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Research Article

Development of a Prototype for Green Hydrogen Production from Natural Sources

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ABSTRACT

The photovoltaic conversion of solar radiation into electricity is one of the ways to harness solar resources. This is achieved through solar cells. A system that combines a photovoltaic array with an electrolyzer allows for the storage of electricity in the form of gas (hydrogen). It is true that hydrogen (H) is one of the most abundant elements on Earth, but it is not available in its pure form in nature. The emerging world needs energy to grow and support its development. This translates into a greater need for electricity production capacity and an increased demand for gas, as economic growth cannot occur without an expansion in energy supply. Ultimately, 90% of new energy needs will be in these regions, and it is our role to support this growth. Due to the acceleration of population growth, energy from fossil resources (oil, coal, natural gas or nuclear) is insufficient to meet the growing energy needs of the planet and has a significant impact on the environment. Moreover, these energies are not renewable. A workable solution must therefore be found. Producing electricity from renewable energies is a solution for the future. For example, Algeria is considered as one of the important countries that have enormous environmental capacities to exploit these energies. This is what prompted us to carry out this work which relates to the study of the system for the improvement and production of green hydrogen by electrolysis from solar energy and sea water, hydrogen being a source of electrical energy in order to use it as fuel because of its distinctive chemical and physical properties and does not cause any polluting emissions. [2]

Keywords: green hydrogen, water electrolysis, solar energy, sea water

1. Introduction

Algeria initiates a green energy dynamic by launching an ambitious program for the development of renewable energies and energy efficiency. This vision of the Algerian government is based on a strategy focused on harnessing inexhaustible resources like solar energy and using them to diversify energy sources and prepare Algeria for the future. Through the combination of initiatives and expertise, Algeria is committing to a new sustainable energy future. To this end, a national renewable energy development program has been mapped out for the period 2011-2030, aiming, in the long term, to produce 40% of the country's electricity consumption from solar energy sources.

This program plans to install nearly 22,000 MW of capacity, with 12,000 MW intended for domestic demand and 10,000 MW for export [1]. Emerging markets need energy to grow and support their growth. This notably translates into more electricity production capacities and an increased need for

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Research Article

gas, as without growth in energy supply, there can be no economic growth. This is where 90% of the new demand will eventually be, and this is where our role is to support that growth [3].

Thus, the needs of the emerging world are both quantitative and qualitative, and they must be met through appropriate production methods. The photovoltaic conversion of solar radiation into electricity is one of the ways to harness solar energy. This is achieved through solar cells. A system combining a photovoltaic field with an electrolyzer allows for electricity storage in the form of gas (hydrogen).

It is true that hydrogen (H) is one of the most abundant elements on Earth, but it is not available in its pure state in nature. It is only found in a combined form. Green hydrogen is a renewable energy source produced by splitting water molecules into hydrogen and oxygen using renewable electricity. This process, known as electrolysis, generates hydrogen without any emissions. Additionally, the byproducts of its combustion are non-polluting, which, combined with economic and ecological reasons, makes hydrogen's time as an energy carrier appear to have come.

In fact, almost all the hydrogen available today comes from natural gas reforming. Thermochemistry is still in the laboratory stage, and electrolysis accounts for less than 1% of the total hydrogen production capacity. The latter is only used if the electricity is either surplus (as in the case of renewables like wind or solar) or cheap and/or if a high purity of the produced hydrogen is required.

Currently, the increasing reliance on renewable sources is leading to the development of electrolysis, a process well-suited for the valorization of these new energies. In addition to physical solutions, such as compressed or liquefied gas—which are still largely unsatisfactory at this stage—original chemical solutions are being explored, including hydrometallurgy and porous solid materials.

I could conclude by saying that the study of this subject is one of humanity's great scientific adventures, which is equally exciting. Our objective is to contribute to a better understanding of a new technology for the production and storage of clean energy. [4]

2. Material and methods

2.1 Experimental devices and equipment

This study will allow us to design and produce a production prototype (PV-Thermal) composed of an electrolysis of seawater supplied by two PV-thermal panels (hybrid). It is a new technology for the production of green hydrogen from natural sources.

