The Effect of Electrode and Catalyst on Hydrogen Production through Electrolysis of Sea Water from Mangrove Area

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Abstract

This study aims to analyze the effect of electrodes and catalysts on the production of hydrogen resulted . through the electrolysis of seawater from the mangrove area. The electrolysis process was carried out by applying a constant voltage of 12 volts to convert electrical energy into chemical energy that occurs in the electrolysis cell. Meanwhile, graphite and stainless steel were used as electrodes with various catalyst of NaOH and HCl. The results indicated that the electrolysis of seawater from the mangrove area with electrode of graphite and HCL catalyst produced a larger volume of hydrogen and longer electrode lifespan compared to the use of stainless steel electrodes. On the other hand, the use of NaOH catalyst and carbon electrodes produces smaller hydrogen volume and shorter electrode lifespan than the use of stainless steel electrodes. Generally, it was identified in this study that the use of graphite electrode and HCl catalyst as well as the use of stainless steel and NaOH catalyst can be used as alternative method on producing hidrogen through electrolysis of seawater from mangrove area.

Keywords: Hydrogen Production, Electrolysis, Electrode, Catalyst.

1. Introduction

Energy need is increasing along with the growth of world energy demand which is also increasing from year to year. The World Energy and Climate Policy Outlook (WECO) in Europe estimates that the growth rate of global primary energy demand between 2000-2030 is 1.8% per year. So far, this energy need had been met primarily by the use of fossil energy such as oil, natural gas and coal. Unfortunately, beside its limited availability, fossil energy will also run out at some point. In addition, the use of fossil energy has also an impact to the environment since it will increase concentrations of greenhouse gases such as CO2 and SO2 as well as other pollutants [1]. Saving energy is indeed a wise step, but it is not enough to solve the problem of an energy crisis that may occur. Accordingluy, expanding the use of other energy sources to replace the use of fossil energy with renewable energy as an alternative energy source is a must.

One source of renewable energy that has the potential to overcome the problem of the energy crisis is hydrogen gas (H2). Hydrogen is the most abundant element in nature, so it is a very cheap raw material of energy. Hydrogen is an alternative energy source that is environmentally friendly with a relatively high energy value. The Center for Technology and Energy Resources and the Chemical Industry explained that hydrogen has the highest energy content, which is 120 MJ/kg, higher than gasoline which only contains 44 MJ/kg of energy. In addition to its relatively high energy content and efficient electron carrier, hydrogen is also a clean fuel or green energy. Therefore, hydrogen is considered as a possible future alternative fuel that can be easily used in fuel cells [2].

However hydrogen cannot be extracted directly but must be extracted from materials containing hydrogen. One way to produce hydrogen is through the electrolysis of seawater. Seawater is used because its availability which is very abundant with natural catalysts that are already attached as a constituent part of seawater. Seawater electrolysis is the separation of water molecules mainly into hydrogen and oxygen due to an electric current. An electric current flows between two electrodes which are separated and immersed in the electrolyte. A diaphragm or separator that may be glass tubes should be used to avoid mixing of gases generated at the electrodes. The electrode, diaphragm, and electrolyte are the elements that configure the electrolysis cell [3].

Utilization of abundant seawater to produce hydrogen through the electrolysis process provides significant advantages compared to the use of fresh water which is one of the main sources of human needs [4]. However, the use of seawater also has a weakness, namely the possibility of corrosion problems at the electrodes due to the chlorine content in seawater. Angaretno et al. stated that the chlorine content in seawater can corrode the electrodes in the electrolysis process [5]. This makes the electrode effectiveness decrease, so that the hydrogen produced through the electrolysis process will also decrease. As it is known that corrosion not only causes damage to the oxidation of metal materials, but also degradation of non-metallic materials, thus causing loss of function of these materials due to chemical interactions with the environment [6]. While the research conducted by Kuang et al. showed that the process of electrolysis of seawater with solar cells and without a negatively charged coating on the anode can last for 12 hours [7].

