A Mechanical Development of a Dry Cell to Obtain HHO from Water Electrolysis

Gustavo Salazar, Wilmer Solis, and Leonardo Vinces

Abstract This article proposes a mechanical development of a dry cell in order to obtain HHO through water electrolysis. Calculations and technical specifications of the materials used for implementation are supported by mathematical, physical and chemical formulas and theories (Faraday´s Law, electrolysis process and mechanical design). The importance of mechanical design is focused on achieving efficient use of the energy provided to the cell that allows the H_2 and O_2 molecules to be separated without overheating the cell, evaporating the water, loss of current due to the geometry of the electrodes (Foucault Current). Moreover, choosing materials for proper implementation and physical robustness is mandatory. In addition, the mechanical design is not justified in different articles. Nevertheless, the mechanical design of the cell and the efficiency in the production of HHO are related. Therefore, the mechanical design and the calculations were performed, as well as the construction of the dry cell to obtain HHO. The results of the implementation and production were placed and compared with what theoretically the dry cell should produce from the law of Faraday. Finally, the volumetric flow of HHO obtained was 2.70 L per minute. It means a production efficiency of 98.68%. It is higher than the majority of the dry cells.

Keywords HHO generation · Electrolysis · Dry cell · Faraday · Mechanical design

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1 Introduction

Currently, global energy demand has increased and will continue for 25% more by 2040, according to the International Energy Agency [1]. In many countries, most of the energy comes from fossil sources like energy generated by coal, oil or its derivatives. An example of this is the energy balance carried out in Peru by the Ministry of Energy and Mines in 2016 recovered by the Latin American Energy Organization [2]. The results of this study show that the main source of energy is natural gas and oil (47% and 30%, respectively), both non-renewable and polluting energy sources. Because of this, there is a need to use a renewable and less polluting alternative fuel. Hydroxy gas or brown gas (HHO) is a clean and renewable source of energy due to the absence of hydrocarbon compounds; therefore, carbon dioxide or other potentially dangerous gases are not released after combustion, it only produces water vapor [3], as shown in (1).

$$HHO_{(g)} + Calor \rightarrow H_2O_{(l)} + Energy \quad (1)$$

HHO is produced by dividing water into hydrogen and oxygen molecules through electrolysis. An electrolyzer, also called a hydrogen generator, is necessary for this process. Some works on this field have been developed, the ones mentioned below are the most important.

Rusdianasari et al. [4] used a software capable of calculating the production of HHO gas and the power consumed of a wet cell according to the number, dimensions of the electrodes, the voltage and current provided. In addition, the authors arrived and compared the value of the HHO flow produced with the value calculated by the software. However, the authors did not justify the characteristics chosen for the design of the wet cell test resulting in an efficiency of 89.13%.

Shah et al. [5] compare the energy efficiency, production of HHO, the maintenance and safety considerations of the dry and wet cell. As a result, they conclude the dry cell being better in all the fields described above with the same input conditions as the cell wet. The authors described the components of the dry cell and the physical characteristics of the mechanical system that influenced the production of HHO. In addition, they present a detailed design of the dry cell. However, the design presented, and the components used for implementation don´t present technical specifications or mathematical calculations that justify them.

Nabil et al. designed in [6] several cells with different numbers of electrodes and configurations. In addition, the authors show a table with all the designs made and they compare the energy consumption, the production of HHO gas, the molarity used and the temperature of each one. However, despite using Faraday's first law in their article, the authors do not compare the production flow of each mechanical design with what the cell should theoretically produce. Moreover, they don't demonstrate the efficiency of each configuration. In addition, the measurements and the shape of the electrodes are not justified.

Because of the cases seen before, it is proposed to make a design based on mathematical calculations, physical and chemical formulas (Faraday´s Law, electrolysis process and mechanical design). Furthermore, the implementation of a correct selection of dry cell components. Finally, the production of HHO of the designed cell will be compared with what should theoretically be produced from Faraday's law.

2 Description of the Proposed Method

To have an overview of the dry hydrogen cell that was designed, the P&ID diagram of the electrolysis process can be seen in Fig. 1.

The diagram shows the instrumentation to be used in the process and the parts that comprise it. In the dry cell is where the separation of water molecules occurs. Moreover, it is where the research will focus on. In order to obtain an efficient mechanical design, the following phases shown in Fig. 2 must be followed.

