Implementation of a prototype water electrolysis system as an alternative to produce hydrogen

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Abstract. The objective of the development of the prototype or scale model of production of hydrogen and oxygen through the electrolysis process of water is to generate an alternative with a sustainable approach, which proposes the supply or source of energy initially with a direct current power source. replaceable in the future by a photovoltaic solar system. For the development of the prototype, it began with the academic compilation of information, then the model was made in CAD, followed by the need to integrate an electronic control system and a mechanical system to obtain the final model, materials were selected and used premises for the development of the two systems, the electronic and physical schematization was carried out, chaired by the assembly and field experimentation. It is important to highlight that the constructed scale model generates hydrogen and oxygen with a low current consumption and a constant voltage, the maximum point of gas generation is the maximum point of energy consumption and its relationship is almost linear.

Keywords: Electrolysis of water, prototype, Hydrogen production, photovoltaic system and CAD modeling.

1 Introduction
Electrolysis\textsuperscript{[1]} is an electrochemical process\textsuperscript{[2]} that uses electrical conductivity \textsuperscript{[3]} of some substances or materials to generate a non-spontaneous oxidation-reduction reaction \textsuperscript{[4]}. Electrolysis derives from electrolytes that are on ionic conductors of positive or negative loads that have the ability to carry electrical energy, generate electrical conductivity in materials and substances \textsuperscript{[5]}. Water electrolysis requires water not to be in its pure state, as pure water is not conductive so it must have some concentrations of salts and some minerals \textsuperscript{[6]} \textsuperscript{[7]}. Electrolysis consists of the chemical decomposition of a substance by means of electricity (electro-electricity and lysis - destruction) \textsuperscript{[7]}. Due to the electric current circulating from the cathode causing reduction, towards the oxidation anode, provided that between them a conductive substance (electrolyte) is present\textsuperscript{[8]}. For the production of electrolysis in water you need a dissolved electrolyte\textsuperscript{[9]} (to increase its conductivity) to introduce two internal electrodes \textsuperscript{[10]} (anode and cathode) being connected to a DC source, the electrolyte transformation of water into hydrogen and oxygen will occur requiring high energy consumption, so it is only used for practical purposes exceptionally \textsuperscript{[11]} \textsuperscript{[13]} \textsuperscript{[14]}.
It is important to define the term renewable energy\cite{15} \cite{16}: they are clean, endless energy sources that differ from fossil fuels\cite{17} \cite{18} especially in their diversity, abundance and willingness potential anywhere on the planet, but mainly in that they do not cause greenhouse gases\cite{19} \cite{20}, nor polluting emissions\cite{21} \cite{22}, therefore, it is proposed in this Paper how to produce hydrogen\cite{23} from a small-scale electrolyze that is powered by the energy generated by a DC source that simulates power through photovoltaic solar panels\cite{24}. The direct current source, will allow the fractionation of water molecules in oxygen and hydrogen, the latter, will be used as an energy vector or serve as an energy storage system\cite{25} \cite{15}.

Thus, the main objective of this document is to present a small-scale prototype as an alternative\cite{26} to the production of hydrogen by water electrolysis\cite{27}; simulating the power supply of a photovoltaic system through a conventional direct current source\cite{28} \cite{29}. The present technological development of an investigative nature, performs in an exploratory and descriptive way, the methodological development of the model\cite{30}, through the implementation of an electrolyze that takes the current of a switched power supply, which in the future can be replaced by a load regulator to receive power through photovoltaic solar panels\cite{31}.

Considering the This Paper begins with the methodological development\cite{32} implemented for the construction of the prototype, as well as the description of the implemented materials. Followed by the experimentation presented in section 3 where tests of operability and operation of the prototype are carried out\cite{33}. Subsequently, in section 4 the results are described and the functional behavior of the system is analyzed, and. Finally, the most significant conclusions of the development of the prototype are presented. Finally, this document will present a scale prototype of a hydrogen production system from the electrolysis of water\cite{34}, fed with a direct current source as an alternative of operation through photovoltaic solar panels as a sustainable and scalable prototype.

