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Efficiency Of Hydrogen Production From Sea Water Using The Electrolysis Process With Solar Energy Photovoltaic Systems

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Abstract

Hydrogen is a future alternative energy source, offering environmental friendliness and renewable properties that can potentially replace fossil fuels. Despite the potential, its synthesis typically requires high energy and costs, posing a constraint on mass production due to low efficiency. Therefore, this study aims to develop hydrogen production technology from seawater using the electrolysis process with solar energy from photovoltaic systems as energy source. The experiments were carried out with different voltages of 10, 15, 20, and 25 volts, using electrode materials made of titanium in mesh and plate shapes. Seawater served as the electrolyte, and it was supplemented with 0.1 mol NaOH and 0.1 mol H_2SO_4. The results showed that the applied voltage had a positive correlation with hydrogen production rate, while the electrolysis process time had no significant effect. In addition, the use of NaOH catalyst with mesh-shaped titanium electrode could yield efficiency of hydrogen production flow rate of 2.06% or 52 ml/minute. This outcome was better compared to the electrolysis of seawater electrolyte with and without H_2SO_4 catalyst, which yielded values of 1.84% or 30.1 ml/minute and 1.42% or 28.9 ml/minute, respectively.

Keywords:
Hydrogen, electrolysis, efficiency, seawater, photovoltaic, titanium.

1 Introduction

Fossil fuels, such as crude oil, natural gas, and coal, are dominant energy sources in global energy consumption. However, the combustion of these fuels has been reported to be the primary contributor to climate change due to the emission of CO_2 [1]. Several studies have shown that climate change typically leads to an increase in global temperature, affecting both natural phenomena and human livelihoods. This condition can also cause alterations in water quality and quantity, shifts in agricultural land and coastal ecosystems, deforestation, and increased levels of natural disasters. To mitigate the adverse effects of climate change and prevent a 2℃ temperature increase, concerted efforts are required to achieve a 25% decrease in CO_2 emissions by 2025. Subsequently, the goal is to achieve zero emissions levels based on the objectives outlined in the Paris Agreement [2] [3].

In line with these efforts, several studies have been carried out to develop an effective hydrogen production technology. At present, the most advanced and widely used technology is reforming hydrocarbon fuel, also known as steam reforming natural gas at high temperatures (800℃-1000℃) [4], with energy sourced from fossil fuels combustion. In addition, various reports have shown that the combustion of fossil fuels to produce heat energy often leads to an increase in CO_2 emissions and significant waste of resources. An alternative method comprises the production of hydrogen from biomass, such as plant residues, wood, as well as agricultural, livestock, and household waste through gasification [5] and pyrolysis [6]. However, this method also causes high CO_2 emissions, which have detrimental effects on the environment. This has led to the development of a novel method, comprising production of hydrogen from water with the electrolysis process using renewable and environmentally friendly energy [7].

A water molecule has three atoms: one oxygen (O) atom and two hydrogen (H) atoms, which have the potential to be the energy of the future. In addition, the extraction of hydrogen compounds typically requires the electrolysis process [8], where water (H_2O) is converted into hydrogen (H_2) and oxygen (O_2) using electric current [9] [10]. During the process, ions either accept or release electrons on the electrode surface, leading to the production of H_2 at the cathode and O_2 at the anode [11].

At present, more than 85% of the global demand for hydrogen is met through the steam reforming process of natural gas. This method operates at high temperatures ranging from 800℃-1000℃ using heat energy derived from the combustion of fossil fuels. However, the combustion process often leads to a significant waste of fossil fuels reserves and a substantial increase in CO_2 emissions [12]. To over these challenges, several studies have proposed the substitution of heat energy sources with nuclear reactors [13].

