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Estimation of the Hydrogen Flux from a PEM Electrolyzer, based in the Solar Irradiation Measured in Zacatecas Mexico

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Abstract: *In this study, the calculated quantity of hydrogen produced in a typical Polymer Exchange Membrane (PEM) electrolyzer is presented. For the hydrogen flux calculation, solar irradiation data as measured by the "Siglo XXI" Solarimetric Station in Zacatecas, Mexico, was used. Solar data was obtained in the period from November 2007 to April 2008, when the mean irradiation measured was 6.6 kW-h* m^{-2}. *In order to obtain the estimation of* H_2, *a linear equation of the behavior pattern of a previously characterized Solar-Hydrogen (SH) system was used. The results indicate that the maximum hydrogen production would be obtained in April, with a value of 9 NL* min^{-1} *corresponding to a radiation intensity close to 900 W* m^{-2}, *while a minimum obtained hydrogen value was calculated as 6 NL* min^{-1} *with respect to a radiation close to 600 W* m^{-2} *for November.*

Keywords: Hydrogen, PEM, Solar irradiation, Zacatecas Mexico

1. INTRODUCTION

At present, the worldwide energy requirements are mainly obtained from fossil fuels. The massive utilization of fossil fuels is causing environmental pollution and global climate change. In order to reduce the detrimental effects caused by fossil energy systems, the use of hydrogen as an environmental clean energy carrier has been suggested. One of the most important points of view concerning hydrogen use is the synergy between this energy carrier and electricity and renewable energy sources. Since the 1980s the Hydrogen Energy concept has been used as a plausible approach to clean energy generation, particularly when the hydrogen gas is obtained from sources such as solar, wind, hydraulic and biomass [1-3]. The electrolysis of water has been recognized as the only current practical method for the production of hydrogen from renewable energy sources. Electrolyzers can be coupled to solar photovoltaic panels or wind turbines to obtain the necessary electricity for splitting the water molecule on the anode into oxygen, protons and electrons. The protons then pass on to the cathode and combine with electrons to form hydrogen. The electrolyzers are considered a kind of distributed way to produce hydrogen that could avoid the inconvenience of gas transport facilities [4-7]. Water can be regenerated later by using a fuel cell, thus completing the hydrogen-water cycle. At present, the estimated cost of obtaining hydrogen from electolyzers remains higher than the cost of producing the oil fuels currently used. However, it is thought that in a proximate future, based on continual technological development and an increase in the use of alternate energy resources, electrolytic hydrogen production costs could be reduced enough to be competitive [8].

A Solar-Hydrogen (SH) system usually consists of providing electric energy to an electrolyzer by means of a solar panel array of photovoltaic system (PVS). The coupling of systems must meet the following conditions:

-It must supply the minimum voltage to perform the water dissociation, theoretically 1.23 V vs NHE.

-It must contain the minimum necessary auxiliary systems in order to achieve the maximum global efficiency.

-Each subsystem, the electrolyzer and PVS, should work in their maximum power points in order to achieve the maximum effi-

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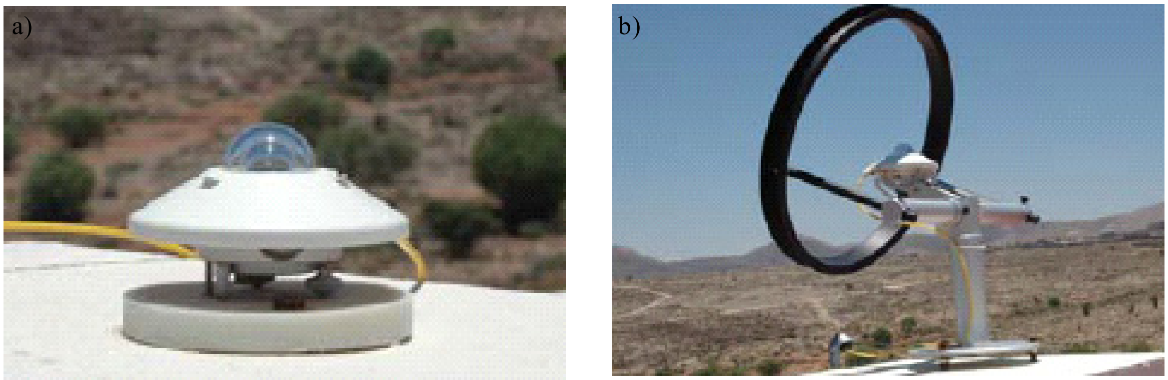

Figure 1. a). Global radiation pyranometer, b). Diffuse radiation pyranometer with shadow ring.

ciency [6].

Furthermore, the SH system generally uses batteries and DC-DC converters to modulate and condition the electrolyzer voltage [9-16].

Mexico is a country with a high solar radiation level and represents a potential locus for the development of SH systems. In particular, the northern region of the state of Zacatecas is situated in a maximum solar irradiation strip. As a contribution to a regional energy inventory, local solar irradiation measurements have been carried out in the "Campus Siglo XXI" Solarimetric Station of the Zacatecas University in recent years. In this study, based on the solar data obtained in the Zacatecas Solarimetric Station, an evaluation of the hydrogen volume produced by a typical SH system is presented. It is concluded that an important quantity of hydrogen as an energy vector could be obtained from the solar radiation as measured in the Zacatecas region.

