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Investigation of hydrogen production performance of a reactor assisted by a solar pond via photoelectrochemical process

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ABSTRACT

In this study, the hydrogen production performance of a reactor assisted by a solar pond by photoelectrochemical method is examined conceptually. The main components of the new integrated system are a solar pond, a photovoltaic panel (PV) and a hybrid chlor-alkali reactor which consists of a semiconductor anot, photocathode and cation exchange membrane. The proposed system produces hydrogen via water splitting reaction and also yields the by products namely chlorine and sodium hydroxide while consumes saturated NaCl solution and pure water. In order to increase the efficiency of the reactor, the saturated hot NaCl solution at the heat storage zone (HSZ) of the solar pond is transferred to the anot section and the heated pure water by heat exchanger in the HSZ is transferred to cathode section. The photoelectrode releases electrons for hydrogen production with diminishing the power requirement from the PV panel that is used as a source of electrical energy for the electrolysis. The results confirm that the thermal performance of the solar pond plays a key role on the hydrogen production efficiency of the reactor.

Introduction

Hydrogen is a clean energy carrier that can be produced from renewable sources. Solar based hydrogen production methods have been extensively investigated in recent years. Among these methods, photoelectrochemical water decomposition is considered as a promising method for hydrogen production [1–4]. Bicer and Dincer [5] investigated the effects of different light intensities on the efficiencies both of the photovoltaic (PV) cell and photoelectrochemical (PEC) hydrogen production experimentally. They used Fresnel lens and dielectric mirror to concentrate solar light and divide into two to be utilized by PV and by PEC. Casallas et al. [6] constructed and tested a novel photoelectrochemical cell for hydrogen production by using a polymeric membrane photocathode that is produced by electro-deposition of CuO/CuO_2 semiconductor photocatalysts on the cathode surface. Test results show that using this photocathode enhances the rate of hydrogen production by increasing the current density and lowering the bias voltage. Acar and Dincer [7] investigated a hybrid chlor alkali-

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photoelectrochemical system that produces hydrogen, chlorine and sodium hydroxide experimentally. This hybrid system maximizes the solar energy utilization by combining photochemical and electrochemical processes. Rabbani et al. [8] developed and analyzed a new photoelectrochemical reactor to produce hydrogen, chlorine and sodium hydroxide. They investigated the effect of applied voltage, amount of catalyst (zinc sulfide) and light intensity on the production rate. Stern et al. [9] used a photocathode that cobalt phosphide (CoP) is photoelectrochemically deposited on a p-type cuprous oxide (p-Cu_2O). Their photoelectrochemical water splitting system has a capability of generating a current density can reach up to 5.3 and 4.2 mA/cm^2 in acidic and basic conditions, respectively. This means that solar hydrogen production can be achieved in both acidic and alkaline electrolysis. Karakilcik et al. [10] studied an experimental insulated solar pond with a surface area of 4 m^2 and a depth of 1.5 m at Adana Cukurova University in order to determine the performance of the inner zones of a solar pond. The highest thermal efficiency of the zones of the pond were found as 28.1% for the heat storage zone (HSZ), 13.8% for the convective zone (NCZ) and 4.5% for the upper convective zone (UCZ) in August.

According to literature, the coupling of photoelectrochemical chlor alkali cell with a solar pond were not encountered. The goal of this study is to combine a photoelectrochemical chloralkali cell with a solar pond to use the heat storage property of the pond. This study also aims to conceptually analyze the performance of the integrated system.

System description

In this study, hydrogen production performance of a reactor assisted by a solar pond with photoelectrochemical method is examined conceptually. The main components of the new integrated system are a solar pond, a photovoltaic panel (PV) and a hybrid chlor-alkali reactor that consists of a semiconductor anot, photocathode and a membrane, and NaCl solution as anolyte. The integrated system uses solar energy that is collected by photocathode, solar pond and PV panels. During sunny days, the cell uses the advantages of photocatalysis and photoelectrolysis.

