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HYDROGEN PRODUCTION FROM DOMESTIC WASTEWATER USING A SOLAR-POWERED ELECTROLYSIS PROCESS

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Abstract

Hydrogen is a promising energy alternative to substitute fossil fuels and reduce greenhouse gas emissions. The electrolysis method is one of the most developed methods for hydrogen production. The electrolysis process requires energy, so renewable energy sources such as solar energy can make hydrogen production cleaner and more sustainable. This research aims to find out how much hydrogen is produced from domestic wastewater using an electrolysis process whose electrical energy comes from solar energy. This research used samples of domestic liquid waste from kitchen washing in the canteen at Universitas Proklamasi 45, with equipment in the form of an off-grid solar power generator, a set of electrolysis equipment, as well as a monitoring and measurement system. The yield of hydrogen produced by the electrolysis process of domestic wastewater with varying concentrations of NaOH (0.25 M, 0.5 M, 0.75 M, 1 M, 1.25 M, and 1.5 M). The total amount of hydrogen produced during the electrolysis process increases as the concentration of NaOH does. In the other hand, On the other hand, the best COD removal was obtained under neutral solution pH conditions, namely when NaOH was added with a concentration of 0.01M. The energy savings obtained from using electrical energy for the electrolysis process of domestic liquid waste using solar energy is 25 Wh.

Keywords: *electrolysis, hydrogen, solar energy, domestic liquid waste, NaOH Catalyst*

1. Introduction

Hydrogen is a promising energy alternative to replace fossil fuels and reduce greenhouse gas emissions because it is the only energy carrier (other than electricity) with zero carbon content that is being considered for industrial decarbonization, transportation, and heat supply. Currently, hydrogen production technology can be grouped into five main categories, namely industrial processes, thermochemical processes, biomass processes, electrolysis methods, and solar energy methods [1].

The electrolysis method is one of the most developed methods for hydrogen production, apart from thermochemical processes [2]. This process involves the splitting of water molecules (H_2O) into hydrogen (H_2) and oxygen (O_2) using electricity. In general, the reaction that occurs is as follows:

$$\text{Anoda: } H_2O \rightarrow 1/2O_2 + 2H^+ + 2e^-$$
$$\text{Katoda: } 2H^+ + 2e^- \rightarrow H_2$$

Various technologies have been developed in the electrolysis process to increase efficiency, including the development of electrolytes such as alkaline water electrolysis (AWE), alkaline anion exchange membranes (AEM), proton exchange membranes (PEM), and solid oxide water electrolysis (SOE) [8]. Carmo et al. [3] discuss polymer electrolyte membrane (PEM) water electrolysis for hydrogen production, providing information on several future research directions and a roadmap to assist scientists in establishing PEM electrolysis as a commercially viable hydrogen production solution.

Although the electrolysis process requires energy, the use of renewable energy sources such as solar or wind energy can make hydrogen production cleaner and more sustainable. Carmo et al. [3] conducted a study on polymer electrolyte membrane (PEM) water electrolysis for hydrogen production. Meanwhile, Chen [4] described recent progress in splitting water into hydrogen using renewable energy sources.

Based on the Indonesian Energy Outlook [5], the potential for solar energy in D.I. Yogyakarta is 30.3 GWp and each location has a different amount of solar energy potential. For example, Nugroho and Kurniawan [6] conducted research at the Proclamation 45 University located in D.I. Yogyakarta has the potential for electrical energy from solar of 31.17 MWh/year and based on research by Kurniawan et al. [7], at the same university but at different locations, the potential is 8.31 MWh/year.

The need for electricity in the electrolysis process encourages various researchers to develop an electrolysis process with cleaner and more sustainable electrical energy. Solar energy is a cleaner and more sustainable energy that can be used in the electrolysis process. Solar cell technology is a new renewable energy technology that utilizes solar radiation. Solar panels are made from two silicon materials which are semiconductors. The first material is phosphorus which is type N (electron), and the second material is boron which is type P (hole). Then they are combined into a P-N junction, the working principle is that when light hits the solar panel, the electrons in the N-type will be overcharged so that the electrons will move to the P-type. The number of electrons produced depends on the sunlight received by the solar panel [9]. The components of a solar energy system consist of several solar panels arranged in series, parallel, or parallel series combinations that convert sunlight into direct current electricity [10].

