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# EXPERIMENTAL STUDY OF THE PRODUCTION OF SOLAR HYDROGEN IN ALGERIA

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## ABSTRACT

Hydrogen is a sustainable fuel option and one of the potential solutions for the current energy and environmental problems. In this study hydrogen is produced using a hydrogen generator with a Proton Exchange Membrane (PEM) electrolyser. An experimental study is done in the Center of Development of the Renewable Energy, Algiers, Algeria.

The experimental device contains essentially a photovoltaic module, a PEM electrolyser, a gasometer and the devices of measures of characteristics of the PEM electrolyser as well as two pyranometers for the horizontal and diffuse global radiance registration. This system in pilots scale is permitted on the one hand, to measured and analyzed the characteristics: of the PEM electrolyser for two different pressures of working (Patm and P=3 bar), on the other hand, to study the volume of hydrogen produces in the time with different sources of electrical power (generator, photovoltaic module, fluorescent lamp), the efficiency for every case is calculated and compared. We present in this paper the variation of the solar hydrogen flow rate produced according to the global radiance and according to the time for a typical day's of August.

**Keywords:** PEM electrolyser, Irradiation, photovoltaic panel, efficiency.

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## 1. INTRODUCTION

Hydrogen is considered as the energy carrier of the future [1, 2], in the so-called hydrogen economy [3, 4]. It can be produced using solar energy in different ways namely; using solar electricity and solar thermal energy [5, 6]. The solar electricity can be used in an electrolyser to dissociate the distilled water into hydrogen and oxygen. Stand-alone PV-electrolysis systems for solar hydrogen fuel production have consisted of an array of photovoltaic modules that supplies DC electricity through storage and power conditioning systems to an electrolyser as shown in major projects in California, Germany, and Saudi Arabia [7–14].

Water electrolysis is considered to be one of the key technologies for hydrogen generation as it is compatible with existing and future power generation technologies and a large number of renewable technologies (solar, biomass, hydro, wind, tidal, wave, geothermal, etc.). Currently most of the commercial water electrolysis technologies use acidic or alkaline electrolyte systems for hydrogen generation. Typical efficiencies quoted are in the 55–74% range with most commercial systems having efficiencies below 65% [15, 16]. The current density is typically around 0.3–0.4 A/cm2 and there are technical difficulties in maintaining the electrolyte balance and keeping hydrogen and oxygen separated. More recently a solid state water electrolysis technology based on polymer electrolyte membrane has been under development and is being commercialised [17–19]. The PEM electrolysis systems can respond rapidly to varying power inputs and therefore can be easily integrated with renewable energy systems. PEM electrolysers operate at relatively low temperatures, typically at 80 °C or below and are generally composed of numerous cells stacked in series. Guillaume Doucet et all. [20] have studied the general characteristics of an integrated and automated hydrogen-based auxiliary power unit (APU). A PEM water electrolyser (production capacity ranging from zero up to 1 Nm3 H2/h), which can be powered by a panel of photovoltaic cells, is used to produce hydrogen at day hours. R.E. Clarke et all. [21] have constructed a complete stand-alone electrolyser system as a transportable unit for demonstration of a sustainable energy facility based on hydrogen and a renewable energy source. The stand-alone unit is designed to support a polymer electrolyte membrane (PEM) stack operating at up to approximately 4 kW input power with a stack efficiency of about 80% based on HHV of hydrogen. Thomas L. Gibson et all. [22] have optimized the efficiency of the PV-electrolysis system by matching the voltage and maximum power output of the photovoltaic to the operating voltage of proton exchange membrane (PEM) electrolysers. The optimization process increased the hydrogen generation efficiency to 12% for a solar powered PV-PEM electrolyser that could supply enough hydrogen to operate a fuel cell vehicle. In our study [23] an experimental study is done in the Center of Development of the Renewable Energy, Algiers, Algeria; hydrogen is produced using a Proton Exchange Membrane (PEM) electrolyser supplied by PV panel; when an electric voltage is applied, hydrogen and oxygen are formed. The electrical properties of the electrolyser are investigated by recording a current-voltage characteristic line. To determine the efficiency, the gases are stored in small gasometers in order to be able to measure the quantities of the gases generated.

