind energy and secondary hydroelectricity supply in Brazil, Solar Energy 78, 670–7, 2005.

[12] Phatiphat, T., S. Rael and B. Davat, Control strategy of fuel cell/supercapacitors hybrid power sources for electric vehicle, Institute National Polytechnique de Lorraine, 2005.