2.1.1 Selection of photovoltaic modules

A photovoltaic cell produces electrical energy by converting light from solar radiation into direct electricity through the use of semiconductors that exhibit the photovoltaic effect. The process of photovoltaic conversion relies on three key mechanisms: the absorption of photons by the material of the cell, the transformation of photon energy into electrical energy (which involves the generation of electron-hole pairs in the semiconductor), and the collection of these generated particles. For photovoltaic cells to function effectively, the materials used must possess two distinct energy levels and demonstrate adequate conductivity to facilitate the flow of current. This underscores the critical role that semiconductors play in the photovoltaic industry. [3]

After conducting research to determine the appropriate type of photovoltaic modules and consulting with specialists in photovoltaic electricity, three type photovoltaic modules were selected. The first one is The Solar Pro 50W solar panels shown in figure 1.a , made with monocrystalline technology, provide a power output of 50 watts each, allowing for a total production of 100 watts when installed in parallel. Each panel operates a current at maximum power Imp = 2.70 A, a voltage at maximum power Vmp = 18.24 V, a short-circuit current Isc = 2.97 A and an open-circuit voltage Voc =21.8 V. The standard dimensions of the panels are approximately 670 mm x 550 mm x 30 mm, and they typically weigh between 5 and 6 kg. With an efficiency of around 15 to 20%, these panels are designed to maximize space utilization. Additionally, they feature a temperature coefficient of about -0.4%/°C, meaning they lose less efficiency as the temperature increases.

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The seconde one, The LAGUA Solar Panel 80W (figure 1.b) is a high-performance polycrystalline solar panel designed to provide efficient energy conversion. With a power output of 80 watts, this panel operates a current at maximum power Imp = 4.44 A, a voltage at maximum power Vmp = 18 V, a short-circuit current Isc = 4.80 A and an open-circuit voltage Voc =22.32 V. The panel features durable construction, ensuring resistance to weather elements, and is designed for easy installation on rooftops or ground-mounted systems. With a size of around 1,640 mm x 670 mm x 35 mm, the LAGUA Solar Panel 80W strikes a balance between compactness and efficiency, making it an excellent choice for off-grid applications, battery charging, and enhancing energy independence. The third one is a hybrid solar panel figure 1.c, also known as a mixed solar collector, is a system that uses both thermal and photovoltaic sensors to operate. An 8-meter coiled copper tube is used at the back of the LAGUA Solar panel, forming a closed circuit to heat seawater with the aim of increasing green hydrogen production and cooling the solar cells to improve the efficiency of the panel. From this, we can say that the innovative idea is to use a hybrid (PV-Thermal) panel.

