Energy 140 (2017) 625–632

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Effect of electrodes separator-type on hydrogen production using solar energy

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ARTICLE INFO

Article history:
Received 11 February 2017
Received in revised form
9 August 2017
Accepted 5 September 2017
Available online 6 September 2017

Keywords:
Hydrogen production
Separator type
Solar energy

ABSTRACT

This paper presents an experimental study for hydrogen production using alkaline water electrolysis operated by solar energy. Attempts to produce pure hydrogen as well as pure oxygen for commercial demands are introduced. Two methods are used and compared for separation between the cathode and anode, which are acrylic separator and polymeric membrane. Further, the effects of electrolyte concentration, solar insolation, and space between the pair of electrodes on the amount of hydrogen produced and consequently on the overall electrolysis efficiency are investigated. It is found that the efficiency of hydrogen production is higher when using the polymeric membrane between the electrodes, in comparison with the acrylic separator. The experimental results show also that, the performance of alkaline water electrolysis unit is dominated by the electrolyte concentration and the gap between the electrodes. The gap of 5 mm leads to a higher hydrogen production rate than the gap of 10 mm.

1. Introduction

Hydrogen was used as an auxiliary fuel, first, in 1920 [1]. Later, in 1973, the petrol crisis gave the world community prompting to search for alternative energy sources to fossil fuel. Furthermore, in recent years, the environmental pollution increased the interest on renewable energy technologies. Hydrogen is a neutral energy carrier of high energy density, and can be considered as a sustainable, environmental cleanliness, and economically viable substitution.

Currently, most of hydrogen production is based on natural gas through thermo chemical processes [2]. An alternative way to produce hydrogen is water electrolysis process. It is a well-known process and is currently adopted in many applications, in order to produce hydrogen with high purity [3,4]. Photoelectrochemical cell is another way to produce hydrogen via reduced input voltage [5]. Nowadays, water electrolysis represents about 4% of the world hydrogen production [6,7]. Producing hydrogen through water electrolysis with the aid of solar energy, using photovoltaic (PV) is a mature and efficient technology. Using electricity produced from solar cells, water electrolysis can produce hydrogen with a purity of 99.9995% and has the capacity of producing hydrogen up to thousands of Nm^3/h [8,9].

Three methods are available in the market to produce hydrogen via water electrolysis. They are, alkaline water electrolysis, polymer exchange membranes (PEM), and solid oxides high-temperature electrolysis [8]. Their concept is almost the same, which is two electrodes and an electrolyte that allows the transport of ions. The operating temperature for alkaline water electrolysis and PEM water electrolysis is between 60 and 90 °C, while the solid oxide is between 600 and 900 °C. The alkaline water electrolysis usually operates with electrolyte concentrated with sodium hydroxide NaOH or potassium hydroxide KOH. It has been widely used in industrial applications and is available in a large number of built units already in operation, because of its lower cost. The PEMs water electrolysis still have limited application in terms of production capacity because of the limited lifetime and corrosion of the cells [10,11]. Also, its cost is high due to expensive polymer membrane electrolytes and platinum electrodes. The solid oxide method requires more heat energy at higher temperatures and still unproven in practical operation [12].

The method of alkaline water electrolysis, used in the present

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http://dx.doi.org/10.1016/j.energy.2017.09.019
0360-5442/

work, has many generous advantages such as flexibility, availability, and high purity compared to the thermochemical processes (steam reforming or coal gasification) [13]. However, the water electrolysis process carries significantly higher costs than hydrogen production from fossil fuels [14]. It is still used for small scale units, whereas large-scale hydrogen production is prohibitively expensive [7]. Hence, hydrogen production via water electrolysis still requires improvement in the efficiency and cost of the material and installations.

Chennouf et al. [15] conducted an experimental work to produce hydrogen using alkaline water electrolysis in Ouargla city (Algeria). Photovoltaic modules were used as a renewable source of energy to feed the electrolysis cell. They used (NaOH) with different concentrations (in the range of 6–26 gm/l) and tested the system at different input voltages. They concluded that, increasing either NaOH concentrations or voltage values results in increasing the current intensity and then increasing the hydrogen production.

Mahrous et al. [16] presented an experimental investigation of alkaline water electrolysis. Higher rates of produced hydrogen were obtained at smaller space between the electrodes and also at higher voltage input. Higher system efficiency was also gained at smaller gap distances between the pair of electrodes. Nagaia et al. [17,18] studied the effect of electrical current, distance between electrodes, and the temperature on the efficiency of water electrolysis at a particular concentration on the solution. Also, they studied the effect of bubbles between electrodes on alkaline water electrolysis.