The use of fossil fuels-based energy for hydrogen production poses significant environmental challenges, with carbon dioxide emissions ranging from 2.5-5 tons per ton of hydrogen produced [14]. To mitigate these challenges, it is important to use clean and sustainable renewable energy sources, such as solar, wind, tidal, or wave. One promising approach for environmentally friendly hydrogen production is the integration of photovoltaic panels with electrolyzes, which have proven to be commercially viable and economically competitive [15]. In this approach, energy generated serves as the electrical energy source for the electrolysis process [16]. Although its efficiency and economic competitiveness is lower compared to hydrogen produced from fossil fuels, studies exploring the use of photovoltaic systems (solar cells) is rapidly advancing. In addition, advancements in this field are expected to lead to increased efficiency and cost-effectiveness in the future [14] [17].

The synthesis of hydrogen through the electrolysis process often requires high costs, leading to decreased efficiency. This challenge can be addressed using an alternative approach that leverages abundant and environmentally friendly resources, such as seawater and free solar energy. Therefore, this study aims to increase efficiency of hydrogen production using seawater through the electrolysis process with solar energy from photovoltaic systems.

Efficiency calculation of the electrolysis process using solar energy from photovoltaic systems or solar cells was carried out using Eq. 1 [15].

$$\eta = \frac{N \times 1.23}{V_{oper}} \times 100\% \qquad (1)$$

where N is the number of electrolysis cells used, V_{oper} is the operating voltage (volts) used during the electrolysis process. In addition, the value 1.23 (V) represents the minimum energy required to produce hydrogen in the electrolysis process [15].

In this study, efficiency of photovoltaic systems was also calculated to obtain the overall efficiency of hydrogen production using the Eq. 2.

$$\eta = \frac{V_{mp} \times I_{mp}}{A \times G} \times 100\% \qquad (2)$$

where V_{mp} is the voltage at maximum power point (volts), I_{mp} is the current at maximum power point (amperes), A is the total area of solar panel (m^2), and G is solar radiation value (W/m^2).

Based on Eq. 1 and Eq. 2, the overall efficiency of hydrogen production using solar energy from photovoltaic systems can be calculated using the Eq. 3 [15].

$$\text{Solar to } H_2 \text{ Efficiency} = \frac{N \times I_{oper} \times 1{,}23}{A \times G} \times 100\ \% \qquad (3)$$

2 Methodology

The materials used in this study consisted of 1 electrolysis reactor unit made of acrylic glass (polymethyl methacrylate), as shown in Fig. 1. In addition, these materials were thermoplastic and transparent with an electrolyte capacity of 5 liters.

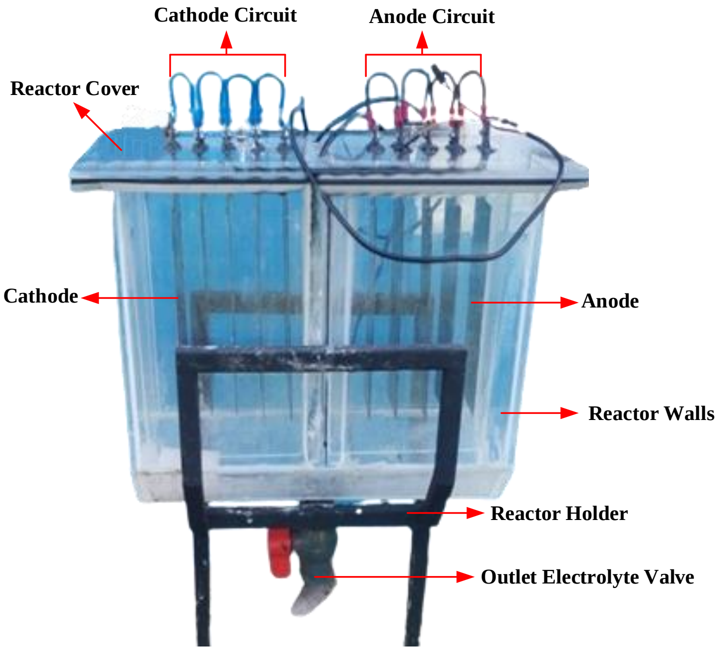
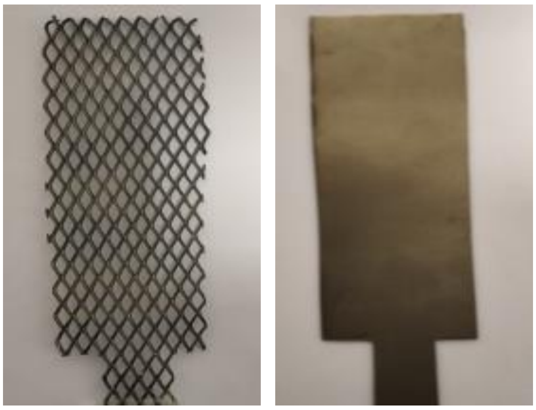


Fig. 1. Electrolysis reactor.