Liquid waste is one of the main contributors to water environmental pollution throughout the world [11]. Along with rapid industrial growth and urbanization, the volume and complexity of wastewater continue to increase, posing serious threats to water quality and aquatic ecosystems [12]. Domestic liquid waste is a type of waste produced by daily activities in the household, including activities such as bathing, washing, cooking, and defecating. This waste has different characteristics depending on factors such as living habits, population, and sanitation infrastructure [13].

Studies have shown that domestic liquid waste generally contains wastewater (such as bathroom and kitchen water), human feces, detergents, organic materials, and other chemical compounds originating from daily household activities [14]. In addition, developments in lifestyle and technology can also influence the characteristics of domestic liquid waste, such as the use of household cleaning products containing certain chemicals or the adoption of more modern sanitation systems [15].

According to studies by Bow et al. [16], the electrolysis process of seawater can produce more hydrogen when a lower proportion of NaOH catalyst is used. The electrolysis process is used by Rustana et al. [17] to produce hydrogen more efficiently and effectively, compare the total volume, production rate, and production duration of hydrogen, produced by electrolyzing seawater from mangrove areas with different concentrations of NaOH added as a catalyst to assess the productivity of hydrogen.

Based on the background above, this research aims to find out how much hydrogen production from domestic liquid waste uses an electrolysis process whose electrical energy comes from solar energy, with variations of NaOH concentration.

2. Materials and Methods

Raw Material Preparation

This research uses domestic wastewater from kitchen equipment washing water in the Universitas Proklamasi 45 (UP45) canteen. Sampling was carried out using procedures by SNI 8990:2001 concerning wastewater test sampling methods for testing physical and chemical parameters. The samples taken are then analyzed for Chemical Oxygen Demand (COD) values using equipment in the Environmental Engineering Laboratory at UP45.

NaOH is used as a catalyst to accelerate the hydrogen formation reaction from domestic wastewater. The NaOH used in the form of pure analytical material was obtained from chemical suppliers in Yogyakarta. NaOH solution of a specific concentration is prepared by dissolving a solid NaOH substance in distilled water, with the composition matching the molarity formula provided by Saputro and Rangkuti [18].

Equipment Preparation

The experiment apparatus was set up as illustrated in Figure 1.

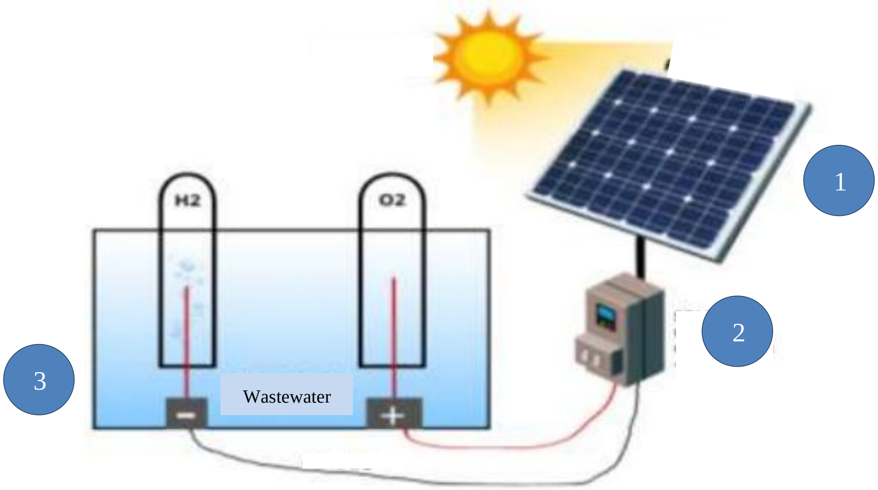

Figure 1. The experimental apparatus setup

The solar power plant used is an off-grid system, that is not connected to the PLN network, where the electrical energy produced by the solar panels will be stored in batteries and then used as an energy source for electrolysis equipment. The series of off-grid solar power generation systems used in this research contains several components as follows:

(1) 120-watt Solar Panel as a producer of electrical energy, which is an important component in the research that will be carried out.

(2) 12V 100Ah battery as storage and supply of electrical energy to loads obtained from solar panels.