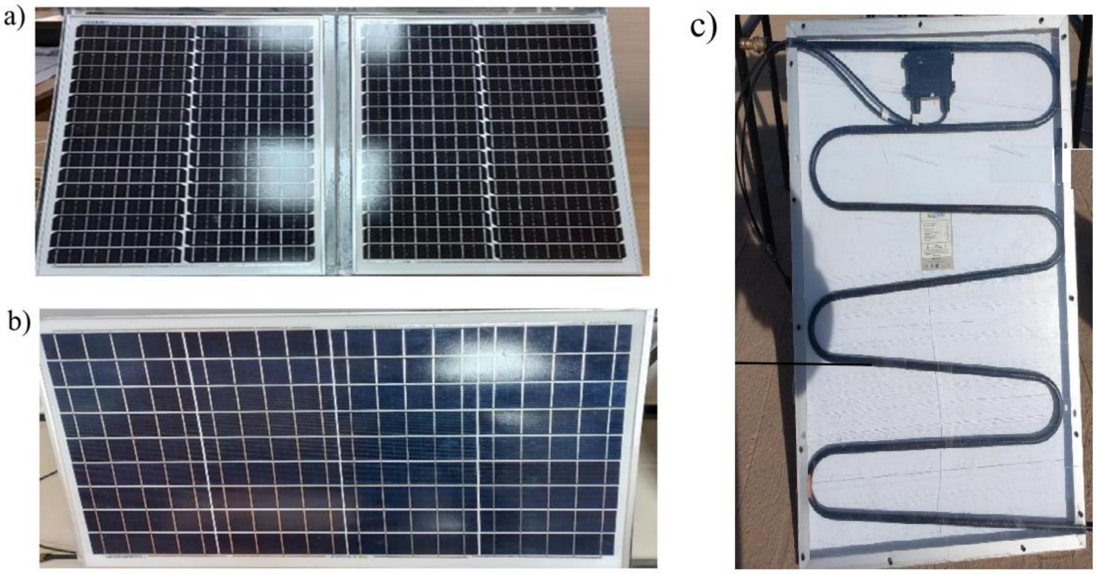

Figure 1. a) Two panels in parallel (Solar Pro), b) LAGUA Solar Panel, c) hybrid solar panel.

2.1.2 Alkaline Electrolysis

Alkaline electrolysis, is a hydrogen production method that involves the separation of oxygen and hydrogen from water through the application of an electric current in an alkaline solution. In this process, an electrolyte, typically potassium hydroxide (KOH) or sodium hydroxide (NaOH), is used to enhance the conductivity of water. When an electric current is applied, water molecules are split at the electrodes: hydrogen is produced at the cathode, while oxygen is generated at the anode. This method is well-established in the industry and is known for its efficiency and cost-effectiveness, making it a vital technology for the sustainable production of hydrogen.

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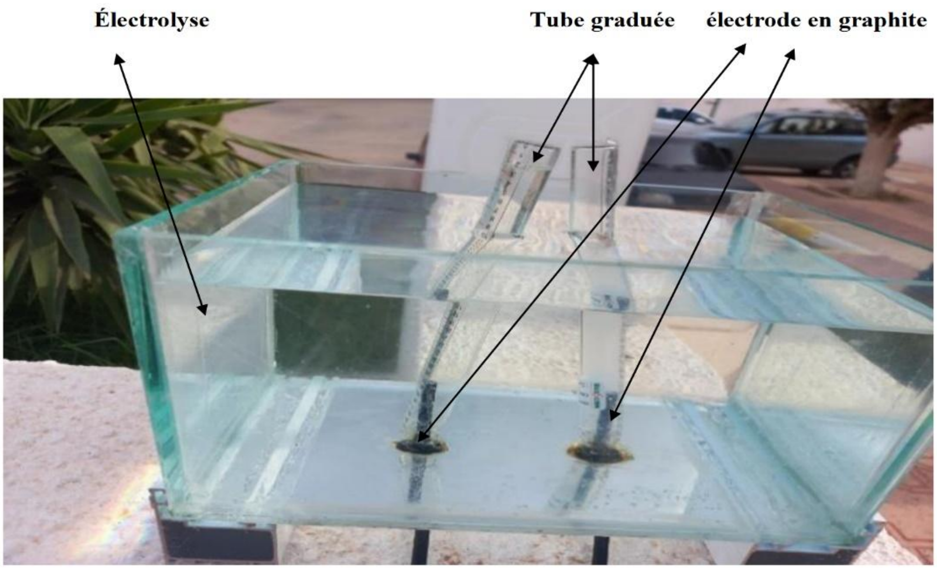

Figure 2. Elements of Water Electrolysis

The catalyst used, as illustrated in Figure 2, comprises several essential components for our experiment. The graduated cylinder, a laboratory instrument for accurately measuring volumes, was used to measure the hydrogen produced in cubic centimeters (cm^3), with each of the two cylinders having a volume of 35 cm^3. The glass tank was designed with two 6 mm holes in the center to accommodate the anode and cathode, both made of carbon, with each electrode measuring 6 mm in thickness and 5.5 cm in length. The surface area of these carbon electrodes is 10.36 cm^2, and the total volume of the glass tank is 11.178 L. The cathode functions as the electrode where the reduction reaction occurs, known as cathodic reduction, and corresponds to the positive terminal (+) in a battery. Seawater was chosen for this experiment due to its rich ionic content, characterized by a salinity of 35 g/L.

