Electrolysis of Seawater for Hydrogen Production: Influence Voltage and Electrode Types.

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ABSTRACT

In fact, fossil fuels cause carbon dioxide (CO2) pollution in the atmosphere and causing global warming. Thus, environment needs to be clean from these pollutions. Renewable energy that environmentally friendly are needed, which is hydrogen gas considered capable of being an alternative to replace the fossil fuels. Electrolysis is one of many ways to produce hydrogen gas. In this study, the seawater has been selected because of its abundant availability. It has high efficiency and low cost to produce the gas. To varying the voltage from 2 volts to 22 volts with an increase of 1.5 volts, the aim of this research was to investigate the impact of the different voltage on rate of hydrogen and the level of production through electrolysis of seawater with estimate time 10 mins time. Copper and graphite electrode have been used in this research. The results have been showed that the productivity coefficient of copper has been recorded 0.41 ml with 0.97 determination coefficient, however, graphite electrodes has been recorded 0.32 ml with determination coefficient of 0.93. The study has been also reported that the maximum of level hydrogen gas was 8.5 ml. it has produced through the electrolysis of seawater that using copper at a voltage of 21 volts. However, graphite electrodes produced a maximum level of hydrogen gas was 9.7 ml at a voltage of 25 volts.

Keywords: Electrolysis; Hydrogen, Metal electrodes; Seawater.

1. Introduction

Recently, the use of energy has been increased due to an increasing populations accompanied by global development. The global energy consumption has been recorded 2 % of increase, this increase starting from 2010 [1]. The mainly supplied that use throughout the world is fossil energy. The fossil fuels produce Carbon Dioxide (CO2) pollution in the atmosphere that it has an effect the environment. It has been also impact on the global warming. Thus, it needs to found a friendly way to keep the environment clean. Renewable energy resources are environmentally friendly. It comes from nature without having to deplete the existing resources on the earth. The mainly produce for the renewable energy sources is hydrogen gas.

The hydrogen gas is one that is considered capable of being an alternative to replacing fossil energy. The environmental has been effected produced by hydrogen gas are very limit. For the hydrogen gas, there are many advantages including combustion energy, which has around 286 kJ/mol. As well as, it also has a little impact on the environment because the combustion emissions produced are form the water [2]. The electrolysis process is one of effective ways to produce hydrogen gas. Globally, the water electrolysis way has been

used widely because it was a method way to produce hydrogen gas. Also, it has been also obtain high purity hydrogen [3]. The electrolysis method is generally using an alkaline solution because it is easy method; however, this technology is bit expensive.

There are many disadvantages of using alkaline solution including high overvoltage and the amount of resistance. 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]. The seawater is a good electrode for use because this electrode is a good conductor of electricity, resistant to seawater corrosion and low cost. The electrolyte has been selected to produce hydrogen through the electrolysis process because of its abundant availability and renewable energy source. It is producing hydrogen with high efficiency and low cost [5]. It needs to understand the abundant availability of seawater and the possible used to produce hydrogen gas through the electrolysis process. In this study, the results will focused on analyze the effect of variations in the voltage. Also, to detect the type of electrodes that used in the electrolysis of seawater to product the hydrogen gas

2. Use electrolysis of seawater to product hydrogen gas

The hydrogen gas is a chemical element that on the periodic table with the symbol H and it has atomic number 1. It is non-toxic, colorless and odorless. In the world, it is the lightest element because it has only 1.00794 smu of atomic mass. There is around 75% of the total mass in the universe, so it was the most abundant elements [6]. It can be used as an alternative fuel because it can replace fossil energy. It can be used in the transportation because the environmental impacts produced by hydrogen gas are very limit. For the hydrogen gas, there are many advantages including combustion energy, which has around 286 kJ/mol. As well as, it also has a little impact on the environment because the combustion emissions produced are form the water [7].

To produce hydrogen gas, it can be use the water electrolysis that uses utilizing unidirectional electrically energy to break up water into hydrogen and oxygen. Electrolysis is the process of decomposing compounds by direct electric current through an electrolyte solution. It can conduct electricity because it contains ions that can move freely. The Electrical conductivity occurs because electrolyte is flowed from the current source and it gives a different charge to the two electrodes that used. The charge has been divided into positive ion (cations) and negative ion (anions). The gas will form at cathode and oxygen will form at the anode. The electrolyte solution that used and metal properties of each type of electrodes factors are affected on amount of voltage. In the electrolysis process, the greater the value of the voltage difference given, the greater the production of hydrogen gas produced. It can be used due to different in the voltage that used because the faster the decomposition reactions, the formation of gas that occurs from the cathode poles will be greater, greater the voltage difference that used and the greater the current obtained in the reactions [8].