Meanwhile, research conducted by Tanasale et al. and Aprilia et al. explained that sea water can be desalinated naturally through mangrove plants [8] [9]. The natural desalination process by mangrove plants is much cheaper and conservative when compared to other seawater desalination methods. As it is known that mangroves need Na and Cl content in seawater for the photosynthesis process, so that mangroves can grow. While, research conducted by Rustana et al. showed that the electrolysis process with seawater from mangrove areas could slow down the rate of electrode corrosion by chlorine, but unfortunately the volume of hydrogen produced through such electrolysis process was very small compared to that produced by the electrolysis of seawater from non-mangrove areas [10]. Furthemore, according to research conducted by Bow et al. and Rustana et al. (2021) showed that NaOH catalyst with low concentration can increase hydrogen production through seawater electrolysis [11] [12].

As known, the electrode is a conductor used to carry an electric current from an electric source to a material in an electrolysis cell. There are various forms of electrodes, namely in the form of wire, plate, or cylinder and usually made of metal such as zinc or copper, etc., but can also be non-conducting metal such as graphite. The graphite electrode was chosen in this study because it has good electrical conductivity and the price is relatively cheap. Graphite also has a diffusion coefficient that tends to be close to its true value when compared to other electrodes such as stainless steel and brass. Accordingly, graphite electrodes are suitable for use in the electrolysis of chloride-containing seawater.

The physical properties of graphite are solid phase and have a density of 2.267 g/cm3, melting point 4300-4700 K, boiling point 4000 K, heat of melting 100 kJ/mol, heat of vaporization 355.8 kJ/mol and heat capacity of 8,517 J/mol K. Its chemical properties are very unreactive at ordinary temperatures and it is directly reacting with fluorine. Meanwhile, burning carbon in limited air will produce monoxide, if the air is excess it will form carbon dioxide, if it is heated in the air it will react with oxygen to form carbon dioxide and react with water to form carbonic acid [2].

In addition to graphite electrodes, stainless steel electrodes are also the right choice. The metal type of Stainless Steel (SS), known as stainless steel as an electrode. It is an iron compound containing at least 10.5% chromium to prevent corrosion (metal rust). Rust resistance is obtained by the formation of a layer of chromium oxide which can prevent the oxidation of iron (Ferrum). Stainless steel can withstand corrosion attack due to the spontaneous interaction of its alloy material with nature

attack due to the spontaneous interaction of its alloy material with nature [13].

2. Methodology

The process of electrolysis of seawater from the mangrove area is carried out by varying the type of electrode and catalyst in order to determine the volume of hydrogen produced and the lifespan of each electrode. The process of electrolysis is the decomposition reaction of an electrolyte by an electric current. The conversion of electrical energy into chemical energy takes place in an electrolytic cell. Electrolytes that are soluble in polar solvents (such as water) dissociate into positive ions (cations) and negative ions (anions). Negative ions are anions because during electrolysis of the solution, it is attracted to the positive charge at the anode, whereas positive ions are cations since they move through the solution towards the negative charge.

This study used graphite and stainless steel rod electrodes with diameters and lengths of 8 mm and 9 cm, respectively. The 12 volt constant potential difference sourced from the power supply was used for the electrolysis process. A constant voltage of 12 volts was used because Yuvaraj (2014) explains that the use of a 12 volt constant voltage difference in the electrolysis process produces a fairly stable volume of hydrogen [14]. Figure 1 shows a schematic of the arrangement of the seawater electrolysis equipment used.

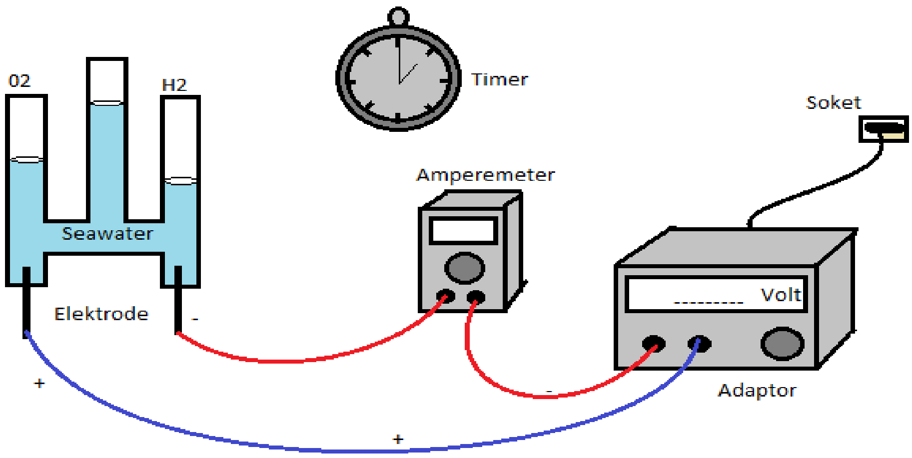

Figure 1 Schematic of setting up electrolysis equipment

The experimental method was used in this study to analyze the effect of electrode types (graphite and stainless steel) and NaOH and HCl catalysts on hydrogen produced through the electrolysis of seawater from mangrove areas. The NaOH and HCl catalysts used in this electrolysis process were in the form of solutions with a concentration of 1 M each. The NaOH (1 M) solution was made by dissolving the solid catalyst in distilled water with a composition following the molarity formula proposed by Saputro (2018), namely [15].