2.1 Calculations of Preliminary Cell Dimensions

For the design of the dry cell, calculations had to be made based on the power available for the process. In this case, we have a 12 V battery and the current will be regulated at 20 A. From this data, we can configure the cell plates. In the same way that series circuits can be created by connecting various chained elements to each other and connecting the power supply only at the ends, it is also possible to do the same with the electrodes. Nevertheless, with the difference that the connection between them occurs through the electrolyte. The plates that remain unconnected are called neutral or bipolar, these plates are not connected to any source of electricity and are placed between two plates connected to different polarities. In this way, it is achieved that in each separation created between the connected plates there is a voltage equal to the total divided by the number of spaces, without the need to adjust the voltage output of the source or use cables.

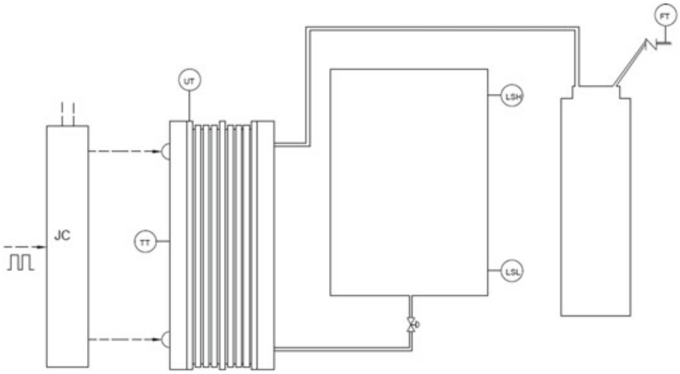

Fig. 1 P&ID diagram of the electrolysis process

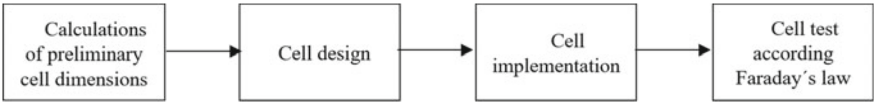

Fig. 2 Block diagram of the proposed method

According to Gamez [7], to calculate the number of plates, the voltage between electrodes and the total source voltage must be considered. The number of plates is obtained by applying Eq. (2):

$$V_C = \frac{V_T}{n - 1} \tag{2}$$

The n is the number of plates per group, V_T the total cell voltage and V_C the calculated voltage between electrodes. The result of n will be 7, two of which will be polarized (cation and anion) and the other five will be neutral. For greater production, the following configuration will be chosen:

$$-\text{NNNNN} + \text{NNNNN}-$$

The N´s are the neutral plates between the polarizing plates (+ −). In addition, it must be considered that the current delivered by the source will be divided into two groups. However, having two negatively polarized plates, hydrogen production will be higher because it has a positive ion.

The geometry chosen for the plates is circular since there will be no electrical losses due to vertices of the electrode. These currents are called Foucault currents. In certain cases, these currents can produce undesirable effects. For example, they increase internal energy and temperature. A conductive material with angular edges and corners has electrical losses (corner effects) as a result of the accumulation of electromagnetic fields in said vertices caused by a non-uniform current density [8].

Moreover, the current that will give energy to the cell will be regulated with a PWM wave, the current will be variable, and the current density will be non-uniform.

Gámez defines the current density as the amount of current that circulates per unit area of an electrode, and is calculated using (3):

$$d_C = \frac{I_E}{S_E} = \frac{I_E}{N_A \times S_E} \tag{3}$$

where d_C is the current density (A/m^2), I_E the intensity of the current flowing through the electrode (A), S_E the surface of the electrode (m^2) and N_A the number of cell groups.

Assuming the same electrode surface, by increasing the current flowing through the cell the production of gas will be increased, but also the voltage necessary to circulate this current, so that the efficiency of the cell will decrease. To avoid this, Gámez mentions that the idea is to maintain a flow of 1000 A/m^2, since, at a smaller area, a higher voltage will be needed to circulate the same amperage, which will generate more heat.

Having an electrode surface (SE) of 0.01 m^2 and a circular geometry of the electrode, an electrode radius equal to 56 mm is obtained. That is the theoretical radius that the cell's circular plate should have. However, for experimentation and ease of machining, a plate with a radius of 75 mm will be implemented. In addition, the excess area can serve as a heat sink for the cell.