The effect of the electrolyte temperature on the rate of hydrogen production was also studied by Kothari et al. [19] and Chennouf et al. [20]. Increasing the temperature of water and electrolyte concentration led to net increase of volume flow of hydrogen gas and efficiency of the electrolyzer. As a consequence, Rabady and Kenan [21] proposed a hybrid thermo-photovoltaic high temperature electrolyzer to generate hydrogen more efficiently. Kargi [22] tested different materials of the electrode (aluminum, stainless steel, graphite) in hydrogen production using photovoltaic cell. The highest accumulative hydrogen gas was obtained with aluminum electrodes and the lowest was with graphite electrodes. Furthermore, numerous Zinc alloys has been tested as cathode materials [23]. It was revealed that, (Zn95%, Cr5%) and (Zn90%, Cr10%), by mass, are the best alloys for cathodes.

El-Askary et al. [24] developed a numerical model which predicted well the hydrogen production process through water electrolysis. Their study showed that the best production process is reached by decreasing the main flow velocity. Hydrogen production process can be raised up by increasing the current density and reducing the gap distance between the cathode and the anode of the electrochemical cell. Also, the bubble diameter formulation of the dispersed hydrogen gas considerably affects the local and global characteristics of the two-phase stream [24]. Balabel et al. [25] investigated theoretically and experimentally the optimum operating conditions for alkaline water electrolysis coupled with solar PV source for hydrogen generation with an emphasis on the electrolyzer efficiency.

In the current study, the effect of the separator material, separation distance and concentration of the alkaline water electrolysis on energy efficiency are tested. It is worth mentioning that the increase in hydrogen productivity is not necessarily accompanied by an increase in the system efficiency. This point will be also discussed in the present work.

2. Electrolyzer system

The electrolyzer model consists of two electrodes known as anode (A) and cathode (C) both of height (h) as shown in Fig. 1, which are located on left and right sides of the cavity, respectively. The gap distance between the electrodes is set to be δ. The cavity contains an electrolyte which is a dilute solution of potassium hydroxide (KOH). An electric current from solar energy passing through the two electrodes disassociates KOH into K^+ and OH^- ions. Hydrogen gas evolves at the cathode while oxygen gas forms at the anode according to the following electrochemical reactions:

At the cathode:

$$4H_2O + 4\bar{e} \uparrow 2H_2(\text{gas}) + 4OH^- \tag{1}$$

At the anode:

$$4OH^- \uparrow O_2(\text{gas}) + 4\bar{e} + 2H_2O \tag{2}$$

3. Experimental approach

In order to investigate the parameters affecting hydrogen production through alkaline water electrolysis, a set of experimental test models is designed and manufactured. Fig. 2 shows the experimental apparatus for Photovoltaic assisted alkaline water electrolysis. The experimental test model consists of PV as power supply along with an electric wires, tank, electrolyzer, rheostat, bubbler, and multimeter (Voltmeter and Ammeter). Electrical energy is needed to produce the electrolytic hydrogen from water. The present work utilizes the solar energy and uses photovoltaic PV cell to supply the electric power to the electrodes. The technical specifications of the PV module used are provided in Table 1 under standard test conditions (STC) which refer to irradiance of 1000 W/m^2 and a cell temperature of 25 °C. A process flow diagram/methodology is affixed in appendix A.

The electrolyzer here is a mono cell system, composed of two electrodes and an electrolyte. It consists of an acrylic box with inner dimensions of (30 × 15 × 15) cm^3 and wall thickness of one cm. The box is divided into two chambers by either an acrylic separator of 1.0 mm thickness or a polypropylene separator of 0.4 mm thickness. The distance between the two opposite

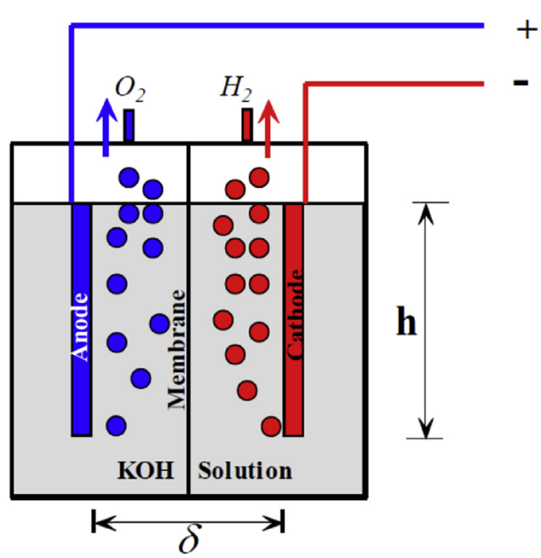

Fig. 1. Schematic representation of the electrolyzer.