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The Effect of Voltage and Electrode Types on Hydrogen Production from The Seawater Electrolysis Process

C E Rustana[1], Sunaryo[2], S J Muchtar[2], I Sugihartono[2], W Sasmitaningsihhiadayah[1], A D R Madjid[1] and F S Hananto[1]

[1] Physics Department, Faculty of Science and Technology, State Islamic University of Maulana Malik Ibrahim Malang-East Java, Indonesia (65144)

[2] Physics Departement, Faculty of Mathematics and Science State University of Jakarta East Jakarta, Indonesia (13220)

E-mail: CE.Rustana@yahoo.com, Sunaryo@unj.ac.id, sxjxm1904@gmail.com, wiwis_hidayah_87@fis.uin-malang.ac.id, armedia@uin-malang.ac.id, faridsamsu@fis.uin-malang.ac.id

Abstract Besides the limited supply, turns out the fossil fuels also causes carbon dioxide (CO2) pollution in the atmosphere and causing global warming. Therefore, renewable energy that environmentally friendly are needed, which is hydrogen gas considered capable of being an alternative to replace fossil fuels. One of many simple ways and effective to produce hydrogen gas is by electrolysis. Seawater was chosen in this research because of its abundant availability, have high efficiency and low cost to produce hydrogen gas. By varying the voltage from 1.5 volts to 24 volts with an increase of 1.5 volts, this research was conducted to determine the effect of the difference in voltage and type of electrode on the volume and rate of hydrogen production through electrolysis of seawater with constant time 10 minutes each. The type of electrode that used in this research are copper and graphite. The result showed that the productivity coefficient of copper electrodes was 0.41 ml with determination coefficient of 0.97; while, productivity coefficient of graphite electrodes was 0.32 ml with determination coefficient of 0.93. This research also shows that a maximum of volume hydrogen gas of 8.5 ml was produced through the electrolysis of seawater using copper electrodes at a voltage of 21 volts. This result is much greater than using the graphite electrodes that only produced a maximum volume of hydrogen gas of 7.1 ml at a voltage of 22.5 volts.

1. Introduction

Currently, the use of energy continues to increase due to an increasing population accompanied by global developments. The increase in global energy consumption was recorded at around 1.5%, always increasing every year starting from 2010 [1]. However, current energy use throughout the world is mainly supplied from fossil energy. In addition to their limited availability, the use of fossil fuels also produces Carbon Dioxide (CO2) pollution in the atmosphere so that it has an impact on global warming. Therefore, environmentally friendly renewable energy resources are needed. Renewable energy is energy that comes from nature without having to deplete the existing resources on earth.

Among the available renewable energy sources, hydrogen gas is one that is considered capable of being an alternative to replacing fossil energy, especially in transportation because the environmental effects produced by hydrogen gas are very minimal. Hydrogen gas also has many advantages, namely, it has a large combustion energy, which is around 286 kJ/mol, it also has very little effect on the environment because the combustion emissions produced are in the form of water [2]. One of the simple and effective ways to produce hydrogen gas is by means of the electrolysis process. The water electrolysis method is widely used because besides being a simple method of producing hydrogen gas, it is also in order to obtain high purity hydrogen [3].

The electrolysis method generally uses an alkaline solution because it is easy to do, but this technology is quite expensive. In addition, the alkaline solution has many disadvantages, namely the high overvoltage and the amount of resistance it has. In addition, the selection of electrodes in the electrolysis process must also be based on the capabilities they have because it will also affect the large or small volume of hydrogen gas that will be produced [4]. A good electrode for use in the electrolysis of seawater is, of course, an electrode that is a good conductor of electricity, the price is economical and is also resistant to seawater corrosion. The use of seawater which is like electrolyte was chosen to produce hydrogen gas through the electrolysis process, because of its abundant availability and promising to become a renewable energy source by producing hydrogen gas with high efficiency and low cost [5]. Understanding the abundant availability of sea water and its potential which can be used to produce hydrogen gas through the electrolysis process, this paper will discuss and analyze the effect of variations in the voltage and type of electrodes used in the electrolysis of seawater on the production of hydrogen gas produced.

2. Production of hydrogen gas through electrolysis of seawater

Hydrogen gas is one of the chemical elements on the periodic table with the symbol H and atomic number 1. Hydrogen gas is a gas that is odorless, non-toxic and colorless. Hydrogen gas is the lightest element in the world because it only has an atomic mass of 1.00794 smu. Hydrogen gas is one of the most abundant elements because there are about 75% of the total mass in the universe [6]. Hydrogen gas can be used as an alternative fuel because it can replace fossil energy, especially in transportation because the environmental effects produced by hydrogen gas are very minimal. The advantage of hydrogen gas is that it has large combustion system energy, around 286 kJ/mol, and has very little effect on the environment because the resulting combustion system is water [7].