2. EXPERIMENTAL SETUP

The solar measurements were carried out at the "Campus Siglo XXI" Solarimetric Station of the Universidad Autónoma de Zacatecas, located on the Zacatecas–Guadalajara road, km 6, Zacatecas. The diffuse and global solar radiation, temperature and pluvial precipitation were measured and registered at this station.

The Solarimetric Station has two CMP 22 (Kipp & Zonen) pyranometers with temperature sensors. The pyranometers, Figures 1a and 1b, are located at 22º46.50´ north latitude, and 102º38.615´ and 102º38.619´ west longitude for the global and diffuse radiation measuring, the latter attached with a M121 Kipp & Zonen shadow ring. Both pyranometers are situated at an altitude of 2,325 m over the mean sea level. No obstacles interfere in the free solar view. The acquisition data system (reading and storage) is a CR100 Data-Logger from Campbell Scientific, which is powered by an independent photovoltaic system with power supply and current regulator. The data was stored in a CFM flash memory module from Campbell Scientific.

The acquisition data system took measurements on a 10 s time interval basis; an average value is registered each minute. The database contains information since October 18, 2007. Solar radiation data for November 2007 to April 2008, considered the months with less irradiance, was used in this work.

The SH system used for the hydrogen estimation consists of a PVS located at the *Instituto de Investigaciones Eléctricas* (IIE) in Cuernavaca, Morelos, Mexico. It consists of 36 PV, monocrystalline silicon modules (Siemens and Shell SP75), with an inclination angle of 18.8 ° and a south orientation for maximum solar energy catchment. The PVS has a nominal 2.7± 10% kW power capacity.

Due its inherent low efficiency and to the local pressure and temperature conditions, the real PVS operation power is between 1.2 and 1.3 kW. The effective PVS area is 21.6 m^2, and considering a measured mean solar radiation of 686.5 W m^{-2}, the PVS efficiency was near to 7.72 %.

The hydrogen generator is a commercial (Hogen 40, Proton Energy systems) electrolyzer that produces 99.999% dry hydrogen by removing damp oxygen to the atmosphere, with a capacity of 1 Nm^3hr^{-1}. The main component of the generator is a polymeric solid electrolyte PSE cell stack, which works by means of pressure, flux, temperature, electric energy and water automatic controls. The electrolyzer nominal voltage is 50 V throughout 25 serial electrolytic cells; only one cell is maintained in parallel to achieve a constant individual cell current. The maximum electrolyzer hydrogen out pressure is 200 psi (13.78 bar).

3. RESULTS AND DISCUSSION

The characterization of the SH system used for hydrogen estimation has been reported previously [17]. Briefly, the main properties of the SH are shown in Table 1. A typical solar irradiance (*G*) vs

Table 1. Daily average value properties of the SH system

	Units	Mean value
Irradiance (G)	W/m^2	688.33
Power (P)	W	1316.18
Current (I)	A	30.64
Voltage (V)	V	42.82
Electrolyzer Temperature (Ts)	ºC	43.08
Ambient Temperature (Ta)	ºC	32.51
Panel Temperature (Tp)	ºC	51.17
Hydrogen Flux (Q_H)	LN/min	9.10
Hydrogen produced daily	LN	3691.27
Water consumption	L	2.21

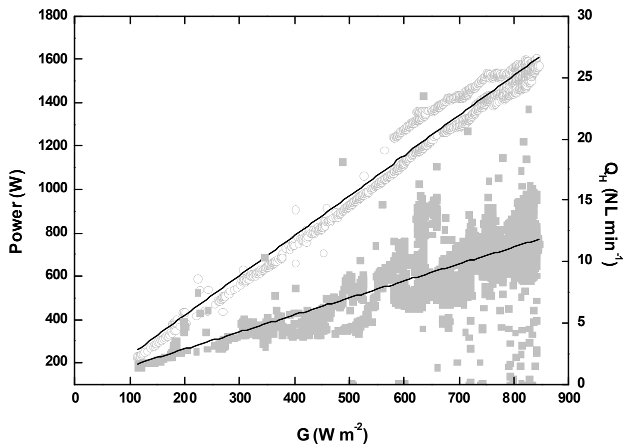

Figure 2. Typical power and hydrogen flux obtained from the SH system.

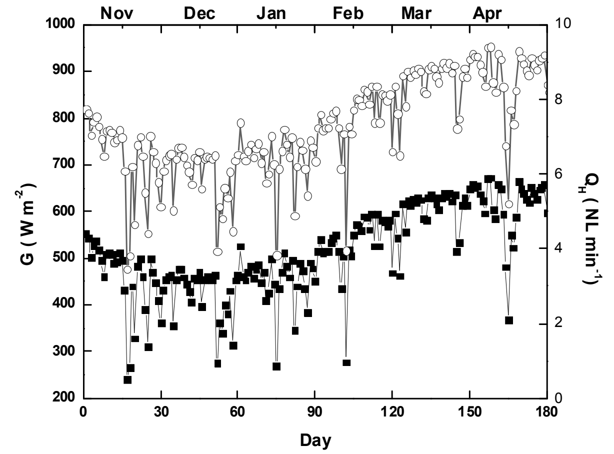

Figure 4. Daily mean irradiance (G, square symbol) measured and calculated hydrogen flux (Q_H, circle symbol).