The reactor had electrode cells consisting of 5 cathode units and 5 anode units, each measuring 10 cm × 5 cm. The electrode material was made of titanium in mesh and plate shapes, as presented in Fig. 2.



(a) (b)

Fig. 2. Electrode cells. (a) Mesh shape, (b) plate shape.

The electrolyte used was seawater taken from Bangka Beach, Krueng Geukueh District, Dewantara, North Aceh Regency, Aceh. Energy source for the electrolysis process was from sunlight with photovoltaic systems. In addition, the number of monocrystalline photovoltaic panels used was 2 units with dimensions of 1320 × 992 × 35 mm (400 Wp).

Fig. 3 showed the mechanism of the electrolysis process, and the reaction occurring at the positive pole (anode) was the oxidation reaction:

$$2\ (H_2O)_{(l)} \rightarrow 4H^+{}_{(aq)} + \ O_2{}_{(g)} + 4e^-$$

Meanwhile, the reaction at the negative pole (cathode) was the reduction reaction:

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

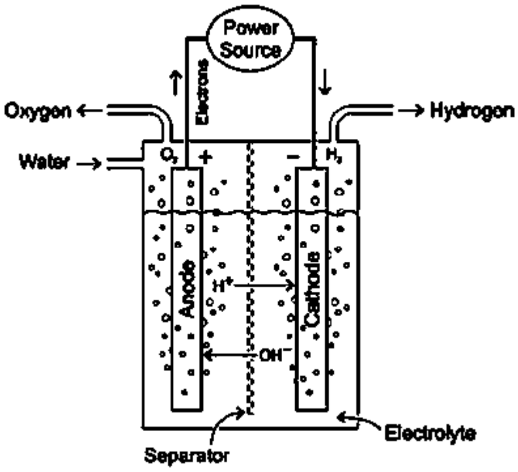


Fig. 3. Schematic diagram of the electrolysis process [14].

Based on Fig. 4, the arrangement of the electrolysis equipment consisted of several main parts, including (a) electrolysis reactor filled with seawater electrolyte, and (b) electrode cells connected to the PV solar panel after passing through a voltage regulator that functioned to regulate the voltage as desired. This reactor consisted of 5 electrode cells in the anode reactor column and another 5 units in the cathode reactor column. A digital Flow Meter was connected to the anode and cathode reactor columns to measure the flow rate of hydrogen and oxygen production from the electrolysis process.

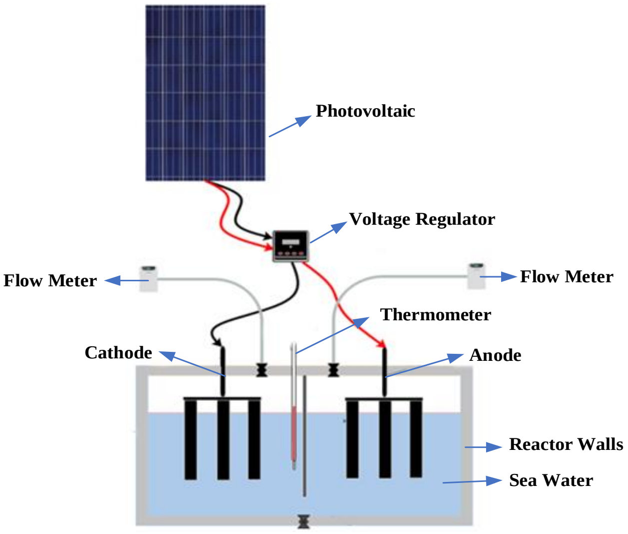


Fig. 4. Arrangement of seawater electrolysis test equipment powered by solar energy.

