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Design of a Simple and Cheap Water Electrolyser for the Production of Solar Hydrogen

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Abstract

Commercially available conventional alkaline electrolyser and advanced polymer membrane electrolysers for water electrolysis are quite expensive. Taking into account this aspect, a very simple and cheap water electrolyser has been designed and fabricated utilising easily available economical materials for small scale production of hydrogen using renewable energy from photovoltaic panel. The construction details of the electrolyser with a schematic drawing of the experimental set-up for PV production of H_2 are given. In order to fabricate the compact electrolyser, two coaxial tubular PVC pipes were used. The lower part of the inner pipe has fine perforations for the transport of ions through electrolyte between the electrodes. Two cylindrical electrodes, cathode and anode are kept in inner and outer pipes respectively. The performance of hydrogen production was measured using a photovoltaic panel directly connected to the electrolyser under atmospheric pressure and in 27wt% KOH solution. Flow rates of hydrogen and oxygen were measured using a digital flow meter. High purity fuel cell grade hydrogen (99.98%) and oxygen (99.85%) have been produced. The experimental results confirm that the present electrolyser has eligible properties for hydrogen production in remote areas. No such electrolyser has been reported prior to this work.

Keywords: Cheap electrolyser, Simple electrolyser, Water electrolysis, Solar hydrogen, Hydrogen energy

1. Introduction

Hydrogen as an important future energy carrier is well established and the world's current use of fossil fuels as the primary energy source is not sustainable and also causing disastrous environmental pollution and climate change [1]. It is emphasized that the global environmental damage caused thermodynamically is more alarming to life on earth than the risk of exhausting the finite amount of fossil fuels being consumed at the present rate [2]. As an energy carrier, hydrogen is the most attractive option with many ways to produce and utilize it [3]. It is abundantly available in nature as compounds of oxygen (water) or carbon (hydrocarbon, carbohydrates, etc.). Water electrolysis represents the most important process to pro-

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duce hydrogen without emitting air pollutants or greenhouse gases [4].

Energy must be supplied to generate hydrogen from either water or carbonaceous material. Electrolysis uses energy to dissociate hydrogen and oxygen from water:

$$H_2O \rightarrow H_2 + 1/2O_2 \qquad E_0 = 1.23\ V \qquad (1)$$

Thus, note that hydrogen is not an energy source, as energy is needed to produce it. Hydrogen has the highest energy density as compared to chemical fuels, making it a high-efficiency energy carrier that can be used for transportation, heating and power generation. It is the cleanest burning fuel and if it is produced from renewable energy sources such as solar and wind power, it even has a zero emission [5] when it is used in a fuel cells to produce electricity. While the utilization of hydrogen is environmentally friendly, it is critical that the production of hydrogen is also sustainable and environmentally friendly. Efficient, clean, abundant and renewable hydrogen is clearly the energy carrier to power the future word.

Water used in electrolysis is, of course, a renewable resource, but for the resulting hydrogen to be considered renewable, the electricity for this process must also have come from a renewable source. Among the renewable energy systems, the photovoltaic cells, which generate direct current electricity when exposed to solar radiation available universally everywhere on the earth, can be considered the most important source of energy [6]. It generates electricity with practically no impact on the environment, have no moving parts to wear out, no noise, modular, which means that they can be matched to a need for power at any scale, can be used as independent power source or in combination with others, and they are reliable with long live. Electrolytic production of hydrogen is a simple process with no moving parts and can be designed as a portable unit. This technique is very clean, reliable and produces high purity of hydrogen gas for most commercial technology.

Alkaline water electrolysis represents one of the best choices for the hydrogen production since it is a technically tried and tested method and is based on an industrial process reaching back nearly 100 years [4]. Any conductive materials can be used as electrodes to electrolyse water when the proper amount of energy is applied. For alkaline water electrolysis Ni-based alloys either amorphous or crystalline have been successfully tested as efficient cathode materials while the choice of anode is mainly focused on mixed Ni-Co oxides with a spinel structure [5]. There are various experimental [6,7] and theoretical [8,9] studies in the literature on the production of hydrogen using photovoltaic-electrolyser system. Kothari et al. [7] studied the effect of the electrolyte temperature varying between 10 and 80 ^{0}C on the rate of hydrogen production of alkaline water electrolysis. A mathematical model has been developed to determine and optimize the thermal and economical performance of large scale photovoltaic electrolyser systems, either with fixed or sun tracking panels using hourly solar radiation data [10]. Lehman et al. [11] reported the performance, safety, and maintenance issues of photovoltaic power plant which used hydrogen energy storage and fuel cell regenerative technology. Nagai et al [12] showed the existence of an optimum space between electrodes on hydrogen production by water electrolysis. Abdallah et al. [13] developed a model for solar–hydrogen energy system by obtaining relationships for and between the main energy and energy related parameters. Paul et al. [14] presented a theoretical analysis of the conditions required for optimum coupling of a PV array to an electrolysers stack in solar hydrogen systems for remote area power supply (RAPS). Bilgen [15] studied the economic feasibility and found that the hydrogen production with fixed PV panels varies from 26 to 42kg/kWp/year and the cost from 25 to 268 $/GJ.