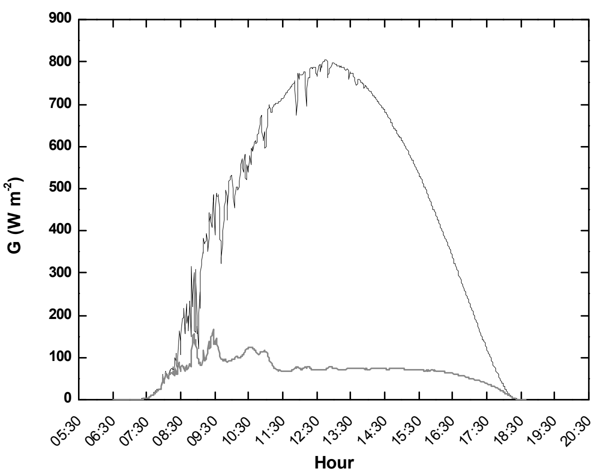

Figure 3. Global (upper line) and diffuse (lower line) irradiances corresponding to January 2, 2008.

quantity of hydrogen generated (Q_H) relation is presented in Figure 2. A great dispersion in experimental data can be seen clearly from this figure, mainly in the hydrogen flux obtained. The dispersion is attributed to the deleterious effect of moisture on the flux meter and to a possible parasitic consumption of hydrogen inside the electrolyzer.

In order to obtain a correlation equation between hydrogen flux and solar irradiance it was necessary to use a statistical procedure involving a pondered least square regression of data. This kind of adjustment was made to the data obtained from seven experimental series performed in the SH system during daily eight-hour measurements [17].

From the pondered statistical analysis of measurements, the following linear equation was obtained:

$$Q_H=bG+a \quad (1)$$

Where Q_H is the hydrogen flux in NL min^{-1} and G is the irradiance in W m^{-2}. The linear regression fitting parameters were: $b = 0.01384 \pm 0.00039$ y $a = 0.13 \pm 0.28$.

From Equation (1), an estimation of the hydrogen produced under Zacatecas solar conditions was made. For the calculations, the solar data measured for 180 days was used. As an illustration of "Campus Siglo XXI" Solarimetric Station measurements, Figure 3 shows the global and diffuse irradiances corresponding to January 2, 2008. From this kind of information, the calculation of the irradiance mean value is feasible. Thus, from Figure 3 data the maximum value was close to 800 W m^{-2} and for the same day the irradiance mean value calculated was 452 W m^{-2} ; the irradiation was 18.245 MJ m^{-2}.

The 180 days from November 2007 to April 2008 were analyzed in the same way. The global accumulated irradiance behavior is shown in Figure 4 (square symbol points). A growing trend of irradiance values can be observed here when the change from winter to spring days occurs. The dispersion of points in Figure 4 is due to the solar energy variation in accordance with the changing weather conditions.

In Figure 4, the estimated hydrogen quantity corresponding to the mean irradiances is also shown. These quantities were calculated as the normal hydrogen flux using Equation (1). The flux of electrolysis gas follows a similar trend as irradiances, in accordance with the linear character of the simulation equation. As a result of these calculations, it can be expected that with the solar energy received in Zacatecas, a hydrogen flux from 6 LN min $^{-1}$ to 9 LN min^{-1} can be obtained if a SH system similar to that previously characterized is used [17]. This hydrogen estimated production could be obtained from 1.5 to 2.2 L of water respectively.

4. CONCLUSIONS

The data obtained at the "Campus Siglo XXI" Solarimetric Station can be used to evaluate the solar renewable energy resource expressed as hydrogen production. The solar radiation measured is greater than national and worldwide mean values. This could mean that Zacatecas state is a strategic place for solar energy utilization. In comparison, the "Instituto Nacional de Medio Ambiente de España" situated in Almeria, considered the main Spanish center for development and use of solar energy, has reported an average irradiation of 351.14 MJ m^{-2} (3.06 kWh m^2d^1) for January 2005, with a daily solar radiation of 8.5 h [19] . This figure is almost half that of 684 MJ m^{-2}, the mean value obtained in Zacatecas for January 2008.

The estimated flux of hydrogen that could be obtained from water electrolysis with the Zacatecas solar conditions could mean, for this region, a feasible implementation of SH systems for producing the energy vector, using PEM electrolyzer technology.

Due to the climatic conditions of the SH system in Cuernavaca México were different to those of the solar irradiance measurement-station in Zacatecas México, the results presented in this study are only a first approach for the estimation of hydrogen generation in a PEM type electrolizer. In order to obtain a more reliable calculation, it would be necessary to characterize a solar irradiance SH system near to the Siglo XXI Solar Station.

5. ACKNOWLEDGMENTS

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