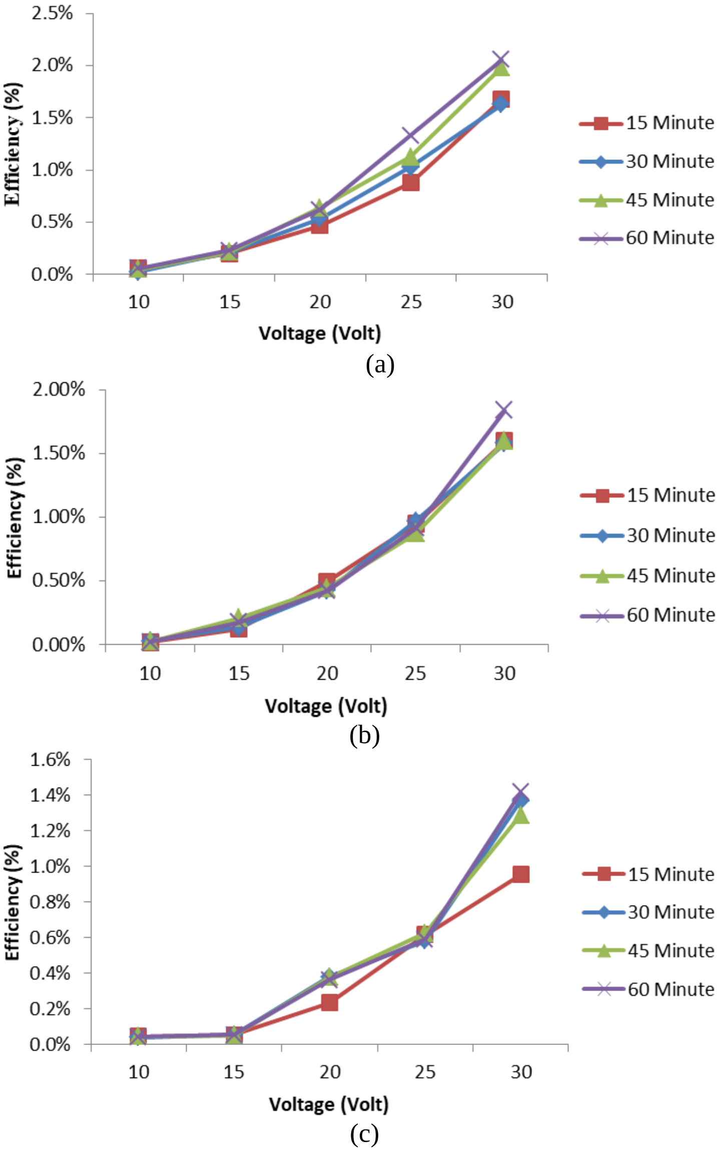
A thermometer unit was also installed in the electrolysis reactor to measure the electrolyte temperature during the electrolysis process.

3 Results and Discussion

Efficiency of hydrogen production with the electrolysis process using solar energy from photovoltaic systems could be calculated using Eq. 3.

3.1 Efficiency of Titanium Mesh Electrode Electrolysis with NaOH, H_2SO_4 Catalysts and without Catalyst

Efficiency curve of the electrolysis process using titanium mesh electrodes with and without the addition of NaOH, H_2SO_4 catalysts, in the electrolyte is presented in Fig. 5.



(a)

(b)

(c)

Fig. 5. Efficiency of H_2 production with the electrolysis process using titanium mesh electrodes. (a) NaOH catalyst, (b) H_2SO_4 catalyst, (c) without catalyst.