The electrolysis system (3) used is a series of simple equipment in the form of electrolysis cells, electrolyte membranes, vessels, electrolyte solutions, and other supporting components, which are capable of breaking down water (H_2O) compounds into oxygen (O_2) and hydrogen (H_2) using an electric current that passes the water.

To monitor the performance of solar power generation systems and measure hydrogen production, used a multimeter, ruler, and time controller. Before being used for testing, the equipment will be calibrated first so that it can work properly.

Main Experiment

Hydrogen production data was collected by electrolyzing samples of domestic liquid waste that had been prepared. The difference in the water level in the measurement tube, which showed the volume of hydrogen produced by the electrolysis process, was then used to compute the volume of wastewater before and after the electrolysis process. This hydrogen volume data was also used to calculate the pace and yield of hydrogen generation, as well as the yield of hydrogen produced by the electrolysis process of domestic wastewater with varying concentrations of NaOH (0.01 M, 0.05 M, 0.1 M, 0.5 M, 1 M, and 1.5 M).

Data collection was carried out throughout 120 hours, with the independent variable being the concentration of NaOH which was used as a catalyst for the electrolysis process. Meanwhile, the dependent variables that will be observed are the amount of hydrogen produced from the electrolysis process, as well as the chemical parameters of the water in the solution (COD).

Data Analysis

Hydrogen yield was estimated by dividing the difference in volume of hydrogen produced at the start and conclusion of the electrolysis process by the total volume of hydrogen produced, as follows:

$$\frac{\text{measured gas volume} - \text{previous gas volume}}{\text{total volume}} \times 100\ \% \qquad (1)$$

The calculation of COD concentration allowances is based on the comparison of the difference in substance concentration in the before and after electrolysis process. The removal efficiency value is calculated using the following equation:

$$\text{Efficiency}\ (\%) = \frac{COD_0 - COD_t}{COD_0} \times 100\% \qquad (2)$$

Where COD_0 and COD_t correspond to the value before and after the electrolysis process, respectively.

The total energy used in the experiment is calculated using the following equation:

$$W = V\ .\ I.\ t \qquad (3)$$

Where : W = Total energy used (kWh)
V = Voltage (Volt)
I = Electrical current (Ampere)
t = Electrolysis time (hours)

3. Results and Discussion

3.1. Hydrogen Production

The total amount of hydrogen generated during the electrolysis of domestic wastewater with varying concentrations of NaOH is displayed in Figure 2.

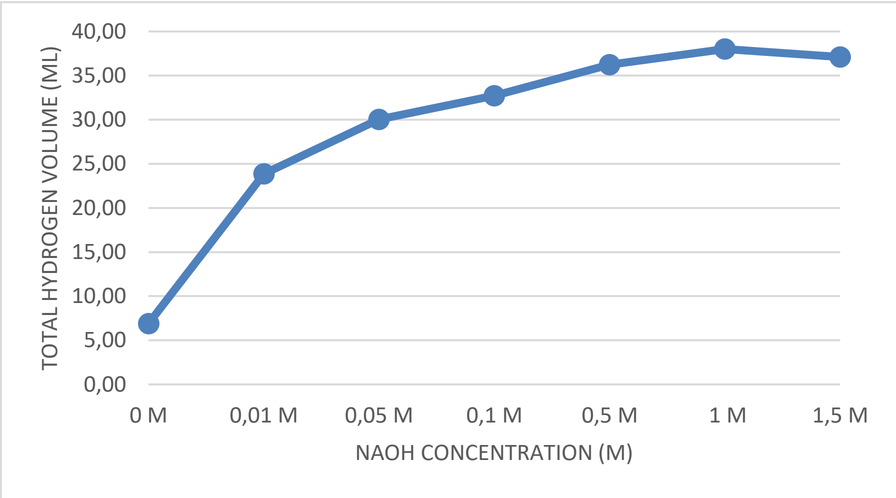

Figure 2. The total volume of hydrogen for each concentration of NaOH

Figure 2 illustrates that as the concentration of NaOH rises, so does the overall volume of hydrogen generated during the electrolysis process. When electrolysis is performed directly into wastewater without the addition of NaOH, just 6 mili liters of hydrogen gas are produced. This value continues to increase as the concentration of NaOH does, peaking at a 1.25 M concentration. After that, the oxygen content tends to decrease. These findings demonstrated that adding NaOH as a catalyst to the electrolysis of domestic wastewater will result in a larger amount of hydrogen produced overall, as compared to the volume of hydrogen produced utilizing regular domestic wastewater.