2.1.3 Experimental scenarios on 50W and 80W Solar Panel:

In this work, the Algerian region of Tlemcen, its latitude is 34.27° so we used a metal support inclined at 34° to have the maximum solar radiation on the panels, was selected as the study area. This section outlines the steps taken to prepare for the various experimental tasks, beginning with the purchase of technically photovoltaic modules (PV 50W) and (PV 80W), followed by the manufacture of water electrolysis, and the acquisition of various measuring instruments. The experiment was conducted on February 13, 2023, from 10:00 AM to 12:00 PM, and involved alkaline electrolysis powered by two 50 W photovoltaic panels connected in parallel, providing a total power of 100 W figure 3. The same day, from 12:00 PM to 2:00 PM, the two 50 W panels were replaced with two 80 W panels, also connected in parallel, yielding a total power of 160 W figure 4. And on May 29, 2023, from 10:00 AM to 1:00 PM this experiment was conducted, involving alkaline electrolysis powered by two 80 W photovoltaic hybrid panels connected in parallel, with a total power output of 160 W figure 5.

All climatic parameters, including solar radiation, wind speed, and ambient air temperature, were measured experimentally using the equipment to measure the electric current, voltage, and electrical resistance of the system, along with their quantities, characteristics, accuracy, and uncertainty.

Measuring equipment used in experimental work are:

- The multimeter, often referred to as a voltmeter, is a tool used to measure voltage, current, resistance, and temperature. To use it, place the wire leads into the appropriate terminals: the black lead into COM and the red lead into VΩ. Select AC voltage (VAC) or DC voltage (VDC), depending on the measurement needed.Be cautious, as measuring voltage with the lead set to mA or 10A can destroy the device's fuse. Place the test probes in parallel with the terminals of the device to be measured.

- A luxmeter is a sensor used to measure illuminance within the visible spectrum. The measurement is absolute, not relative. The unit of measurement is lux.
- A thermocouple is a sensor used to measure temperature. It consists of two different types of metals joined at one end. When the junction of the metals is heated or cooled, a variable voltage is produced, which can then be converted into a temperature reading.
- A stopwatch is a time-measuring instrument. We use it to calculate the time taken to fill the tube with hydrogen gas.
- A Convertisseur est un appareil électronique qui produit du courant alternatif à partir du courant continu. Il est directement connecté aux batteries.
- Batteries are optional components in a photovoltaic system and are used to store electricity for the regulator and the inverter.
- Le régulateur est une unité électronique dont le rôle est de gérer les flux de courant.

Figure 3. Experience using 50 W panels.

Figure 4. Experience using 80 W panels.

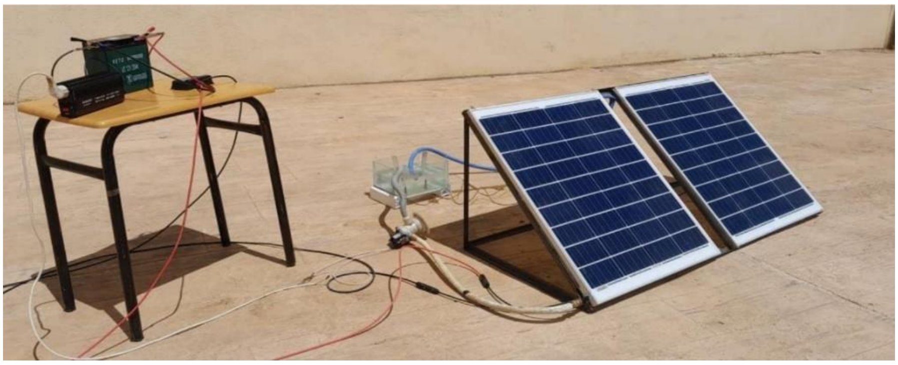

Figure 5. Experience using 80 W hybrid panels.

Journal of Information Systems Engineering and Management
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Research Article

3. Results and discussion

The experimental work was conducted on the 13 of February and 29 of May of the year 2023 in Tlemcen area (latitude is 34.27°, metal support inclined at 34° to have the maximum solar radiation on the panels) at northwest Algeria. Measurements were taken for three experiments using 50 W panels, 80 W panels, and 80 W hybrid panels. the parameters determined in this experiment are: water temperature (Te), ambient temperature (Ta), panel temperature (Tp), illuminance E, voltage U, current I, volume of hydrogen VH_2, and volume filled each minute ΔV.

