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Simulation of hydrogen production system with hybrid solar collector

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ABSTRACT

In this study, the simulation of hydrogen production system demonstrated with electrolysis of water by hybrid solar collector. The mathematical model created by in accordance with the system flowchart. For this numerical study, three cities located in west, middle and east of Turkey, were considered which are Istanbul, Konya and Erzurum.

Borland Delphi 7 programming language used for numerical analyses. The insolation and solar irradiance of these cities were taken into consideration and the values of the solar irradiance of the cities compared to each other. For each case, a simulation of the system made keeping temperature constant (373 K) and increasing the pressure up to 0.1 MPa and 0.5 MPa. In the other case, the pressure kept at constant (0.1 MPa), the temperature increased up to 573 K. It observed that City of Konya was quite convenient in terms of hydrogen and oxygen production compared to Istanbul and Erzurum, and the pressure had a very low effect on hydrogen and oxygen production; but the temperature is an important component in hydrogen and oxygen production system. The results for hydrogen production compared to literature and found a difference around 1.08%.

Introduction

There are many studies related to the hydrogen production with electrolysis of water with solar energy. In order to increase the hydrogen production, there are some methods in this field such as using different types of electrolyses, production at the different pressure, wind power, wave energy and biomass energy. At the present circumstances, the hydrogen production systems are more expensive compared to other fuel production systems. In the future, of course, its cost will drop and this clean energy can be used as a common resource energy.

Padin, Veziroglu, Shahin [1], designed and simulated a new hydrogen production system by electrolysis of water using hybrid solar collector at high temperatures, and they found that the results were doubled in production compared to the classical hydrogen production systems.

Rzayeva, Salamov, Kerimov [2], developed a mathematical model of hydrogen and oxygen production system by electrolysis of water using the solar energy. They studied the production of hydrogen and oxygen under 0.1 and 0.4 MPa

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pressures and achieved to goal by studying the characteristics of volt-ampere of electrolyser and photovoltaic systems.

Gretz [3], studied the potential of solar energy conversion into hydrogen and other fuels, and examined the conditions related to the thermodynamics and energy for water decomposition. He discussed different water decomposition techniques.

Tani, Sekiguchi, Sakai and Ohta [4], conducted studies about optimization of solar hydrogen systems by considering the hydrogen production cost. They produced hydrogen with a hydrogen generator. The required voltage was supplied by a photovoltaic module. They analysed the system's current and voltage characteristics.

Lich, Wang, Mukerji, Soga, Umeno and Tributch [5], studied the attainable efficiency of solar energy conversion for water decomposition and observed the conversion performed with different semiconductors.

Kharkats and Pleskov [6], studied the solar energy conversion to electrical and heat energy, and they conducted a research about the solar energy storage systems. They studied the solar radiation, the decomposition and the characteristics of battery storage and systems optimization point under different design conditions.

Torres, Rodriguez and Sebastian [7], simulated the system which housed the photovoltaic array, electrolyses, fuel cell, hydrogen tank and battery; and they compared results obtained from different locations of Mexico.

Carpetis [8], used the electrical energy and executed the electrolysis of water with the photovoltaic solar energy conversion. He compared the results of calculation with available experimental data and performance of the hydrogen production plant.

Xiao, Guan [9], designed a solar thermoelectric-photovoltaic hybrid generation system for hydrogen production. They used MATLAB/SIMULINK software for mathematical model of the hybrid system and they simulated and analysed the current of the various sub-systems and the energy of the hydrogen storage tank. They proved the solar hybrid system is reliable and effective and they found the current provided by the solar hybrid system increases with the increasing of solar intensity.

Acar and Dincer [10], experimentally studied a hybrid system which produces hydrogen via water splitting reaction and converts the by-products into useful industrial products. They tested the system at four different temperatures 20, 40, 60, and 80 °C and three different light settings, no light (0 W/m^2), 600 W/m^2, and 1200 W/m^2. They found the hydrogen production rate increases with increasing of temperature and light intensity. Under no light conditions at 20 °C, the system produces about 145 mL/h hydrogen with energy efficiency of 25.4%. At 80 °C under 1200 W/m^2 irradiation, the same system generates 295 mL/h hydrogen with energy efficiency of 19.6%.

Derbal-Mokrane, Bouaichaoui, El Gharbi, Belhamel, Benzaoui [11], used parabolic collector technology considering its simplicity of operation which proved its profitability and its reliability by TRNSYS simulation program and hour by hour simulation of the energy gained by the collector was determined using the Algerian site radiation data for better power generation. They find the values very favourable to set such a power station in this area and they obtained 52% efficiency for the system.

Ngoh, Ohandja, Kemajou, Monkam [12], designed and optimized a large scale hybrid solar hydrogen production system using solar photovoltaic and thermal energy. The system they designed consists of the solid oxide steam electrolysis system coupled to a photovoltaic array through a direct current converter and coupled to a parabolic collector through a heat exchanger. Under local tropical conditions, they obtained 0.064 kg/s of theoretical production rate of hydrogen.

Farivar [13], developed dual chamber photoelectrochemical (PEC) reactor for water splitting systems. He tested different geometries to have a uniform flow with minimum recirculation zones inside the photoreactor chamber, and proved with simulation results that by increasing the current density the hydrogen production rate increases.

Topriska, Kolokotroni, Dehouche, Wilson [14], developed a semi-empirical numerical model for a solar hydrogen system powered by photovoltaic panels to produce hydrogen for cooking on Jamaica. They run the experiments 63.6% electrolysing efficiency and with a daily cooking demand of 1.7 kg of H_2 gas, which is sufficient for the cooking needs.

Methodology

The simulations of hydrogen and oxygen production systems with solar energy conducted with Borland Delphi 7 program. For this purpose solar data of three cities, Istanbul, Konya and Erzurum considered and solar data of these cities were used [15].

By using hybrid solar collectors at high temperatures, the electrolysis of water performed; and the system's flow chart prepared. The mathematical model of the system's components (hybrid collector, electrolyses, hydrogen and oxygen storage tank, battery, hot water storage tank) were established. Quantitative calculations for Istanbul, Konya, and Erzurum conducted as considering the insolation and solar irradiance for twelve months.

The system comprised of the hybrid collector, the electrolyses, the battery, the flow regulator, the power regulator, the battery charge controller, pump and hot water storage tank. The block scheme of the hybrid solar collector water electrolysis hydrogen production system demonstrated in Fig. 1.

The input energy for the decomposition process of hydrogen and oxygen as a result of the electrolysis of water is equal to the change occurred in enthalpy [1],

$$\Delta H = \Delta G + \Delta Q \tag{1}$$

In the hybrid collector the solar energy converted into electrical and thermal energy. The electrical energy produced by solar collector formulated as;

$$E_{1e} = \eta_e A q_I R \tag{2}$$

And produced thermal energy as;

$$E_{2t} = \eta_t A q_I R \tag{3}$$

The total energy produced by the hybrid collector as;

$$E_{etk} = E_{1e} + E_{2t} \tag{4}$$