## 2. DESCRIPTION OF THE SYSTEM

The system consists of a 0.46 W photovoltaic module (PV), a 0.64 W Proton Exchange Membrane electrolyser, a generator with a variable voltage, fluorescent lamp of a 1000 W, two gazometers with capacity of a 250 ml and the devices of measures of characteristics of the PEM electrolyser as well as two pyranometers (PYRANOMETRE EPPLEY PSP) for the horizontal and diffuse global radiance registration. The experiences are summarized by the following detailed block diagram:

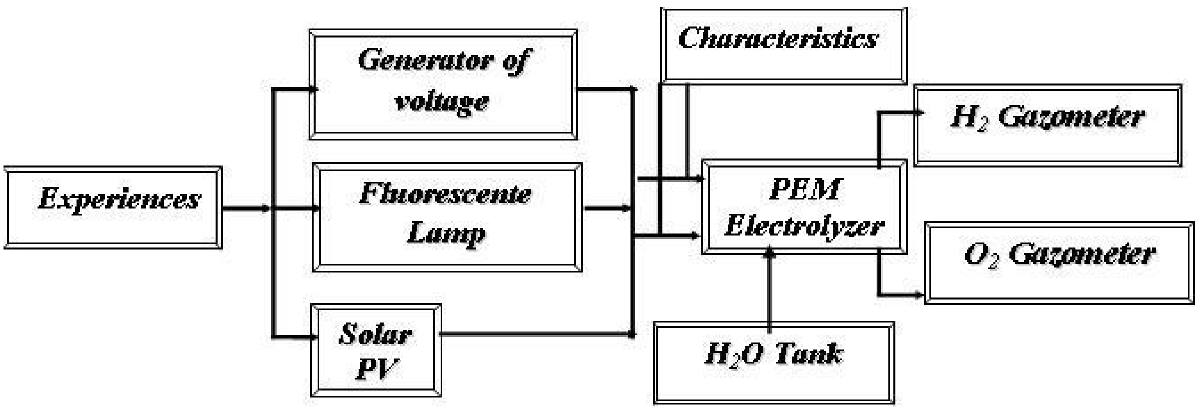


**Fig.1.** schematic description of the experiences

The principal part of the PEM electrolysis unit is a membrane-electrode unit. A layer of catalyst material has been applied to both sides of the thin proton conducting membrane

(PEM = proton exchange membrane). These two layers form the anode and cathode of the electrochemical cell. As we see in fig. 2, on the anode side gaseous oxygen, electrons and H+ ions are formed when an external voltage is applied. The H+ ions pass through the proton-conduction membrane to the cathode and form gaseous hydrogen there with the electrons flowing through the external conducting circuit. In this way, electrical energy is transformed into chemical energy and stored in the form of hydrogen and oxygen.

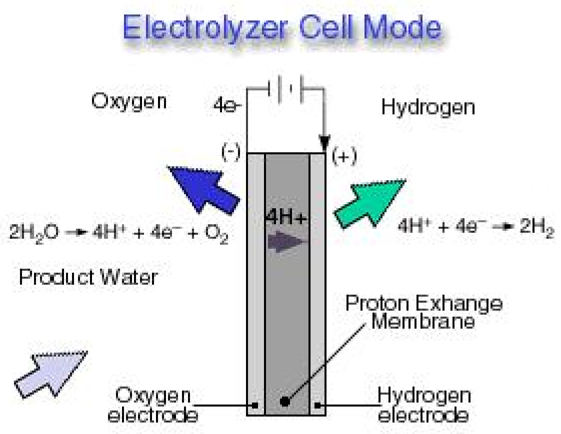


**Fig.2.** Functional principle of a PEM electrolyser

Electrolyser generates hydrogen and oxygen in a ratio of 2:1 (fig.2), the volume of the hydrogen generated is measured as a function of the time t. The start of the time measurement when the water in the gasometer (H2) passes the lower mark; we measure the voltage U and the current I during electrolysis. We repeat this experiment with another current.

## 3. EXPERIENCES

Several experiences are made first of all to compare the characteristics of the PEM electrolyser for two different pressures, the experimental set-up is performed according to fig. 3.