Using 50 W panels and analyzing the curve representing the variation of H_2 volume as a function of time figure 6.a, it is observed that it takes 18 minutes to produce 32.5 cm³ of hydrogen. This indicates a relatively consistent production rate within this timeframe, allowing for an evaluation of the efficiency of the electrolysis process under the specific conditions of the experiment. Upon examining the curve representing the variation of illuminance as a function of $ΔV_1$ figure 6.b, it can be concluded that illuminance and the change in volume $ΔV_1$ occur simultaneously. This correlation suggests that as the illuminance increases, there is a corresponding change in the volume of hydrogen produced, indicating a direct relationship between light intensity and the efficiency of the electrolysis process. According to the curve representing the variation of current I_1 as a function of illuminance E figure 6.c , it is observed that the current I_1 varies proportionally with the illuminance, reaching a maximum value of 593.51 W/m². This indicates a strong relationship between the intensity of the light and the current produced, suggesting that as the illuminance increases, the current also increases, enhancing the overall efficiency of the electrolysis process. It is observed that both illuminance and current are parameters that influence the production of H_2 figure 6.d. The relationship between these factors suggests that higher light intensity and current levels contribute positively to the efficiency of hydrogen production during the electrolysis process. Understanding how these parameters interact can help optimize the conditions for generating hydrogen, making the system more effective.

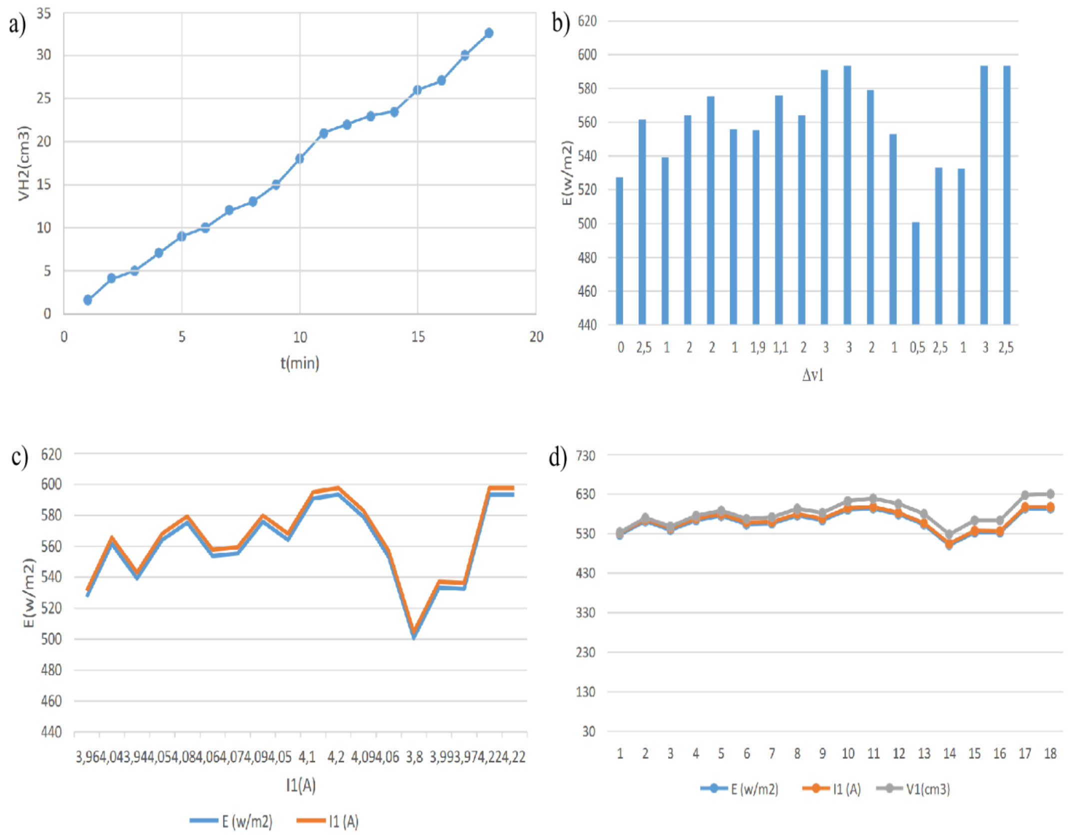

Figure 6. The Variations Using 50 W panels a) of H_2 Volume as a Function of Time, b) of H_2 Volume as a Function of Time, c) of Current as a Function of Illuminance and d) of H_2, I_1, and Illuminance.