One of the processes to produce hydrogen gas is water electrolysis which is carried out by utilizing unidirectional electrical energy to break up water into oxygen and hydrogen. Electrolysis is the process of decomposing compounds by direct electric current through an electrolyte solution. Electrolyte solutions can conduct electricity because they contain ions that can move freely. Electrical conductivity occurs because the electrolyte solution is flowed from the current source and will give a different charge to the two electrodes used. The resulting charge will be divided into negative ions (anions) and positive ions (cations). Hydrogen gas will form at the cathode and oxygen will form at the anode. The factors that influence electrolysis are variations in the amount of voltage applied, the metal properties of each type of electrode and the factor of the electrolyte solution used.

In the electrolysis process, the greater the value of the voltage difference given, the greater the production of hydrogen gas produced. This can occur due to variations in the voltage difference used, because the greater the voltage difference used, the greater the current obtained in the reaction, the faster the decomposition reaction, the formation of hydrogen gas that occurs from the cathode poles will also be greater [8]. The amount of current and voltage generated by electrolysis cells depends on several factors, namely the size of the electrodes and the content of the electrolyte solution (salt) [9]. The electrochemical equation for electrolysis of water is described as follows:

At the cathode: $4H^+(aq) + 4e^- \rightarrow 2H_2\ (g)$ (1)

At the anode: $2H_2O\ (l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$ (2)

Total reaction: $2H_2O(l) \rightarrow 2H_2\ (g) + O_2(g)$ (3)

The energy used comes from the electricity that is flowing that leads to Gibbs energy (ΔG) as follows:

$$\Delta G = \Delta H - T\Delta S \quad (4)$$

The reverse voltage required in the electrolysis process to occur can be obtained by the ΔG equation [10]

$$V_{rev} = \frac{\Delta G}{nF} \quad (5)$$

With n = 4 and F which is 96,485 J in the standard state (298.15 K and 1 atm), the reactions that usually occur in the electrolysis process are as follows:

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g) \quad \Delta H^\circ = 572\ kJ \quad (6)$$

With the value $\Delta G = 474.74$ kJ. mol^{-1} and $\Delta S = 0.3262$ kJ. mol^{-1}, produces a reversible voltage value of V_{rev}= 1.23 Volt

However, the electrolysis of mostly abundant sea water rather than the purified or fresh water is a more promising way to generate clean hydrogen energy. Sea water is water that comes from the sea, has a high salt content (salinity) and has a salty taste. The world's oceans have an average salinity of 3.5%. The salt content in seawater is 55% chloride, 31% sodium, 8% sulfate, 4% magnesium, 1% calcium, 1% potassium and bicarbonate, bromide, boric acid, strontium, and fluoride which only less than 1%. Seawater is electrolyte due to its salt composition. Electrolyte solution is a compound that can conduct electric current. The electrolyte solution can function as a conductor of electricity, where the electric current is carried by the movement of ions [11]. NaCl dissolved in water will break down into Na+ ions and Cl- ions.

The chlorine content in seawater can cause corrosion that is the degradation of materials (metals) due to electrochemical reactions with their environment. Basically, it is a reaction of metals into ions on a metal surface which is in direct contact with aqueous environment, in this research it is sea water and oxygen. The chlorine content of salt in sea water causes corrosion to the metal to be faster, because it has electrolyte properties that will provide a good atmosphere for the oxidation-reduction reaction [12]. The rate at which corrosion occurs is greatly influenced by the salinity level of seawater. Corrosion rate will increase with increasing salinity of sea water due to the influence of chloride [13].
The production of hydrogen by electrolysis of sea water that contains Sodium chloride (NaCl) make seawater as a natural catalyst [14] will occur a cation reduction reaction at cathode as follows:

$$Na^{+}\ (aq) + e^{-} \rightarrow Na\ (s)\ E^{0}red = -2.71\ volt \quad (7)$$

$$2H_2O(l)+2e^{-}\rightarrow H_2(g) + 2OH^{-}(aq)\ E^{0}red= -0.828\ volt \quad (8)$$

The more positive "the oxidation is, the easier it is for the substance to oxidize. Therefore, chlorine gas will be oxidized at the anode. So that the overall reaction that occurs in the electrolysis of seawater is:

$$2Cl^{-}(aq)\rightarrow Cl_2(aq)+2e^{-}\ E^{0}oks = +1.36\ volt \quad (9)$$

$$2H_2O\rightarrow O^{2}(g)+4H^{+}(aq)+4e^{-}\ E^{0}oks = +1.23\ volt \quad (10)$$

From the total reaction it can be seen that using seawater electrolyte, hydrogen is formed at the cathode; while chlorine gas is formed at anode [15].