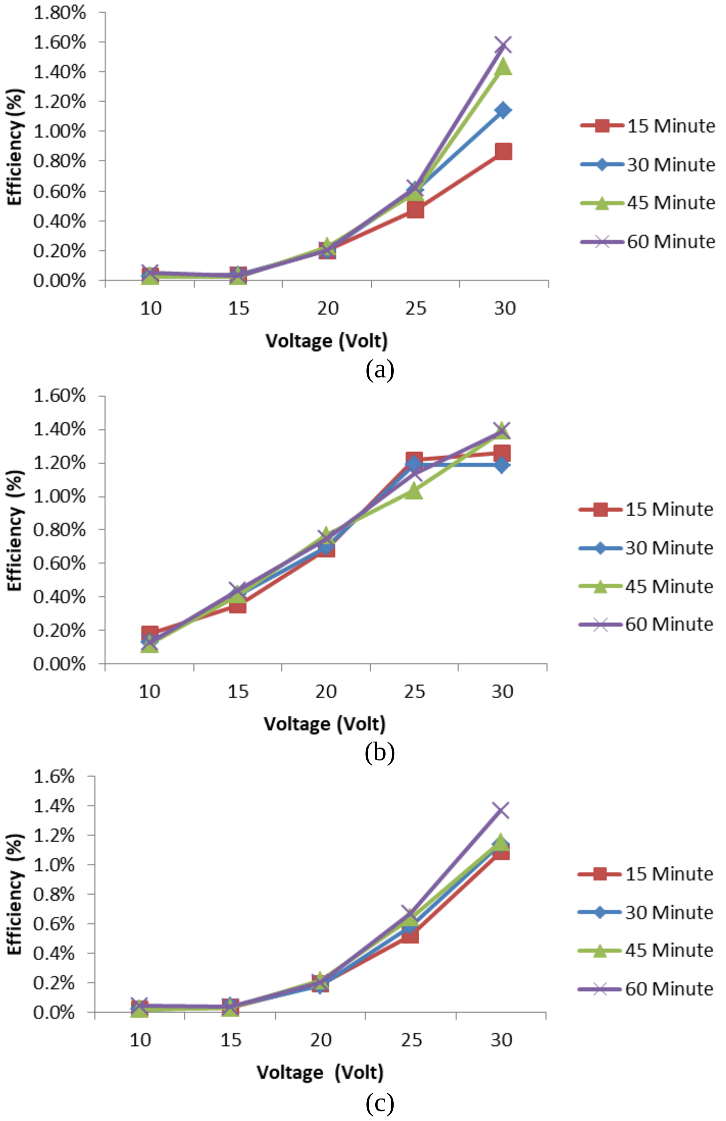
The highest efficiency of 2.06% was obtained from process using titanium mesh electrodes with the addition of NaOH catalyst into the electrolyte. For the electrolysis with the addition of H_2SO_4 catalyst, efficiency of 1.84% was achieved. Meanwhile, the lowest efficiency was obtained from hydrogen production using titanium mesh electrodes without adding catalysts, with a value of 1.42%.

The electrolysis process using the NaOH catalyst yielded higher hydrogen production efficiency compared to H_2SO_4 catalyst. Therefore, in the electrolysis process using seawater as the electrolyte, it was more efficient to use a strong base catalyst compared to a strong acid. A strong base catalyst could enhance the conductivity of seawater electrolyte solution more effectively compared to a strong acid catalyst.

3.2 Efficiency of the Electrolysis using Plate-shaped Titanium Electrode with NaOH and H_2SO_4 Catalysts

Fig. 6 presented the graph showing the variation of voltage against efficiency of hydrogen production using the electrolysis process with plate-shaped titanium electrodes.

Fig. 6 showed that the highest efficiency of hydrogen production using mesh-shaped titanium electrodes was 1.58% when seawater electrolytes were given NaOH catalysts. The electrolysis using H_2SO_4 catalyst obtained efficiency of 1.39%, while the lowest value of 1.37% was recorded in hydrogen production with seawater electrolyte without the addition of catalysts.



(a)

(b)

(c)

Fig. 6. Efficiency graph of H_2 production with the electrolysis process using titanium mesh electrodes. (a) NaOH catalyst, (b) H_2SO_4 catalyst, (c) without catalyst.