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Research Article

Switching to 80 W panels and analyzing the curve of H_2 volume as a function of time (Figure 7.a), it is observed that hydrogen production increases, taking only 13 minutes to produce 33.8 cm^3. The curve of H_2 variation as a function of illuminance (Figure 7.b) reinforces the simultaneous nature of illuminance and hydrogen production, suggesting that higher light intensity results in more hydrogen being produced, thus improving electrolysis efficiency. The curve illustrating ΔV and current I (Figure 7.c) shows that the volume of ΔV_2 increases as amperage rises, indicating a direct link between the current and hydrogen production.

Finally, there is an inverse relationship between voltage and temperature (Figure 7.d), where higher temperatures lead to decreased voltage, potentially impacting the system's efficiency. Higher temperatures can negatively affect voltage output, reducing the overall effectiveness of the electrolysis process.

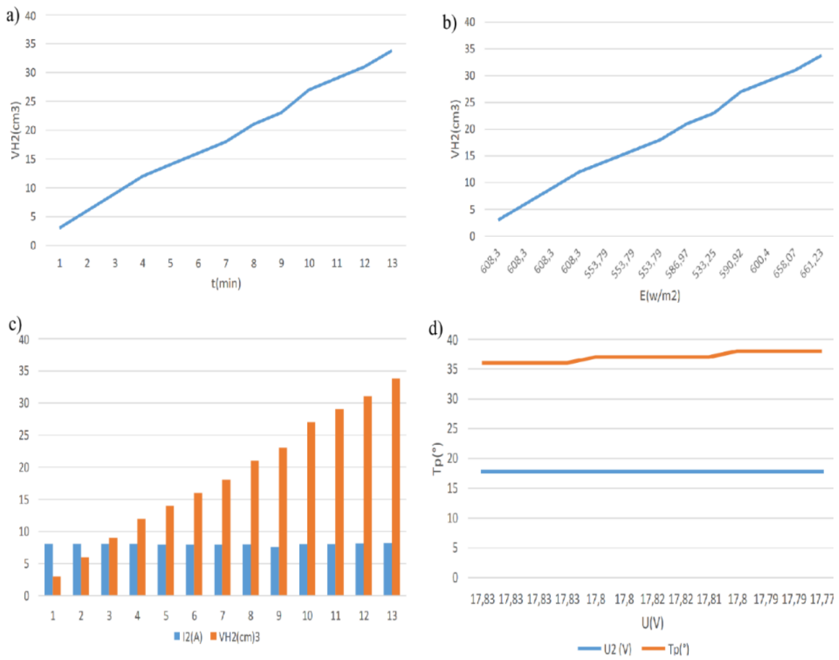

Figure 7. The Variations Using 80 W panels a) of H_2 Volume as a Function of Time, b) of H_2 Volume as a Function of Illuminance, c) of ΔV as a Function of Current I and d) of tension U and temperature.

Based on Experiment 2 (80 W panels), we can conclude that the panel temperature negatively affects the system's performance, leading to a decrease in total power output. This is primarily due to the reduction in voltage, which subsequently lowers the overall efficiency of the system. In the 80W panel, the production time is shorter compared to the 50W panel. The volume of hydrogen collected in the tube with the 80W panel is greater than that of the 50W panel. Additionally, the volume filled per minute with the 50W panel is lower than that with the 80W panel. Furthermore, the maximum voltage of the 80W panel is higher than that of the 50W panel. A comparison between the 50W PV panel and the 80W PV panel is presented in Table 1.

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Research Article

Table 1. Comparison of parameters between 50W PV and 80W PV.