2 Methods and Materials

2.1 Methodology

For the development of a prototype at scale, Figure 1 presents the methodological workflow diagram, beginning with the system sizing process, which initially requires an academic information search where the initial need to develop CAD modeling, with two integrated systems for the proper functioning of the prototype: electronic control system and mechanical system. The first mentioned system must satisfy the needs of the project and control the scale model, selected as the central axis to carry out this task, the Atmega 328p microcontroller is identified, compatible with Arduino systems; simply remove the original microcontroller from the card and mount the Atmega 328p, it also highlights the flexibility to program the new microcontroller, since the free Arduino software allows its configuration. Also, a PCB board that connects to the microcontroller is required to have all the connections in one module.

On the other hand, it is necessary to build the mechanical section of the prototype that is fundamentally responsible for carrying out the physical electrolysis process and consists in the development of hydrogen cells (HHO); They are basically made up of two positive, three negative and sixteen neutral plates separated from each other by a neoprene gasket that separates the anode and the cathode, so that the gas generated in the anode (oxygen) does not mix with that generated in the cathode (hydrogen). This system will be fed by a water tank, connected through hoses. The prototype has temperature and level sensors, which send signals to the microcontroller, which in turn processes them and transmits them to a visual indicator or LCD screen. After the electrolysis process is run and the hydrogen and oxygen are obtained, all this will be deposited in a bubbling tank made of PVC. The hydrogen and oxygen generated by the electrolysis process will be measured by rotameters, these will be responsible for defining the flow generated.
After developing the control system and mechanical system, the two are integrated into a compact module built with 1-inch structural tubes. Additionally, a satin stainless-steel plate was installed for mounting the aforementioned measuring instruments, indicator and two rotameters to measure flow. After assembling the prototype, the sensors or measuring instruments are calibrated. Finally, field tests or final experimentation are carried out, obtaining promising measurements of hydrogen and oxygen.

2.2 CAD Modelling
The 3D schematization of the module was developed after the collection of information using the CAD tool or SolidWorks Software, dimensioning it on a real scale in order to facilitate its construction. Modeling integrates mechanical and electronic control systems; Basically, the elements that compose it are: H2 cell, structure, water tank, instrument panel, power supply, control panel, hydraulic and gas system, among others (See Figure 2).
2.3 Control System
The materials required for the development of the electronic control system are described below:

2.3.1 PCB Board. A printed circuit board (PCB) as shown in Figure 3 is a sheet of rigid insulating material, covered by copper tracks on one or both sides to serve as connections between the various components to be mounted on it. Depending on the type of plate, copper can in turn be protected by a layer of photosensitive resin.[35] [36]. For our model it was necessary to develop it for integration with the microcontroller.

2.3.2 Atmega 328-p microcontroller. Sensors and other electronic elements generate digital signals; these signals have to be received and mapped to the required values. To solve this is used the Atmega 328-p microcontroller, shown in Figure 4, this on a PCB board previously designed for operation and easy compatibility with its electronic components, simplifying connections and giving a better appearance to the module. It is important to note that this microcontroller is compatible with the Arduino platform, being thus easy to program.
2.3.3 **Programing IDE.** The source code for the IDE is published under the GNU General Public License. The IDE supports C and C++ languages using special code structuring rules. The IDE supplies a software library of the Wiring project, which provides common I/O procedures, the user-written code requires only basic and simple functions. The IDE uses the avrdude program to convert the executable code into a hexadecimal-encoded text file that is loaded into board Atmega using a loading program into the board firmware.[38]

2.3.4 **Current Sensor to Arduino.** The hydrogen gas flow of an electrolyte cell is directly proportional to the intensity of the consumed current. In order to measure the current consuming the cell, it is necessary to implement the module an ammeter to know that variable. The maximum current to be measured in the cell is 20 amps, little less than the maximum current of the power supply. Therefore, the ACS712 current sensor of allegro (See Figure 5), which meets most requirements, will be used. This Hall effect current sensor provides the most economical solution with a fairly acceptable accuracy to measure the current intensity of the cell and with the appropriate size to adapt it to a PCB board being also compatible with it.[39]