**Fig.3.** Production of hydrogen with an electrolyser supplied by a generator in the CDER laboratory

Second, we determine the volume of hydrogen produced as well as by solar way (fig. 4) and by the two others ways which consist on the one hand to simulate the sun with a fluorescent lamp in the laboratory (fig. 5). And on the other hand to supply the PEM electrolyser by a generator of voltage in the laboratory (figure 3).

**Fig.4.** Installation of the production of solar hydrogen in the CDER

Finally, we determine the efficiency of the electrolyser; the electrical Wel and the chemical WH2 energies of the generated hydrogen are calculated.

$$Wel = U.I.t \tag{1}$$

$$WH2=n.H \tag{2}$$

Where U = voltage,I = current,t = time,n = quantity of hydrogen,H = molar caloric content (molar reaction enthalpy) of hydrogen.

One differentiates between the lower caloric content Hu and the upper caloric content Ho.

The difference between the two is the molar enthalpy of vaporisation (condensation enthalpy) q of water.

$$Ho = Hu + q$$

The efficiency of the electrolyser can be calculated using equations (1) and (2):

$$\eta = \frac{W_{H2}}{W_{el}} \tag{3}$$

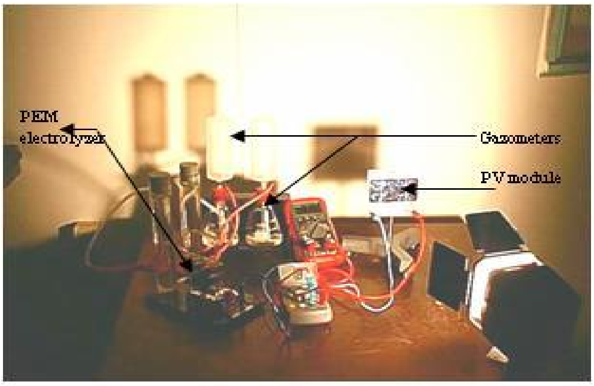


**Fig.5.** Production of hydrogen with an electrolyser supplied by fluorescent lamp in the CDER laboratory

## 4. RESULTS

The results are presented in the following paragraphs. First, of the PEM electrolyser for two different pressures of working (Patm and P=3 bar) are shown. Then, volume of hydrogen produces in the time with different sources of electrical power (generator, Photovoltaic module, fluorescent lamp). Finally, we calculate the efficiency for every case.

### Characteristics

The performance of the PEM electrolyser for two different pressures of working Patm and P=3 bar in the experience shown in (figure 3) is presented in fig. 6.

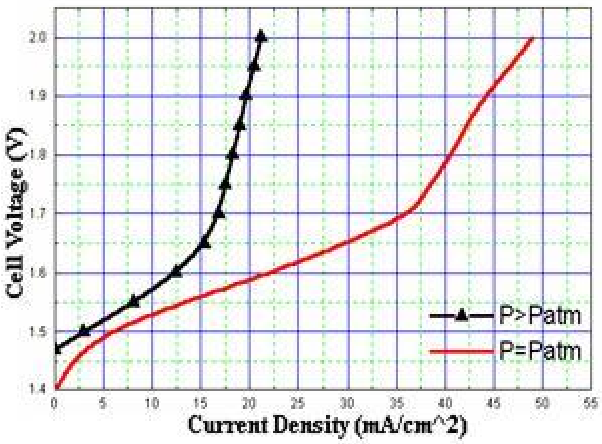


**Fig.6.** variation of the cell voltage and the current density as function of pressure

Operating pressure has a significant influence on PEM electrolyser performance. The effect of an increase in oxygen pressure from Patm to 3 bars produces an ideal voltage increase of 0.06 V and a current density decrease of 26 mA/cm2 at 2 V. These results demonstrate that an increase in the oxygen pressure leads to a significant improve in the polarisation at the cathode.

**Hydrogen production**

The system was operated every day over five months period of March to July 2001, and data where segregated for a typical day in June. The most important parameter to be measured is the amount of hydrogen produced and stored in the gazometers from a given amount of solar energy.

We have establish input values for global radiance in function of the flow rate of hydrogen production for a typical clear day with a temperature range of 30-35 °C [4],(see fig.7).