2.2 Cell Design

The software called Inventor [9] was used to design the plates. Two types of plates will be designed: neutral and polarized. The polarizing plates will have an extension in one corner, as seen in Fig. 3 so that it is attached to the stud that will pass through the cell to assemble it. This stud will be connected to a pole of the power supply. However, the extension made on the plate will be with a rounded corner to avoid the phenomenon of stray currents. The neutral plate will not be connected to any pole of the power supply and will be fully circular as seen in Fig. 3.

For the separation between electrodes and to ensure the sealing of the same, nitrile O-ring will be used. Due to the current that will pass through the cell, a separation of 4–8 mm is recommended. Because of the current that will pass through the cell and the high gas productions, the electrolyte will bubble and foam, appearing spaces without liquid between the electrodes that will reduce the efficiency of the cell. Consequently, 6.99 mm thick O-rings were chosen, standardized measurement of this material [10]. To give greater physical strength to the cell, 18 mm thick acrylic will be used. The design of these acrylic plates is seen in Fig. 4.

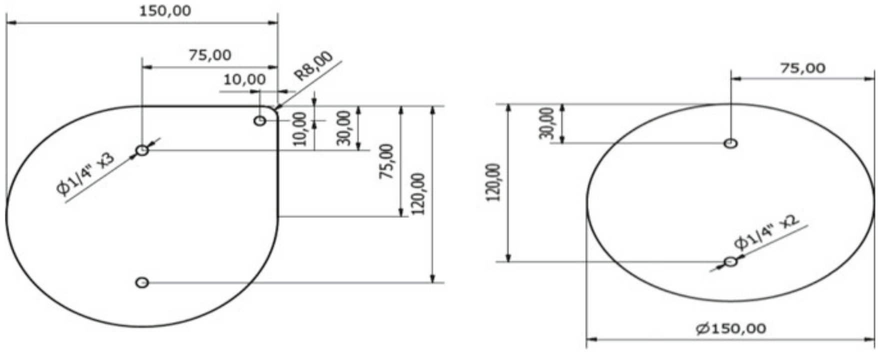

Fig. 3 Detailed plane of the polarized and neutral plate

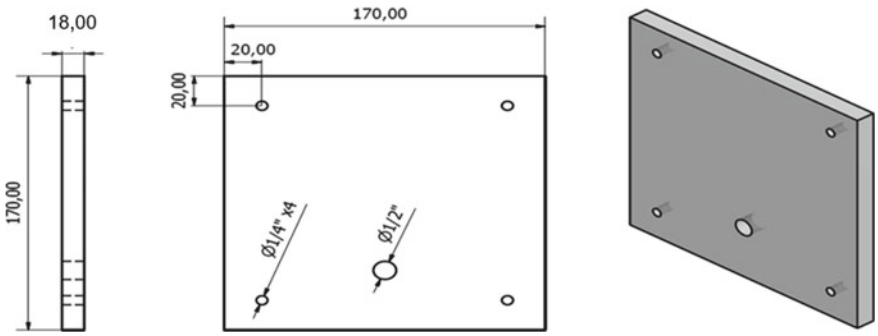

Fig. 4 Detailed plane of acrylic plate

2.3 Cell Implementation

To carry out the implementation of the cell it was necessary to make a previous study of the materials to be used. The 316 L stainless steel was used in the plates since the dry hydrogen cell will be in constant contact with salts and water and this material offers a high electrical conductivity for electrolysis (electrical resistivity: 70–78 × 10–8 Ω × m). In addition, it has a high resistance to corrosion due to its chemical composition [11]. In the case of the O-rings, nitrile was used, since it is not high priced, its working temperature is adequate (−20 to 90 °C) and it is very durable [12]. For the electrolyte, KOH was chosen with a concentration of 10%, since it is the best electrolyte for any application and at this concentration, the best results are obtained. This is because it supports more varied conditions and leaves no residue. Sodium hydroxide, on the other hand, generates a brown residue that clouds the solution and soils the cell, progressively reducing its efficiency if it is not cleaned periodically [13, 14]. Finally, to seal the cell, 18 mm thick transparent acrylic and Teflon couplings were used to enter the solution and exit hydrogen. After choosing