2.3.5 **MAX6675 module for thermocouple (type K).** The MAX6675 thermocouple sensor is a specialized analog-to-digital signal converter for type K thermocouples. With this module it is possible to easily connect a thermocouple to any microcontroller via a one-way SPI interface. Within this small circuit is the electronics needed to amplify, compensate and convert to digital the voltage generated by the thermocouple, which makes it very easy to connect a thermocouple to a microcontroller. The only problem is that this circuit is only achieved in SOIC encapsulation, so it is not so easy to use it in the protoboard. However, in this module we find the MAX6675 with all the necessary electronics and the appropriate terminals to facilitate its use. [41]
2.3.6 **Type K thermocouple.** This sensor supplies an electrical voltage depending on the temperature. A thermocouple doesn’t directly measure temperatures, but the temperature difference between the hot end and the cold end. The combination of different metals induces certain signals that allow effective temperature measurement. Thermocouple probes vary depending on the requirements, in our case we opted for a thermocouple with a 10 mm probe for the tank and a thermocouple with a 100 mm probe for the cell.

2.3.7 **Rotameters.** The rotameter or flowmeter is an industrial flow meter used to measure the flow of liquids and gases. The rotameter consists of a tube and a float. The float's response to flow changes is linear, and a flow range of 10 to 1 is standard. Conclusively the ZEAST rotameter shown in Figure 7 is chosen, this one with a measurement range of 3 LPM (liters per minute) being among the desired measurement ranges for small-scale prototyping.

2.4 **Mechanical system**

2.4.1 **H2 cell.** The cell, shown in Figure 8 consists of two positives exposed, three negative and sixteen neutral ones separated from each other by neoprene packaging and a separating membrane, two connections for liquid inlet and two for gas outlet, two 16 x 16 x 0.8 cm acrylic plates and two reinforcement frames.
2.4.2 Water tank. The tank shall be connected to the cell and the bubblers by means of a hose circuit. In addition, it will have a temperature sensor and a level sensor that will send a signal to the microcontroller when the water level is very low.

2.4.3 Deposit bubblers. The bubbling devices are the devices responsible for removing excess water that comes out of the cell, as well as protecting it from possible gas combustion, which would cause a dangerous explosion. The bubblers were manually made from PVC pipe as it is a corrosion-resistant and easy-to-machine material.

2.4.4 Power supply. This 300w power supply will be responsible for sending electrical energy to the cells, so that they can perform the electrochemical electrolysis process.

2.4.5 Instrument panel. The instrument panel is where the flow meters, LCD display, LED indicators, control buttons and power switch will go. The material of this is satin stainless steel, for greater durability.
2.4.6 **Structure.** The frame or chassis where the elements that make up the system are housed in general consists mainly of a 3/4-inch square tube (See Figure 10).

![Figure 10. Structure](image)

2.5 **Flow diagram of electronic control system**

![Flow diagram of electronic control system](image)

![Figure 11. Flow diagram of electronic control system](image)
The connection diagram shown in Figure 11, is made taking into account the requirements for the operation of the electronic system in general, this circuit is proposed that will connect the temperature sensors, level sensor, LCD display and other elements, to the microcontroller atmega 328P, this for the time of the assembly have a correct idea of what are the connection pins between the different devices

2.6 Module connection diagram

After CAD modeling, the identification of the elements of the module, the development of the electronic control system and its schematization, it is important to highlight the physical connection diagram of the module presented in Figure 12, which allows the assembly to be known in detail, made at the time of building the module.

It is important to highlight in the connection diagram, that in the H2 cell is where all the electrochemical process happens. Which is powered by a water tank that integrates a level sensor. The hydrogen and oxygen produced are deposited in a special container called "bubbling tank", being essential to know the outflow of gases generated by the H2 cell through a pair of flowmeters or rotameters, connected to the bubbling out.

![Figure 12. Model connection diagram](image)

2.7 Experimentation

The experimentation process involves the functional checking of the different sensors implemented in the system, in order to guarantee that the measurements indicated on the module or LCD screen are correct. Starting, with the level sensor, in which manual tests are carried out, checking its proper operation. Subsequently, the tank and cell temperature sensors are verified, both must have the same or very close values when the cell is empty; the sensors present similar measurements as evidenced in figure x, corroborating their correct operation. (See Figure 13)
On the other hand, a crucial factor when carrying out the tests with the electrolysis module are the electrical variables of voltage and current, since these will allow projecting the consumption of the system and, based on this value, being able to determine the generation capacity of the photovoltaic solar system for future implementation. To measure the values, a voltage and current divider can be applied, or simply using Ohm's Law depending on the proposed electrical circuit. Figure 14 ... shows the voltage and current values calculated by the developed algorithm, contrasted with the values evidenced by a measuring instrument or multimeter.