All the current method and projected technologies of producing hydrogen from solar energy are much more costly (greater than a factor of 3) when compared with hydrogen production on large scale from fossil fuels plants [16]. However when relatively small quantities of hydrogen are required, on site electrolysis of water may be more economical than other methods. Renewable energy-hydrogen systems for RAPS are potential an early niche market for zero-emission hydrogen energy technology because of the high costs of conventional energy sources in such applications [17]. This work aims to design a very simple, cheap and efficient alkaline electrolyser utilising easily available economical materials for small scale production of hydrogen using renewable energy by direct coupling of photovoltaic panel.

2. Materials and Methods

2.1 Design and Fabrication of Electrolyser

The electrolyser was self fabricated in the laboratory consisting of two coaxial PVC pipes, easily and cheaply available on the hardware shops in the market. The nominal diameters of the outer

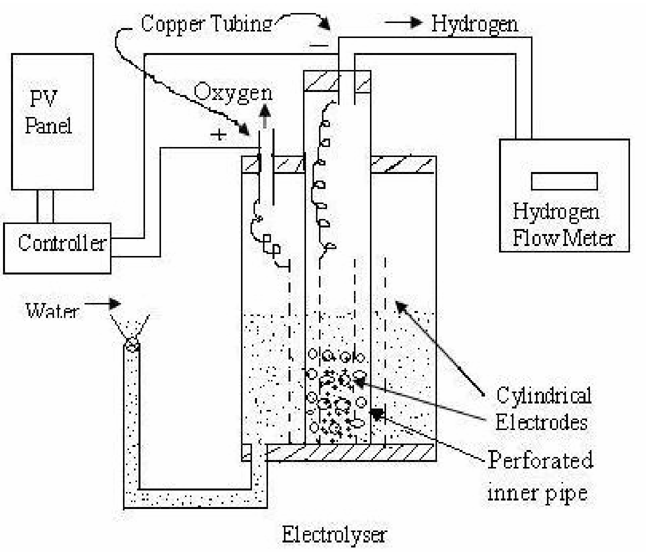

Figure 1. Schematic diagram of the water electrolyser for photovoltaic hydrogen production

and inner pipes are 2” and 1”, and their heights are 10” and 12” respectively. The schematic diagram of the electrolyser with photovoltaic panel, digital hydrogen flow meter and other accessories is shown in Figure 1. Fine perforations (<1 mm diameter) in the lower portion of 3” height in the inner pipe were made all-around by piercing a red-hot needle, for the transport of ions through electrolyte between the electrodes. Two cylindrical electrodes were used, cathode was made of nickel plated stainless steel sieve and anode was of stainless steel sieve. Cathode was kept in the inner pipe and anode was placed in the outer pipe. The electrodes were connected through copper tubing to the photovoltaic panel directly via a voltmeter and an ammeter. These copper tubing served as electrical connectors as well as outlet for the hydrogen and oxygen gases separately. Leak proof fittings of the copper tubing and coaxial pipes were made using rubber corks.

Provision for feed water and electrolyte was made as shown in the figure. Electrolyte level in the electrolyser can be adjusted to any desired level by adjusting the vertical position of the feeding funnel connected with rubber tubing to the bottom of the electrolyser. The change in level of electrolyte causes a change in the active area of the electrodes and hence the rate of hydrogen production can be varied easily to the desired value by manipulation of the electrolyte level in the unit. The attractive feature of the presently designed electrolyser is that the material of construction is very cheap, available everywhere and any one can fabricate it easily in his houses. There is no such electrolyser reported in the literature. This is a novel contribution on the design of the cheapest electrolyser, costing about Rs.50/- in Indian currency or one dollar.