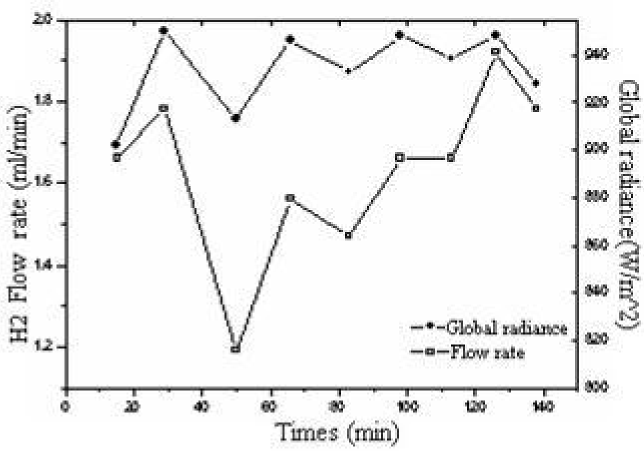


**Fig.7.** the flow rate of hydrogen produces as function of global radiance and time

The variation of the production of gaseous hydrogen by the PV produced dc electricity which supply the electrolyser were proportional on the global radiance intensity and have an approximately value of 1.98 ml/min for a 960 W/m2 solar radiation. Also we can see in figure 8 the volume of hydrogen produced with each kind of supply use in the experiences.

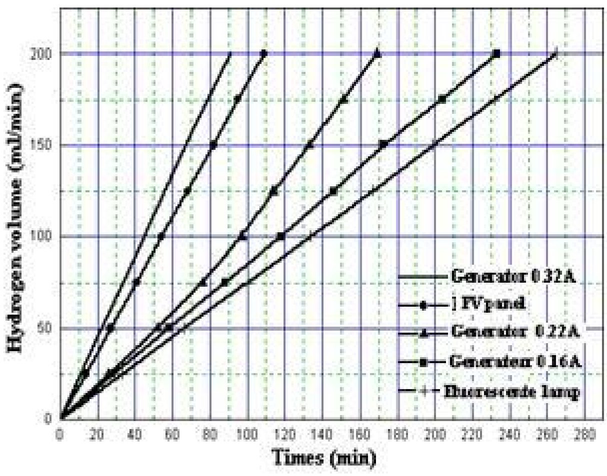


**Fig.8.** volume of hydrogen produced for different case as function of time

The fig. 8 shows the change of the quantity of hydrogen produces according to the time. We can see that the volume of hydrogen is more important in the case of the experience in the roof of the laboratory, and that because of the more important temperature which is favoured by the solar radiation.

**Efficiency**

We have calculated the efficiency of the PEM electrolyser in different experiences; results are presented in the table shown below:

| Supplies | Generator 0.32A 640mW | Generator 0.22A 383mW | Generator 0.16A 264mW | Solar radiation 0.22A 461mW | fluorescent lamp 0.13A 204mW |
|---|---|---|---|---|---|
| Efficiency % | 92.53 | 71.54 | 70 | 91.55 | 70.50 |

The efficiency of the electrolyser is greatly dependent on the respective operating condition. We can see that the efficiency of solar hydrogen production is approximately as important as the hydrogen production by generator supply. As one would expect, the electrolyser efficiency is higher for higher temperature cosed by solar radiation in the experience in the roof of the laboratory shown in fig. 4.

## 5. CONCLUSION

Hydrogen is only as clean as the energy sources and feed stocks used to produce it. Because more energy is needed to create hydrogen than can be derived from it, it cannot be thought of as sustainable unless renewable energy sources are used to make it.

Reducing reliance on fossil and nuclear energy sources will free the nation from costly foreign involvement and improve the health and well being of its citizens. It will do this by significantly reducing greenhouse gas emissions and the amounts of other poisons attributable to fossil and nuclear energy sources in the air, land and water.

The promise of PV/electrolysis stems from their versatility in providing both fuel and power. Solar technology can provide power. Excess power generated at these times can be used to produce hydrogen via electrolysis. When the sun is not shining, stored hydrogen can be used to run electrical generators.

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