$$M = \frac{g}{Mr} \times \frac{1000}{mL}$$

Furthermore, the volume of hydrogen produced through the electrolysis of seawater from the mangrove area was determined using the water displacement method. The water displacement method was carried out by measuring the change in seawater level in the measuring tube at the cathode after the electrolysis process took place within the specified measurement time. By knowing the change in seawater level in the measuring tube at the cathode where hydrogen was produced, the volume of hydrogen can be determined by multiplying the cross-sectional area of the tube and the change in seawater level in the tube. Measurements of changes in seawater level was carried out every 20 minutes until the volume of hydrogen produced through the electrolysis process showed a decreasing or constant trend and even stops. It was observed by looking at changes in seawater level in the tube. After the hydrogen gas volume was known, the hydrogen gas production rate was calculated using the following equation [16].

$$\frac{Volume\ of\ hydrogen\ gas}{Time\ of\ electrolysis}$$

Data were analyzed using descriptive quantitative methods. Meanwhile, the lifespan of the electrode was determined by observing the length of time since the electrolysis process started until such electrolysis process stoped.

3. Result and Discussion

Figures 2 and 3 show the volume of hydrogen produced every 20 minutes by electrolysis of seawater from the mangrove area that was carried out at a potential difference of 12 Volts and with HCl and NaOH catalysts, respectively. Figure 2 shows the polynomial relationship between hydrogen volume and measurement time with coefficient of determination (R2) equal to 0.999 and 0,996 respectively for graphite and stainless steel. From Figure 2, it could be analyzed that the use of HCl catalyst in the electrolysis of seawater from the mangrove area can produce more hydrogen and the electrode lifespan was longer for graphite compared to stainless steel.

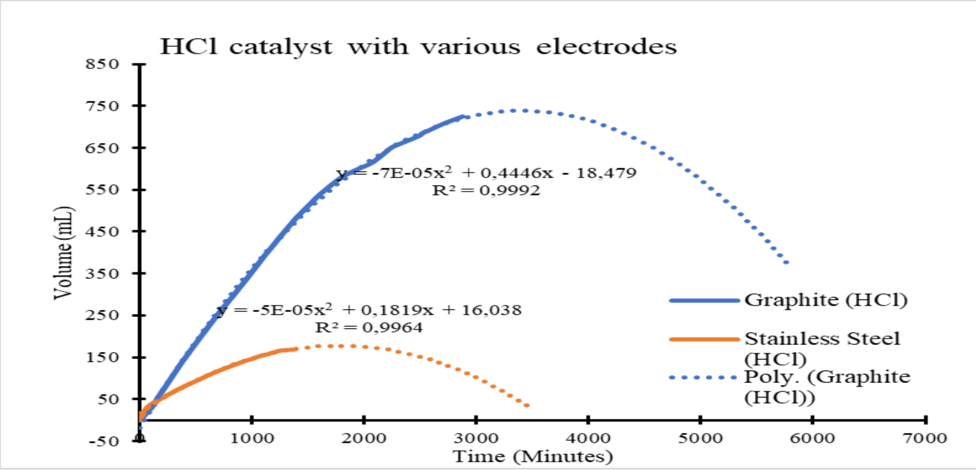

Figure 2. Graph of the relationship between hydrogen volume (ml) and time (minutes) in the process of electrolysis of seawater from mangrove areas with HCL catalyst

Meanwhile, Figure 3 shows a graph of the polynomial relationship between the volume of hydrogen and the measurement time for every 20 minutes of the electrolysis process that used NaOH catalyst with R2 of 0.999 for graphite and 1 for stainless steel, respectively. In contrast to the HCl catalyst, that the use of NaOH catalyst in the electrolysis of seawater from the mangrove area showed that the use of stainless steel electrodes produced more hydrogen and the electrode lifespan was longer than graphite.