2.2 Photovoltaic production of hydrogen

The applicability of the electrolyser has been ascertained for the production of hydrogen using alkaline electrolyte and renewable energy from photovoltaic panel. The electrolyte used was 27% potassium hydroxide solution in distilled water. The solar photovoltaic panel (SPV) is with maximum output of 36 W with an open circuit voltage of 20.5 V and short circuit current of 3.0 A. This module was supplied by NEDA (Non Conventional Energy Development Agency), Uttar Pradesh, India. The PV module is supported on a tilted structure from steel frames. The tilt angle is fixed at 300 with horizontal and the structure is mounted such that the module is facing south direction. The SPV module generates the dc power that is transferred to the water electrolyser directly. The PV panel and the electrolyser voltages and currents are measured using a digital voltmeter and an ammeters with accuracies of 0.01 V and 0.001 A respectively.

In the water at the negatively charged cathode, a reduction reaction takes place, with electrons (e-) from the cathode being given to the water to form hydrogen gas (the half reaction balanced with basic electrolyte):

Cathode (reduction):

$$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq) \qquad (2)$$

Anode (oxidation):

$$4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^- \qquad (3)$$

Overall reaction:

$$H_2O(l) \rightarrow H_2(g) + 1/2O_2(g) \qquad (4)$$

The produced hydrogen gas has twice the volume of the produced oxygen gas. The rate of the hydrogen production at the cathode in the inner pipe and oxygen at the anode in the outer pipe were measured using a digital flow meter with an accuracy of 0.1 ml/min. Gases were analysed with a gas chromatograph.

3. Results and Discussion

The output power of the PV system however fluctuates depending on solar insolation over the whole day. The data collected on a sample day in the month of May 2008 at Banaras Hindu University, India, representing such variation of output

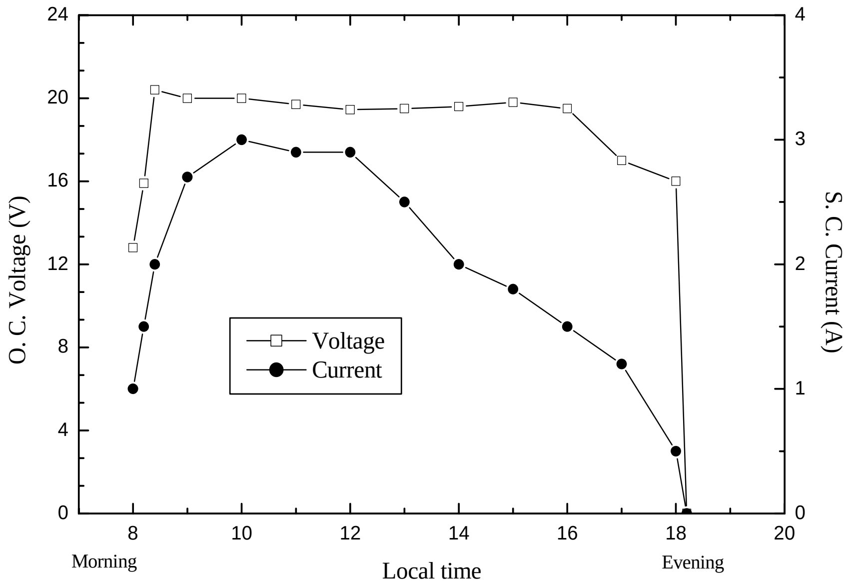

Figure 2. Open circuit voltage and short circuit current developed by the PV system on a certain day in May 2008