Parametrs	PV (50W)	PV (80W)
Production Time (min)	18	13
Volume of hydrogen (cm^3)	32.5	33.8
Amperage I_{max}	4.22	8.2
Δvm (cm^3)	1.77	2.36
Voltage (V)	17.83	17.99

Using 80 W hybrid panels, and according to the curve showing the variation of H2 volume over time in (Figure 8.a), it takes 10 minutes to produce 34 cm^3 of hydrogen. This observation highlights a relatively fast production, which may be linked to the efficiency of this electrolysis system. The curve of the variation of water temperature Te as a function of Δv (Figure 8.b) is linear, indicating that the volume of Δv increases with the rise in water temperature.

This linear relationship suggests that as the water heats up, the volume of gas produced, particularly hydrogen in the context of electrolysis, increases. This can be attributed to the acceleration of electrochemical reactions at higher temperatures. Noting also that the relationship between voltage and temperature is inverse; as the temperature increases, the voltage decreases (Figure 8.c).

This inverse correlation indicates that higher temperatures can negatively affect the voltage output, potentially reducing the overall efficiency of the system. It is evident that both illuminance and amperage play crucial roles in influencing hydrogen production (H_2) (Figure 8.d). Higher levels of illuminance correlate with increased amperage, which enhances the electrolysis process. This relationship underscores the importance of optimizing light exposure and current levels to maximize hydrogen generation efficiency. Understanding how these parameters interact can significantly contribute to improving the overall performance of the electrolysis system and the effective production of hydrogen.

From this last experiment (Using 80 W hybrid panels) , we can conclude that the volume of hydrogen (H_2) increases with the rise in water temperature, illuminance, and amperage. This observation suggests that optimizing these factors can enhance the hydrogen production efficiency during the electrolysis process. As the water temperature rises, along with increased light exposure and current levels, the electrolysis system performs better, leading to greater hydrogen generation. Understanding this relationship is essential to improving the overall efficiency of hydrogen production methods.

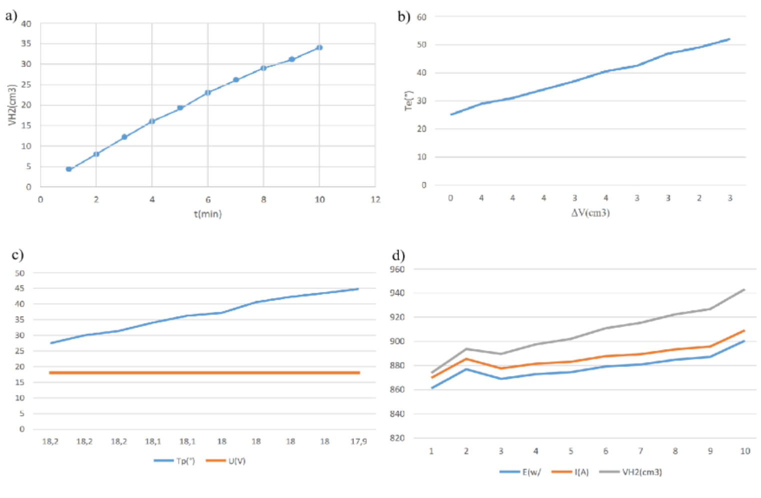

Figure 7. The Variations Using 80 W hybrid panels a) of H_2 Volume as a Function of Time, b) of Te as a Function of ΔV , c) of tension U and temperature, and d) of Illuminance, H_2 Volume and amperage.

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Research Article

Conclusion:

Based on our experiment, we can conclude that three main parameters influence the production of green hydrogen from photovoltaic energy: water temperature, illuminance, and current. Increased illuminance leads to a corresponding increase in current, enhancing the electrolysis process. The electric current is directly proportional to the volume of hydrogen produced, demonstrating the importance of optimizing current levels for efficient electrolysis. Additionally, closed circuit parameters affect seawater temperature, with warmer water significantly influencing hydrogen production, indicating that maintaining an optimal temperature is crucial for efficiency. Utilizing natural photovoltaic and solar thermal sources for green hydrogen production ensures non-polluting options. Furthermore, renewable energy sources, particularly solar energy, have been harnessed as the primary source of electrical current for water analysis, ensuring the operation of a circulation pump and employing solar thermal energy for heating water, which is a major factor in increasing green hydrogen production. Understanding these parameters and their interactions can help optimize conditions for more effective hydrogen production, contributing to sustainable energy solutions.

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