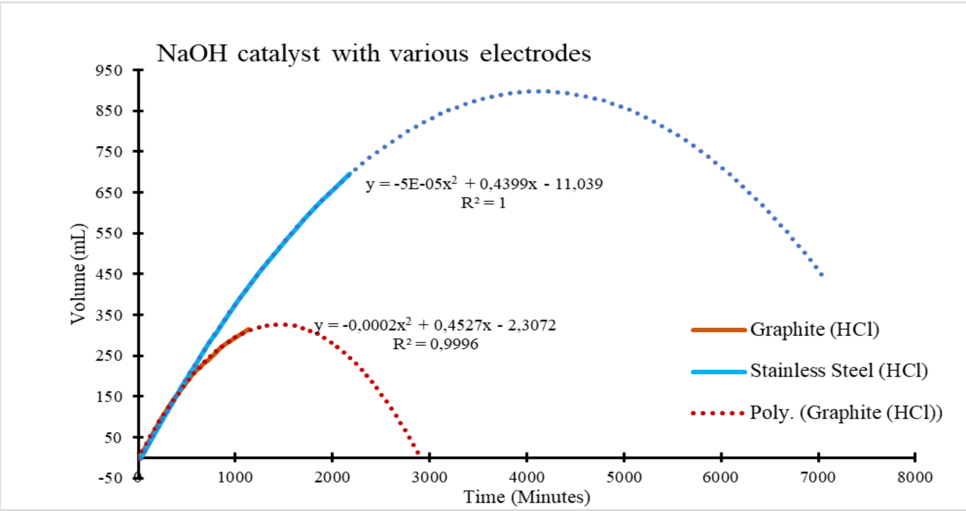

Figure 3. Graph of the relationship between hydrogen volume (ml) and time (minutes) in the process of electrolysis of seawater from mangrove areas with NaOH catalyst

From the graph of the polynomial relationship between the volume of hydrogen and every 20 minutes of measurement time, it could be seen that the hydrogen produced through the electrolysis of seawater from the mangrove area was more and the electrode lifespan was longer, respectively, for graphite with HCl catalyst and stainless steel with NaOH catalyst. It was confirmed by Figure 4 below.

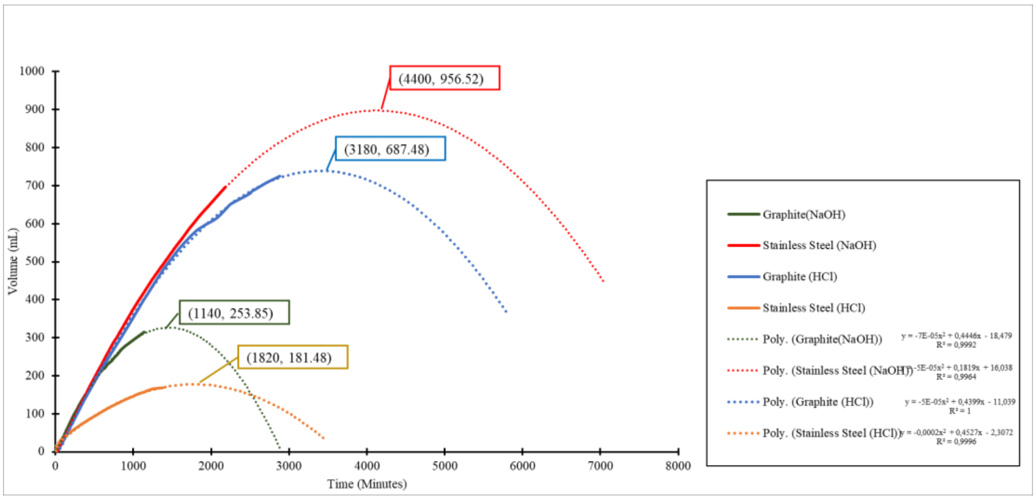

Figure 4. Graph of the relationship between hydrogen volume (ml) and time (minutes) In the process of electrolysis of seawater from the mangrove area with a variety of electrodes and catalysts.