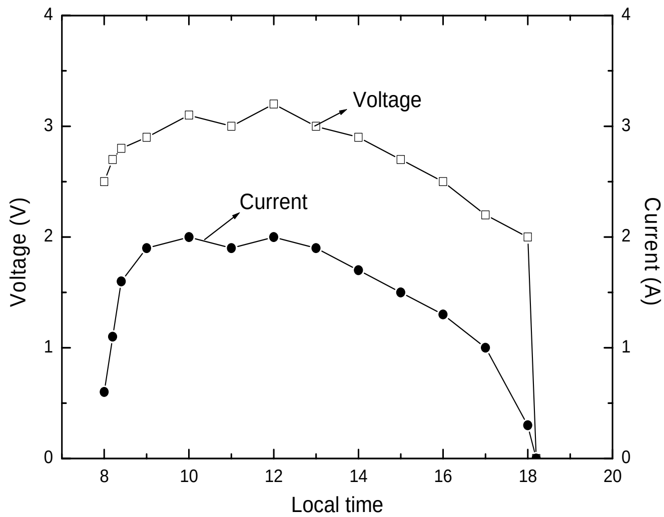

Figure 3. Load voltage and load current during electrolysis

open circuit voltage and short circuit current developed by the PV system are shown in Figure. 2. The open Circuit voltage steeply rises to 20.8 V in the morning around 8.40 am (local time) and remains almost constant till 4.00 pm then drops suddenly. Similarly the short circuit current increases in the morning showing a plateau of maximum current about 2.9 A between 10.00 am to 12.00 noon then it decreases slowly to zero around 6.00 pm. It can be seen from the figure that during afternoon the short circuit current decreases while the open circuit voltage remains almost same. This decrease in current may be due increase in the internal resistance of the PV cells at higher temperature of the panel in the afternoon period.

Figure 3 shows the load current and voltage of the electrolyser during the electrolytic production of hydrogen by directly connecting the solar PV panel to the terminal of the electrolyser on the sample day. There is a substantial decrease in load voltage in comparison to open circuit voltage.

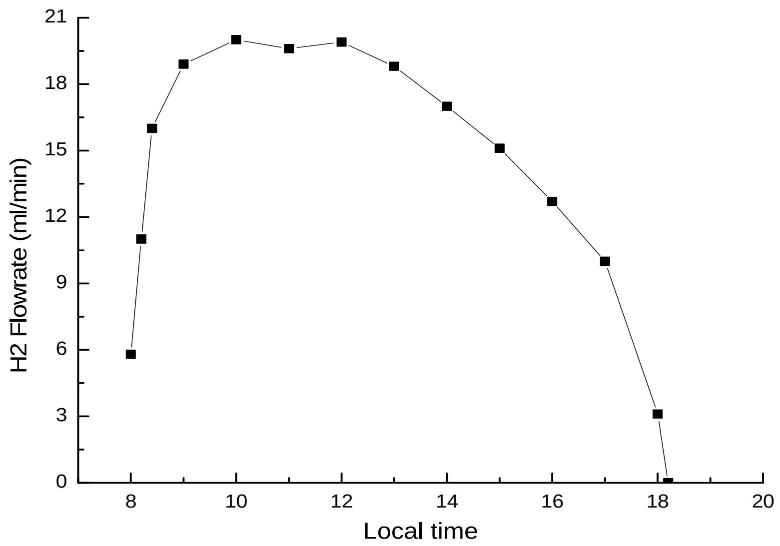

Figure 4. Flow rate of electrolytic hydrogen production

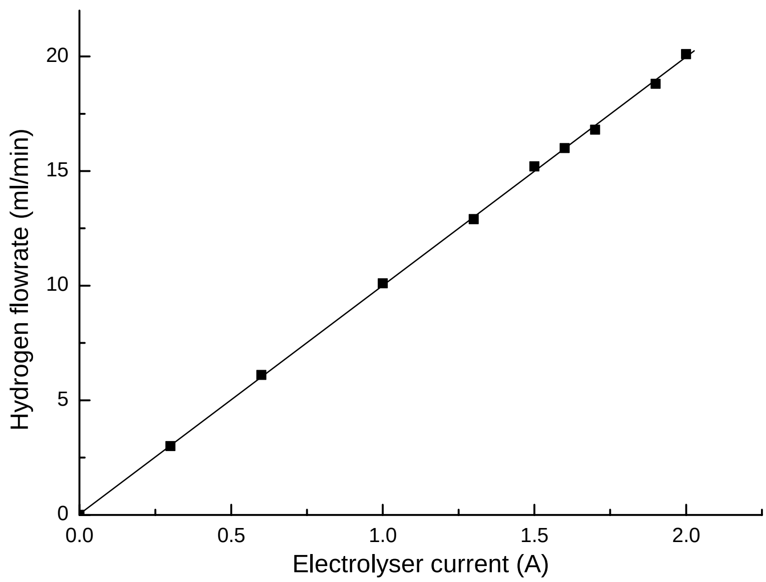

Figure 5. Hydrogen flow rate versus the electrolyser current

Load current also decreases. The corresponding flow rate of hydrogen production is shown in Figure 4. From the figures 3 and 4 it is clear that the hydrogen generation is directly affected by the electrolyser load current. Gas chromatographic analyses of the gases produced show high purity hydrogen (99.98%) and oxygen (99.85%), suitable for the use in fuel cell. Figure 5 shows the relationship between the hydrogen flow rate and the electrolyser current. A linear relationship exists, showing 10.10 ml hydrogen generation per ampere of current. The efficiency of the electrolyser is calculated as per the following equation:

$$\eta = \dot{M}.Cv/V.I \quad (5)$$

Where, $\dot{M}$. is mass flow rate of hydrogen (g/s), Cv is calorific value of hydrogen (J/S), V and I are load voltage and corresponding current respectively. The average efficiency of the electrolyser is found to be 51.57%. The average efficiency of the present electrolyser is comparable to the previously reported values in the literature. Thus, the electrolyser is simple in construction, cheap and efficient for small scale production of hydrogen in remote areas utilising renewable energy by direct coupling to photovoltaic panel.