3. Electrode

An electrode is a conductor used to pass an electric current from a power source to a material. There are various forms of electrodes, namely in the form of wire, plate and usually that are made of metal such as zinc or copper, but can also be non-metal with an electrical conducting material such as graphite. Copper electrodes were chosen in this study because this material has high electrical conductivity, excellent heat resistance, high temperature resistance and low price, making it suitable as an electrode in this electrolysis research [16]. The physical properties of the copper electrode include a thermal conductivity of 380.7 W /m-k, a melting point of 1083°C, a specific heat of 0.092 Cal /g°C, and a coefficient of thermal expansion of $17x10^{-6}$/°C. The chemical properties of the copper electrode are 99% copper in composition, with a density of 8.9 g/cm^3.

However, graphite electrode was used since it has good electrical conductivity and cheap. Graphite also has a diffusion coefficient that tends to be closer to the true value when compared to other electrodes such as stainless steel and brass, so that the graphite electrode is suitable for use in the electrolysis process of seawater which contains chloride [17]. The physical properties of graphite are solid phase, density 2.267 g/cm^3, melting point 4300-4700 K, boiling point 4000 K, heat of melting 100 kJ / mol, heat of evaporation of 355.8 kJ/mol and heat capacity 8,517 J / mol K. Its chemical properties are very unreactive at ordinary temperatures, reacts directly with fluorine, if it burns in limited air it will produce carbon monoxide, if excess air will form carbon dioxide, when heated in air it will react with oxygen forms carbon dioxide and reacts with water to form carbonic acid [18].

4. Research methods

This research was conducted using the experimental method. The electrolysis process of seawater is implemented by varying the voltage and type of electrode to determine the volume of hydrogen gas produced. The electrolysis process occurs when the electrodes in the electrolyte solution are given a voltage difference. This study uses copper and graphite electrodes. The variation of the voltage difference given from the 1.5 volt battery and AC-DC adapter that converts the AC source into a DC voltage source, there are sixteen kinds of voltage variations, 1.5, 3, 4.5, 6, 7.5, 9, 10.5, 12, 13.5, 15, 16.5, 18, 19.5, 21, 22.5, 24 volts. The following diagram shows the setup of the electrolysis equipment.

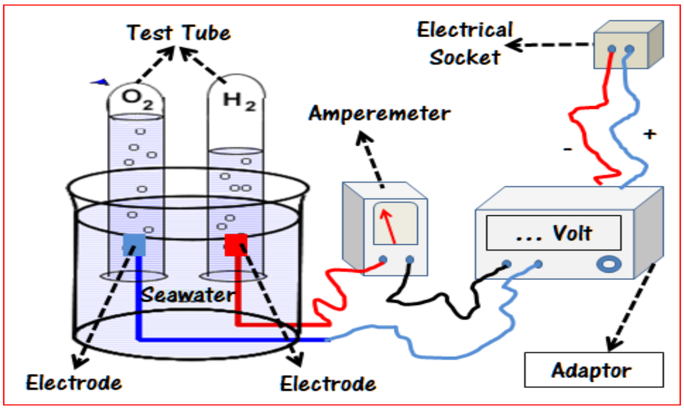

Figure 1. Process electrolysis

The data collection technique in this research is the "water displacement" method to obtain the volume of hydrogen gas, which will also be used to calculate the rate of hydrogen gas production. The "water displacement" method is to measure the volume of gas produced by a chemical reaction based on the reduced volume of water in the test tube used. The technique of analyzing the data in this research is descriptive quantitative, that is, after the volume of hydrogen gas is known from the water displacement method, then the calculation of the hydrogen gas production rate is carried out by dividing the resulting volume of hydrogen gas obtained by the time required for electrolysis [19].