Fig. 1 represents the schematic of the proposed integrated system. The saturated hot NaCl solution at the HSZ of the solar pond is transferred to the anot section and the heated pure water by heat exchanger in the HSZ is transferred to the cathode section. The depleted aqueous solution of sodium chloride is enriched by using a salt reservoir. The anode and cathode section of the cell is separated by a membrane whose function is allowing the transport of Na^+ ions to the cathode section where the OH ions are neutralized. Another function of the membrane is to separate the released H_2 and Cl_2 gases. Cathode section of the cell has a transparent window to allow the illumination of the photocathode by solar light.

Hydrogen gas is released from the photocathode according to the following reaction.

$$2H_2O_{(l)} + 2e^- \rightarrow H_{2(g)} + 2OH^-_{(aq)} \quad E^0 = -0.8277V \tag{1}$$

At the same time, chlorine gas is released from the anode according to the following reaction.

$$2Cl^-_{(aq)} \rightarrow Cl_{2(g)} + 2e^- \quad E^0 = 1.36V \tag{2}$$

According to Equations (1) and (2), the total cell voltage (E^0) is 2.1877 V. It is clear that this value is higher than the 1.23 V needed for water electrolysis.

The Na^+ ions form by NaCl dissociation in the anode section and migrate to the cathode section through the membrane. So, NaOH forms in the cathode section according to the following reaction.

$$Na^+_{(aq)} + OH^-_{(aq)} \rightarrow NaOH_{(aq)} \tag{3}$$

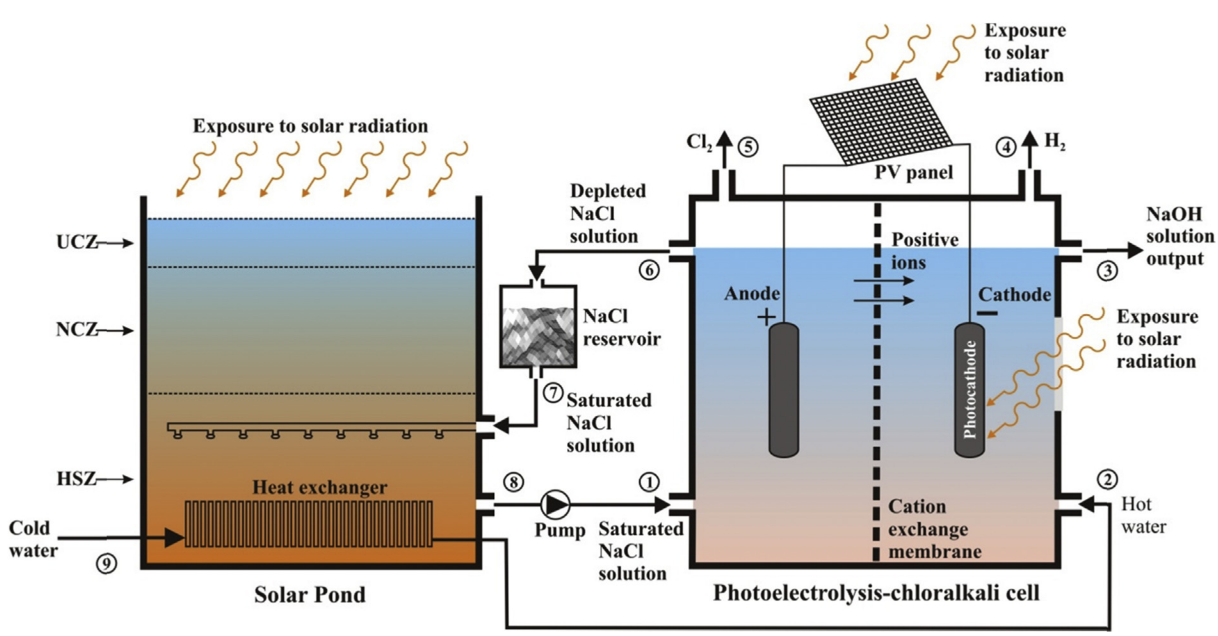

Fig. 1 – Schematic of the integrated system.