Finally, with the parameters of the sensors adjusted and the verification of the voltage and current meters, a series of tests were performed on the module where the flow values were verified with respect to the hydrogen and oxygen gases, with which determined the production of the developed system.

3. Results and analysis

Figure 15 shows the final result of the dimensioning process that included, modeling, component selection, programming and module assembly. The final product is a scale model of an electrolysis system based on the use of water, which is versatile and portable, and also has direct current power source feeding in order to generate a sustainable system in the future.
Once the module finishes its configuration and the measurement instruments are calibrated and / or verified, we highlight the indication through the LCD display of real data. The module is put into operation and a series of experimental tests are carried out that show production of hydrogen and oxygen, measured through two flow indicators or rotameters as presented in Figure 16, with a hydrogen flow of 2 liters per minute and an oxygen flow of 1 liter per minute. Hydrogen was produced through the connection of the plates to the positive terminal of the source and oxygen in the plates connected to the positive terminal.

The module produced 1 litter of oxygen per minute and 2 litters of hydrogen per minute with a current draw of 16 amps at a constant voltage of 11.6 Volts. Figure 17 presents the values of hydrogen and oxygen flow with current variation, where it was shown that the flow of gases varies with the flow of current consumed by the cell, provided that the voltage remains constant. This increase in the flow of gases may be the product of the electrolytic solution of the water, that is, of the amount of sodium hydroxide that varies with respect to the electrical resistance of the water, generating the current change.
or the temperature change, product of water heating for the production of hydrogen despite not being a system designed to produce it in the vapor phase, which is usually more efficient.

![Graph](image1.png)

**Figure 17.** Flow (H₂; O₂) relative to the current

Additionally, the temperature reached by the cell with a current consumption of 16 amps is 65 °C, with respect to the tank temperature which is 26 °C, with a temperature increase of 39 °C. This incurs a 150% increase compared to initial system temperature. Finally, the figure 18 shows the relationship between the flows of hydrogen and oxygen gases with respect to temperature, where a significant increase in temperature is evident as the gas is produced. If we compare it with the previous figure, the current increase is linear and the temperature increase is not.

![Graph](image2.png)

**Figure 18.** Flow (H₂; O₂) from temperature
4. Conclusions

The flow of hydrogen and oxygen produced is related to the cell current h2, and this current depends on the amount of dilute sodium hydroxide in the water, since it increases or decreases the electrical conductivity of the water, obtaining a maximum current consumed from 16 amps for our case study with a production of 2 liters per minute of hydrogen and one liter per minute of oxygen. Two aspects are important to highlight; The first is that in the present study the composition of the water was not analyzed, so the amount of sodium hydroxide present is unknown, and the second is that, depending on the region where the equipment is used, production may be affected or benefited by the composition of the water.

The temperature in the cell is another factor that directly influences the amount of production of hydrogen and oxygen by the electrolysis module. In the system presented in this Paper, it was observed that with the increase in the flow of gases, in the same way, the increase in temperature up to 60 °C. It is important to highlight that the system benefits from the increase in temperature, it cannot be compared with a Large-scale water vapor electrolysis system that handles temperatures up to 700 °C.

The current system presents losses due to convection, conduction and radiation; this is because the increase in the temperature of the cell causes the water to evaporate, generating humidity present in the exhaust gases. For the current model, saline gases were not measured, so their composition is unknown.

The current system is a functional module, capable of producing hydrogen and oxygen from the use of a direct current source. The system was designed in such a way that the module can supply electrical consumption through the power source for a photovoltaic solar system that generates the demand for the prototype. The use of a 12v charge regulator and a system between two and three panels connected in parallel is recommended. This recommendation is made from a manual estimation product of the ampere hour method, for this reason it is important to validate the chosen system through a specialized simulation.

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