The graph in Figure 4 shows that the hydrogen produced through the electrolysis of seawater from the mangrove area had not yet reached the highest point or maximum volume. The use of graphite electrodes with HCl catalyst and stainless steel electrodes with NaOH catalyst indicated that duration time of the electrolysis process had reached more than 3000 minutes (about 50 hours). Based on the polynomial trend-line plot with the coefficient of determination (R2) close to 1 as shown in Figure 4 and Table 1, it could be understood that the maximum volume of hydrogen produced through the electrolysis of seawater from the mangrove area with a graphite cathode and HCL and NaOH catalysts reached 678.48 ml in 3180 minutes (53 hours) and 253.85 ml in 1140 minutes (19 hours), respectively. As for stainless steel, the maximum volume of hydrogen produced with HCl and NaOH catalysts respectively were 181.48 ml achieved in 1820 minutes (33.33 hours) and 956.52 ml in 4400 minutes (73.33 hours).

Table 1. The highest volume of hydrogen produced for certain time during the electrolysis of seawater from the mangrove area with various electrodes and catalysts

ELECTRODE TYPES	**CATALYST TYPES**				**R^2**	
	HCl		**NaOH**			
	V_{max} H (ml)	Time (minute)	V_{max} H (ml)	Time (minutes)	HCl	NaOH
Grafit	678,48	3180	253, 85	1140	0.9992	0,9996
Stainless Steel	181,48	1820	956,52	4400	0,9983	1

With a diameter of ± 9 mm and length of 9 cm, the graphite and stainless steel electrodes with HCl catalyst were estimated to be able to respectively produce more than 678.48 ml and 181.48 ml of hydrogen. Whereas, the graphite and stainless steel electrodes were possible to produce higher than 956.522 ml and 253.85 of hydrogen through the electrolysis of seawater from the mangrove area with NaOH catalyst. At the same time, the process of electrolysis of seawater from the mangrove area using graphite electrodes with HCl catalysts and stainless steel electrodes with NaOH catalysts were able to slow down the corrosion process of electrodes by chlorine and increased the lifespan of electrodes. This result was better than the research on hydrogen production through the electrolysis of seawater with copper electrode conducted by Rustana (2021), Slama (2013) and Kuang et al. (2019) which only survived from effect of corrosion in producing the highest hydrogen volumes, respectively for about 28 hours 20 minutes (1700 minutes), 17 hours (1020 minutes), and 12 hours (720 minutes) [12], [17] [7]. This means that the process of electrolysis of seawater from the mangrove area using graphite electrodes with HCl catalysts and stainless steel electrodes with NaOH catalysts that could be applied as one of alternative method or strategy in producing the maximum volume of hydrogen and at the same time for increasing the lifespan of electrodes by slowing down the corrosion process of the electrodes by chlorine.

This result was supported by the graph of the relationship between the production rate of hydrogen and the measurement time of the electrolysis process of seawater from mangrove area as shown in Figure 5.

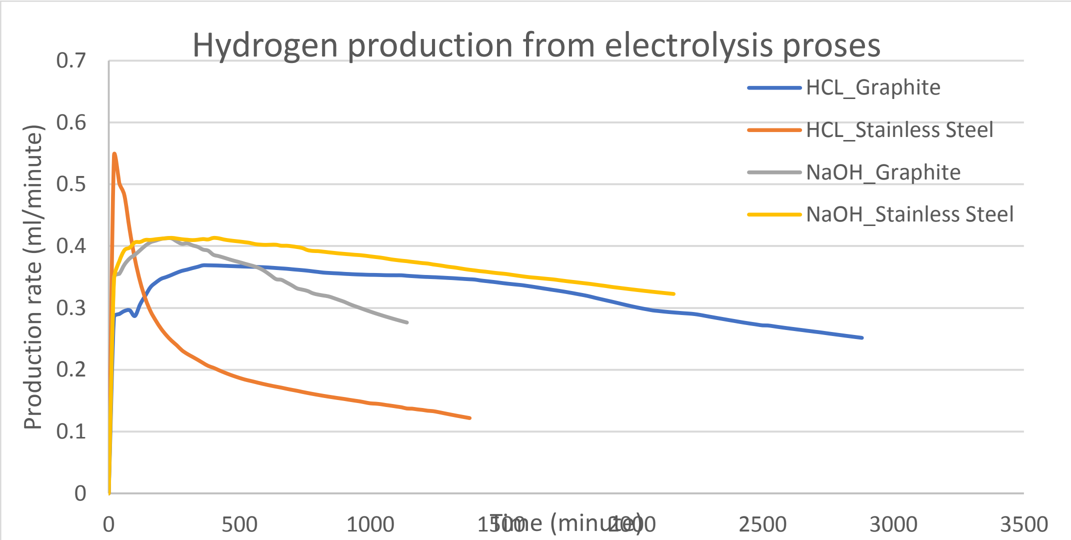

Figure 5. Graph of the relationship between hydrogen production rate (ml) vs time (minutes) in the electrolysis process of seawater from the mangrove area with a variety of electrodes and catalysts