Based on the results, the electrolysis with the addition of NaOH catalyst using mesh-shaped electrodes led to higher efficiency compared to the use of H_2SO_4 catalyst. This showed that NaOH catalyst, a strong base, was more suitable for use in seawater electrolysis process than H_2SO_4 catalyst, which is a strong acid.

3.3 Overall Efficiency

The overall efficiency of hydrogen production using the electrolysis process with solar energy from photovoltaic systems is presented in Table 1.

Table 1 showed that the highest efficiency in hydrogen production using titanium electrodes was obtained from the electrolysis process using mesh-shaped titanium electrodes with electrolyte added to the NaOH catalyst. This was directly proportional to hydrogen gas production results obtained. The highest hydrogen production flow rate was recorded in process with mesh-shaped titanium electrodes and electrolytes added with NaOH catalyst.

The effect of acid and base catalysts on the electrolysis process for hydrogen production accelerated the reaction of breaking down water molecules into hydrogen and oxygen gases by lowering the activation energy required [12] [14]. Several studies had shown that acid catalysts, such as H_2SO_4, HCl, and HNO_3 could increase hydrogen ions (H+) concentration, leading to the attraction of electrons from the negative electrode (cathode) to form hydrogen gas. Base catalysts, including NaOH and KOH, could increase the concentration of hydroxide ions (OH-), thereby repelling electrons from the positive electrode (anode) and forming oxygen gas [19]. Acid and base catalysts were known to have the ability to affect the stability of water molecules, making them easier to decompose by electric current [20].

Table 1. Overall efficiency of hydrogen production with seawater electrolysis process using solar energy from photovoltaic systems

Electrode	Voltage	Catalyst	Efficiency (%)	H_2 flow (ml/min)
Titanium mesh	30 Volt	NaOH	2.06	52
Titanium mesh	30 Volt	H_2SO_4	1.84	30.1
Titanium mesh	30 Volt	Without catalyst	1.42	28.9
Titanium plate	30 Volt	NaOH	1.58	30.9
Titanium plate	30 Volt	H_2SO_4	1.39	21.5
Titanium plate	30 Volt	Without catalyst	1.37	22.5

The selection of suitable catalysts for use in the electrolysis process had not been specifically regulated, as the catalyst's performance depended on various factors, such as the type of material, structure, morphology, composition, operating conditions, and the source of water or electrolyte [21]. In acidic solution electrolysis, acid catalysts, such as H_2SO_4 or HCl could be used to increase solution conductivity and accelerate the electrolysis reaction. Meanwhile, in basic solution electrolysis, base catalysts, such as NaOH or KOH is also used to increase solution conductivity and accelerate the electrolysis reaction. This was in line with the study conducted by Y. Wahyono (2017), showing that the use of NaOH catalyst led to higher hydrogen production compared to others [22].

Mesh-shaped electrodes could produce higher hydrogen yields compared to plate-shaped electrodes, primarily due to the larger surface area. Consequently, the larger contact area facilitated more extensive electrolysis, producing higher levels of hydrogen compared to the plate-shaped variant [23]. The contact area in the electrolysis process referred to the surface area of the electrode in contact with the electrolyte, which influenced the reaction rate in the electrolyte decomposition process. These results were consistent C.E. Rustana et al. (2021), stating that the type and shape of the electrode affected hydrogen production rate in the electrolysis process [24].

4 Conclusion

In conclusion, this study successfully examined the performance of seawater electrolysis reactor powered by solar energy with photovoltaic systems. The results showed that the use of mesh-shaped titanium electrodes was superior to plate-shaped electrodes, with efficiency of 2.06% and 1.58% respectively. This was due to the larger surface area during the electrolysis process, leading to a higher flow rate of hydrogen gas production. In addition, the influence of catalysts on the electrolysis process showed that strong bases (NaOH) could achieve higher hydrogen production efficiency, reaching 52 ml/min with mesh-type electrodes. In comparison, plate-type electrodes gave hydrogen production levels of 30.9 ml/min. Based on these results, the use of base catalysts enhanced the conductivity of seawater electrolyte solutions, thereby increasing hydrogen production.

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