5. Result and Discussion

Table 1. The Measurement result of the volume and rate of hydrogen gas production using copper electrodes in the electrolysis of seawater

No	Voltage (Volt)	Current (A)	Volume of Hydrogen (ml)	Production Rate of Hydrogen (ml/min)
1	1.5	0.05	0.3	0.03
2	3	0.08	0.5	0.05
3	4.5	0.12	0.7	0.07
4	6	0.15	1.3	0.13
5	7.5	0.18	2.1	0.21
6	9	0.21	2.7	0.27
7	10.5	0.25	3.5	0.35
8	12	0.27	4.3	0.43
9	13.5	0.31	5.1	0.51
10	15	0.36	5.8	0.58
11	16.5	0.42	6.4	0.64
12	18	0.51	7	0.7
13	19.5	0.6	7.8	0.78
14	21	0.7	8.5	0.85
15	22.5	0.55	8	0.8
16	24	0.53	7.7	0.77

Table 2. The results of measurement of the volume and rate of hydrogen gas production using graphite electrodes in the electrolysis of seawater

No	Voltage (Volt)	Current (A)	Volume of Hydrogen (ml)	Production Rate of Hydrogen (ml/min)
1	1.5	0.03	0.2	0.02
2	3	0.06	0.4	0.04
3	4.5	0.09	0.6	0.06
4	6	0.01	0.9	0.09
5	7.5	0.13	1.8	0.18
6	9	0.15	2.5	0.25
7	10.5	0.18	3.3	0.33
8	12	0.2	3.8	0.38
9	13.5	0.25	4.2	0.42
10	15	0.31	4.6	0.46
11	16.5	0.35	5.1	0.51
12	18	0.42	5.8	0.58
13	19.5	0.5	6.3	0.63
14	21	0.53	6.5	0.65
15	22.5	0.6	7.1	0.71
16	24	0.38	5.2	0.52

Figure 2 below shows the results of the volume of hydrogen gas produced by the electrolysis of seawater at various voltages for each type of electrode in a constant processing time of 10 minutes. When using copper electrodes, the volume of hydrogen gas produces a hydrogen gas productivity coefficient of 0.41 ml / minute (R^2 = 0.97). Meanwhile, the use of a graphite electrode resulted in a volume productivity coefficient of 0.32 ml / minute (R^2= 0.93). These results show that the use of copper electrodes can produce a larger volume of hydrogen gas compared to using graphite electrodes in the electrolysis of seawater.

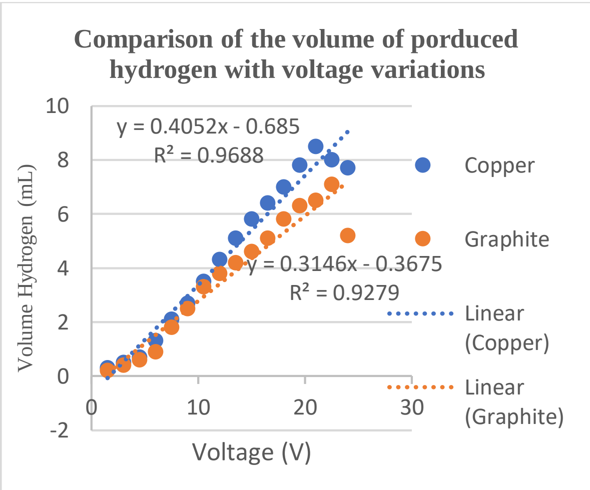

Figure 2. Comparison of the volume of produced Hydrogen with Voltage variations

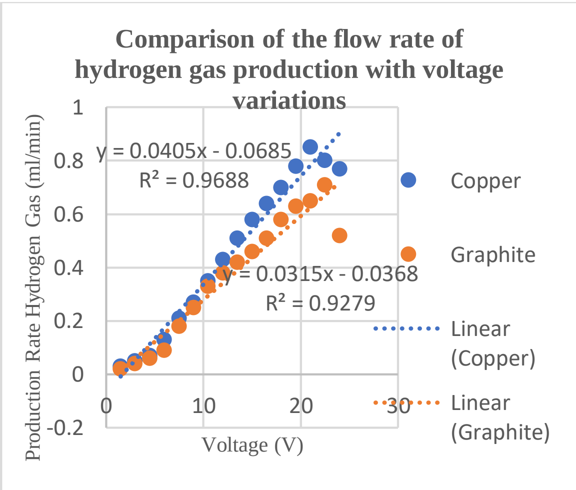

Figure 3. Comparison of the flow rate of hydrogen gas production with voltage variations

Figure 2 shows that the higher the voltage used in the electrolysis of seawater for each type of electrode has an impact on the increase in the volume of hydrogen gas produced through the process. The value of R2 > 0.7 represents the strong relationship between the independent variable X (the voltage variation) and the dependent variable Y (volume of hydrogen gas). This is understandable because the greater the applied voltage, the faster the reaction of decomposition of seawater will be. Thus, the volume of hydrogen gas produced will increase. Whereas, the value of b in the simple linear regression equation serves to show the magnitude of the change in the value of Y (the production of hydrogen gas) due to changes in the value of X (voltage variation) given to the electrolysis of seawater. From these values of determination coefficient, it can also be seen that the type of electrode that has a more optimal performance in producing the production rate and volume of hydrogen gas at various voltages used. However, at voltage variations ranging from 22.5 to 24 volts, the volume of hydrogen gas produced through the electrolysis process using the two types of electrodes also decreased, this can be understood to happen because of the chlorine content in seawater that causes a decrease in function, thereby accelerating the damage to the metal electrodes [12] and of course it will decrease in the resulting volume of hydrogen gas which was produced.