The graph in Figure 5 indicates that the production rate of hydrogen resulted for every 20 minutes of measurement time of the electrolysis process with NaOH catalyst was better for stainless steel compared to graphite. In case of HCl catalyst, the production rate of hydrogen produced by electrolysis process was higher for graphite than stainless steel electrode. The highest production rate of hydrogen was achieved by electrolysis process with stainless steel electrode and HCl catalyst, before decreasing rapidly in a relatively short time (red line plot). The second maximum value of hydrogen production rate was achieved by electrolysis process with stainless steel electrode and NaOH catalyst. However, after reached such maximum value, the production rate of hydrogen also gently decreased as shown with yellow line plot. Similarly, the production rate of hydrogen was also gently decreased after reaching the maximum value in the electrolysis process with graphite electrode and HCl catalyst (blue line plot). In addition, the maximum value of hydrogen production of stainless steel with NaOH catalyst was higher than graphite with HCl catalyst (yellow vs blue line plot). Meanwhile, the maximum value as approximately same as the maximum value of hydrogen production rate of electrolysis process with stainless steel electrode and NaOH catalyst was achieved by electrolysis process of seawater from mangrove area with graphite electrode and HCl catalyst as shown by grey line plot. However, after reaching the maximum value, the production rate of hydrogen resulted in the electrolysis process of seawater from the mangrove area with graphite electrodes and NaOH catalysts was sharply decreased in contrast with the decreased pattern of the hydrogen production rate from the use of stainless steel electrode and NaOH catalysts. This result proved that the use of stainless steel electrode and NaOH catalyst resulted a better hydrogen production rate than graphite electrode and HCl catalysts. It was supported by the results of research by Louise et al., (2021) which stated that stainless steel in various concentrations of media can be used to study the activity of stainless steel electrode on the breakdown of water molecules to produce hydrogen and oxygen gases [18]. In addition, the results of Yilmaz's research (2010) also explained that NaOH could break down hydrogen and oxygen bonds better in water [19].

Although they have a different pattern of decline, the production rate of hydrogen that was produced through the electrolysis process of seawater from the mangrove area had decreased over time after reached the maximum values. This was understandable because both graphite and stainless steel electrodes were corroded due to chlorine, so that the electrode lifespan and the effectiveness of the seawater electrolysis process were decreased. As explained by El-Bassuoni et al. (1982) that the potential difficulty in producing hydrogen through the seawater electrolysis process is chlorine which is an undesirable product since it can cause corrosion at the anode and can cause major problems in the electrolysis process The obstacles that arise in the process of electrolysis of seawater are the evolution of chlorine and the corrosion it causes at the anode [20]. The evolutionary reaction of chlorine and oxygen at the anode is a necessary and efficient electro-catalyst to restrain the corrosion rate and the formation of deposits on the electrodes [21] [22] During electrolysis, a change in the color of seawater was observed during electrolysis both when using graphite and stainless steel electrodes. The color change is thought to be due to the corrosion process at the electrodes, especially the anode used due to Cl ions. This can be seen by the erosion of the electrode and the decrease in the volume of hydrogen produced due to the electrode not working effectively

4. Conclution

The volume of hydrogen and electrode lifespan in the electrolysis process of seawater from mangrove areas using graphite and HCL catalyst was greater than that of stainless steel electrodes. On the other hand, the use of graphite electrodes and NaOH catalyst in the electrolysis of seawater from mangrove areas resulted in a smaller volume of hydrogen and less time with the electrodes compared to the use of stainless steel electrodes. In general, variations of electrodes and catalysts affect the production of hydrogen and the time of use of these electrodes in the electrolysis of seawater originating from mangrove areas. However, the use of graphite electrode and HCl catalyst as well as the use of stainless steel and NaOH would be an alternative method or strategy to produce hydrogen through electrolysis process of seawater from mangrove area.

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