4. Conclusions

A simple, cheap and efficient electrolyser was built for hydrogen generation in the remote area using solar photovoltaic energy. The system was designed, fabricated and experimentally tested for small scale production of high purity fuel cell grade renewable hydrogen. The average efficiency of the present electrolyser is comparable to the previously reported values in the literature. The cost of the electrolyser in Indian currency would be about Rs.50/- or one dollar.

References

[1] Veziroglu, T. N. 2000. Quarter century of hydrogen movement 1974-2000. *Int J Hydrogen Energy* 25: 1143-1150.

[2] Lodhi, M. A. K. 1997. Photovoltaics and hydrogen: further energy options. *Energy Convers Manage* 38(18): 1881–93.

[3] Marshall, A.; Sunde, S.; Tsypkin, M.; and Tunold, R. 2007. Performance of a PEM water electrolysis cell using $IrxRuyTazO_2$ electocatalysts for the oxygen evolution electrode. *Int J Hydrogen Energy* 32: 2320–2324.

[4] Marshall, A.; Sunde, S.; Tsypkin, M.; and Tunold, R. 2007. Performance of a PEM water electrolysis cell using $IrxRuyTazO_2$ electocatalysts for the oxygen evolution electrode. *Int J Hydrogen Energy* 32: 2320–2324.

[5] Suffredini, H. B.; Cerne, J. L.; Crnkovic, F. C.; and Machado, S. A. S.; and Avaca, L. A. 2000. Recent development in electrode materials for water electrolysis. *Int J Hydrogen Energy* 25: 415-423.

[6] Ahmad, G. E.; and Shenawy, E. T. El. 2006. Optimized photovoltaic system for hydrogen production. *Renewable Energy* 31: 1043-1054.

[7] Kothari, R.; Buddhi, D.; and Sawhney, R. L. 2005. Studies of the effect of temperature of the electrolytes on the rate of production of hydrogen. *Int J Hydrogen Energy* 30: 251–63.

[8] Rzayeva, M. P.; Salamov, O. M.; and Kerimov, M. K. 2001. Modelling to get hydrogen and oxygen by solar water electrolysis. *Int J Hydrogen Energy* 26: 195-201.

[9] Orecchini, F.; Santiangeli, A.; and Dell'Era, A. 2006. A technological solution for everywhere energy supply with sun, hydrogen and fuel cells. *J Fuel Cell Sci Technol* 3(75).

[10] Bilgen, E. 2001. Solar hydrogen from photovoltaic electrolyser systems. *Energy Convers Manage* 42: 1047–57.

[11] Lehman, P. A.; Chamberlin, C. E.; Pauletto, G.; and Rochelau, M. A. 1990. Operating experience with a photovoltaic hydrogen energy system. *Int J Hydrogen Energy* 24: 505–517.

[12] Nagaia, N.; Takeuchia, M.; Kimurab, T.; and Okaa, T. 2003. *Int J Hydrogen Energy* 28: 35-41.

[13] Abdallah, M. A. H.; Asfour, S. S.; and Veziroglu, T. N. 1990. Solar–hydrogen energy system for Egypt. *Int J Hydrogen Energy* 24: 505–17.

[14] Paul, B.; and Andrews, J. 2007. Optimal coupling of PV arrays to PEM electrolysers in solar-hydrogen systems for remote area power supply. *Int J Hydrogen Energy* 33: 490-498.

[15] Bilgen, E. 2004. Domestic hydrogen production using renewable energy. *Solar Energy* 77: 47-55.

[16] Marcelo, D.; and Dell'Era, A. 2008. Economical electrolyser solution. *Int J Hydrogen Energy* 33: 3041-3044.

[17] Isherwood, W.; Smith, J. R.; Aceves, S. M.; Berry, G.; Clark, W.; and Johnson R. 2000. Remote power systems with advanced storage technology for Alasks villages. *Energy* 25: 1005-1020.

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