3.2. COD Removal Efficiency

The COD Removal efficiency during the electrolysis of domestic wastewater with varying concentrations of NaOH is displayed in Figure 3.

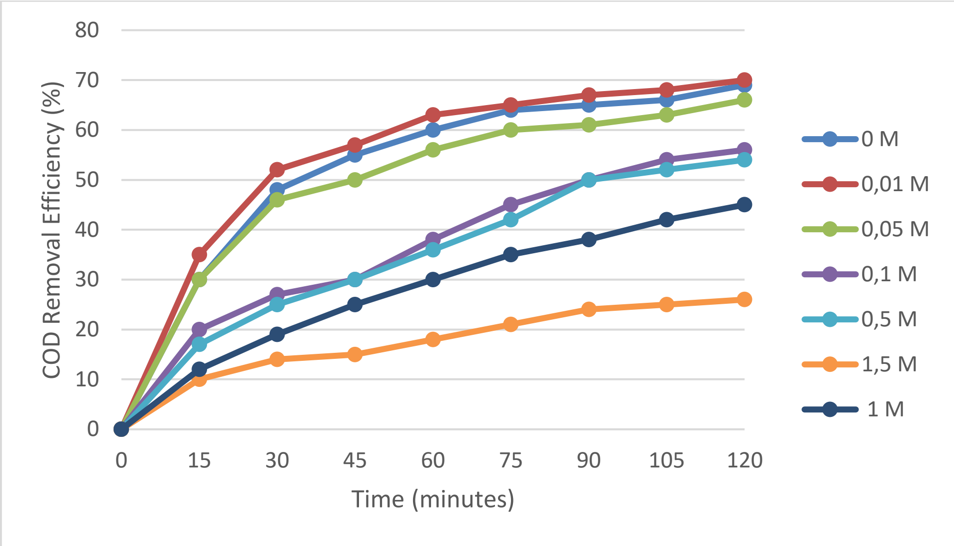

Figure 3. COD Removal Efficiency during electrolysis with varying NaOH concentration

Based on Figure 3, it can be seen that the best COD Removal Efficiency at the end of the process was obtained in the electrolysis process with the addition of 0.01 M NaOH, which is 70%. On the other hand, the smallest value was obtained with the addition of 1.5 M (25%). This is because based on measurements, the domestic wastewater containing 0.01 M NaOH has an initial pH close to neutral. Meanwhile, the domestic wastewater measurements without adding NaOH showed the pH of the solution was 6.5. After being mixed with NaOH with a concentration of 0.01 M, the pH becomes 7.1, then rises again to 8.5, 10.1, 11.6, 12.5, and 13.1, respectively for NaOH concentrations of 0.05 M, 0.1 M, 0.5 M, 1 M, and 1.5 M.

Based on Safari et.all [19], one of the crucial parameters in the electrochemical reaction is the initial pH because it influences the form of the electrogenerated active species and OH^- and other highly reactive hydroxyl radicals. During the electrolysis process, a pH increase is observed when the initial pH is acidic. The explanation for this phenomenon is that the development of hydrogen at cathodes causes the release of over-saturated CO_2.

3.3. Energy Saving

The energy used in this experiment comes from electricity produced from solar power plants with solar panel capacity of 120 Wp. The electrical energy is stored in a 12 V battery which is then supplied to the electrolysis equipment with an average current of 1 A. The total energy used in the electrolysis process for two hours is as follows.

$$W = V . I. t = 12. 1. 2 = 24 \text{ Wh}$$

Based on the calculations above, it is found that the energy savings obtained from using electrical energy for the electrolysis process of domestic liquid waste using solar energy is 25 Wh.

4. Conclusion

The domestic wastewater electrolysis process has two advantages, namely that it can produce hydrogen as an alternative fuel and reduce pollutant levels in wastewater. The research results showed that the addition of the NaOH catalyst can influence the results obtained. The total amount of hydrogen produced during the electrolysis process increases as the concentration of NaOH does. In the other hand, On the other hand, the best COD removal was obtained under neutral solution pH conditions, namely when NaOH was added with a concentration of 0.01M. The energy savings obtained from using electrical energy for the electrolysis process of domestic liquid waste using solar energy is 25 Wh.

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