Figure 3 shows the rate of hydrogen gas production against voltage variations for each type of electrode used in the electrolysis of seawater. The use of copper electrodes in the seawater electrolysis process resulted in a hydrogen gas production rate coefficient of 0.041 ml / minute (R^2= 0.97). The graphite electrode produces a hydrogen gas production rate coefficient of 0.032 ml / minute (R^2= 0.93). These results show that the use of copper electrodes can produce a higher hydrogen gas production rate than using graphite electrodes in the electrolysis of seawater. The results of this study as shown in Figure 3 indicated that the greater the applied voltage, the greater the production rate of hydrogen gas produced through the electrolysis of seawater. This is in accordance with the research results of Jumiati et al. (2013) [20] who explains that the greater the voltage causes, the electric current is also greater, and the reaction of decomposition of sea water that occurs will also be greater and gas formation of will also get faster and bigger. In addition, the results of this study are also in line with the results of research by N Bellel and M Sahli (2011) [21] which explains that the variation of the flow of hydrogen gas produced will continue to increase with increasing variations in the voltage used.

From graph 3 it can also be seen that at the variation of the voltage from 22.5 to 24 volts, the production rate of hydrogen gas produced in the electrolysis process using copper electrodes has decreased. Meanwhile, the use of graphite electrodes in the electrolysis of seawater shows that the rate of hydrogen gas production only decreases when the voltage reaches 24 volts. This decrease in the rate of hydrogen gas production is understandable because copper electrodes have less resistance to chlorine than graphite electrodes. Due to the presence of chlorine in salt in seawater, the copper electrodes are corroded, causing a decrease in the effectiveness of the copper electrodes. This is in accordance with the research by NH Saputra, et al. (2020) [22] which indicated the electrodes that experience corrosion due to sea water can cause a decrease in the effectiveness of such electrodes in conducting electricity. However, the results of the research show that the use of copper electrodes is far better than the use of graphite electrodes in producing hydrogen gas through the electrolysis of seawater.

In this case, the use of copper electrodes produces a larger volume of hydrogen gas compared to the use of graphite electrodes in the electrolysis of seawater. The results of this study are in accordance with the results of research by Slama (2013) [23] who conducted research to test various types of electrode materials in producing hydrogen gas in the electrolysis process. Slama's research using NaCl solution in the electrolysis process concluded that the copper electrode is first, bronze is second, stainless steel is third and graphite is last. The results of the study using copper electrodes show that the largest volume of hydrogen gas produced through the electrolysis of seawater occurs at a voltage of 21 volts. At this 21 volt voltage difference, the volume of hydrogen gas produced through the electrolysis of seawater using copper electrodes is 8.5 ml with a production rate of 0.85 ml / minute. This result is much greater than the volume of hydrogen gas produced in the electrolysis of seawater using a graphite electrode at a voltage difference of only 7.1 ml of 22.5 volts and a production rate of 0.71 ml / minute. The results of this study as described above indicate that the productivity rate of hydrogen gas produced through the electrolysis of seawater using copper or graphite electrodes has different results compared to the results of research by N Bellel and M Sahli (2011). As it is known that N. Bellel, and M. Sahli showed that the best voltage to produce the largest hydrogen gas production rate up to 3.5 ml / min was obtained through the electrolysis of brine using a graphite electrode at a voltage of 18 volts. This can be understood because there are differences in voltage and salinity variations in the electrolyte solution used.

6. Conclusion

Based on the analysis of the results of the study, it is concluded that the variations in the voltage and type of electrode have an effect on the volume and rate of hydrogen gas production through the electrolysis of seawater. Copper electrodes in the electrolysis of seawater have a greater impact on the productivity of hydrogen gas. The volume and the rate production of hydrogen production was respectively 8.5 ml (R2 = 0.97) and 0.85 ml / min (R2 = 0.97) occurred when using copper electrodes with a variation of 21 volts.

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