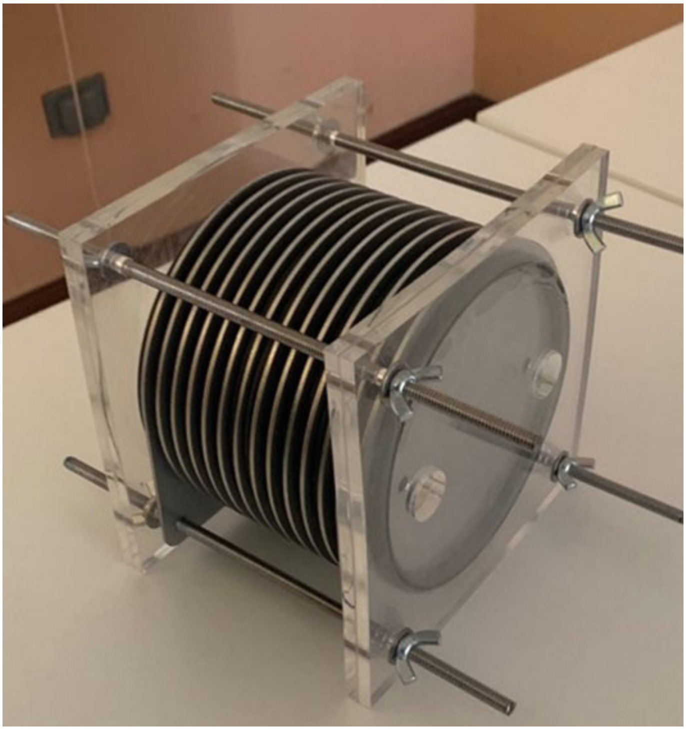

Fig. 5 HHO dry cell assembled

all the materials, the cell assembly is carried out. Subsequently, tightness tests were performed to avoid leaks. In Fig. 5, the fully assembled cell can be seen.

2.4 Cell Test According to Faraday´s Law

The electrolysis process is basically based on Faraday's laws for electrolysis, thus having both the first (4) and the second law that refers to the fact that the amount of altered substance in an electrode directly depends on the electric current in Coulombs. In addition, the mass deposited in an electrode is proportional to its molecular weight or chemical equivalent.

$$Q = I \times t \tag{4}$$

where Q is the necessary energy (C), I the current intensity supplied (A) and t the time (s). Then, we proceed to calculate the number of chemical equivalents of a substance deposited in an electrode with (5):

$$n^{\circ}\text{eqq} = \frac{Q}{F} \tag{5}$$

In this equation, "n° eqq" is the number of chemical equivalents of a substance deposited in an electrode, which is directly proportional to "Q" (1200 C). The necessary energy calculated with Faraday's first law (4), divided between Faraday's constant, "F". The chemical equivalent found with (5) must be transformed to mass of H_2, considering the molecular weight of H_2 (2 g/mol) and its valence electrons (+2) we can obtain that its "eqq" is 1. With this calculation, the mass of H_2 (m_{H_2}) can be transformed using the following relation (6):

$$n^{\circ}\text{eqq} \times \frac{1\text{g}}{1\text{eqq}} = m_{H_2} \tag{6}$$

Knowing the mass of hydrogen to be obtained per minute, 0.0124 g H_2, now it is desired to pass this mass to volume, specifically to liters, for this the ideal gas equation is used, replacing the values at normal conditions resulting in 152 mL per minute to calculate the production of O_2 we can use the proportionalities of the volume of H_2 ($\dot{V}_{H_2}$) and O_2 ($\dot{V}_{O_2}$) that have a ratio of 2: 1. Therefore, the volume of HHO ($\dot{V}_{HHO}$) produced per compartment can be obtained. Since there are 12 compartments, the equation is obtained in (7):

$$\dot{V}_{HHO} = \left(\dot{V}_{H_2} + \dot{V}_{O_2}\right) \times 12 \tag{7}$$

Assuming 100% efficiency, this value found in (7) is approximately 2.73 L/min.

3 Results

In order to obtain the production efficiency of the dry cell, we implemented the P&ID shown in Fig. 1, using a rotameter as a flow meter. In the test, the rotameter indicated an HHO flow rate of 2.7 L/min with a peak current of 20 A. This result gives us an efficiency of 98.68% as shown in Table 1.

Table 1 Production comparison

	Rusdianasari [4]	Our work
HHO production (L/min)	0.1028	2.73
Efficiency	89.13%	98.68%

4 Conclusion and Future Work

Our development can increase efficiency by 9.55% compared to the cell of Rusdianasari. Moreover, the mechanical design is just the beginning of this work. The purpose of developing this dry cell is to generate electricity by using an engine without any kind of gasoline.

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