The content of the electrolytes solution (salt) and the size of the electrode are the factors that influence on the amount of current and voltage generated by electrolysis cells [9]. The electrochemical equation for electrolysis of water is described as follows:

At the cathode: $4H + (aq) + 4e^- \rightarrow 2H2 (g)$ (1)

At the anode: $2H2O (l) \rightarrow O2(g) + 4H + (aq) + 4e^-$ (2)

Total reaction: $2H2O(l) \rightarrow 2H2 (g) + O2(g)$ (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].

$$Vrev = \Delta G/ nF \quad (5)$$

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:

$2H2O(l) \rightarrow 2H2\ (g) + O2\ (g)\ \Delta H^{\circ} = 572$ kJ

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

The seawater has been used more than the purified or fresh water and in the electrolysis of mostly abundant. To generate clean hydrogen energy, it has been used the seawater for that purpose. The seawater is coming from the sea, and it has a high salt content. As well as, it has a salty taste. In the oceans, the water has average of 3.5% of salinity water. That seawater has many elements including 31% sodium, 55% chloride, 1% calcium , 4% magnesium, 1% potassium 8% sulfate, and boric acid, bicarbonate, strontium, bromide, and fluoride which only less than 1%. The Seawater is electrolyte belong to its salinity composition. Electrolyte solution can works as a conductor of electricity, where the electric current can be carry by the ions movement [11]. NaCl has dissolved in water and it will break down to Na+ ions and Cl- ions. Corrosion cause by the chlorine content in seawater that is the degradation of materials (metals) due to electrochemical reactions with their environment. In general, it was a reaction of metal into ions on a metal surface which was in direct contact with aqueous environments. In this study, it is seawater and oxygen. The sea water content chlorine causes the corrosion to metal to be faster, because it will provide a good atmosphere for the oxidation reduction reaction [12]. The salinity level of the seawater is effecting on the rate of corrosion. The increase of water salinity causes the increasing of rate of corrosion that influence of chloride [13]. The production of hydrogen by electrolysis of sea water that contains the sodium chloride (NaCl) which make seawater as a natural catalyst [14] will be occur a cation reduction reaction at cathode as follows:

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

$2H2O(l) + 2e^{-} \rightarrow H2\ (g) + 2OH^{-}\ (aq)\ E^{0}$ red= -0.828 volt (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:

$2Cl^{-}\ (aq) \rightarrow Cl2\ (aq) + 2e^{-}\ E^{0}$ oks = +1.36 volt (9)

$2H2O \rightarrow O^{2}\ (g) + 4H^{+}\ (aq) + 4e^{-}\ E^{0}$ oks = +1.23 volt (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

The electrode has a conductor been used to pass the electric current from the power source to a materials. There are different forms of electrodes, including in the form of plate, wire and often that are made of metal like copper or copper. It can be also non-metal with electrical conducting materials such as graphite. In this research, the copper electrodes have been selected, because this material has a high electrical conductivity, an excellent heat resistance, a high temperatures resistance and low cost, making it suitable as an electrode in this research [16]. For the physical properties, thermal conductivity of copper electrode is 380.7 W /m-k, a melting point is 1083°C, a specific heat is 0.092 Cal /g°C, and thermal expansion coefficient is $17x10^{-6}$/°C. For the chemical properties, the copper electrode is 99% in composition, and the density is 8.9 g/cm3. However, graphite electrode has been used since it has a good electrical conductivity and cheaper. Graphite has been also a diffusion coefficient that it tends to be closer to the true value when compared to other electrodes such as stainless steel and brass. It is suitable for use in the electrolysis process of salty water which contains chloride [17]. The physical properties of graphite are solid phases, which density is 2.267 g/cm^3, melting point is 4300-4700 K, boiling point is 4000 K, heat of melting is 100 kJ/ mol, heat of evaporation is 355.8 kJ/mol and heat capacity is 8,517 J/ mol K. The chemical properties are very unreactive at ordinary temperatures, react directly with fluorine. It burns in limited air that produces

carbon monoxide. It 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. Materials and methods

The experimental method has been used in this research. To determine the volume of hydrogen gas that produced, electrolysis process of seawater was implemented by varying the voltages. The electrolysis process has occurred when the electrodes in the electrolyte solution is given a different voltage. In this study, copper and graphite electrodes have been used.

The different of the voltage given from 2 volts battery and AC-DC adapter that converts the AC source into a DC voltage sources. There are sixteen kinds of voltage variations including 2, 2.5, 3, 4, 5.5, 7, 8.5, 10, 12, 14, 15, 17, 22, 25, 27 volts. To obtain the volume of hydrogen gas, data collection technique in this study was the water displacement method. It also is used to calculate the hydrogen gas production rate. The water displacement has been used to measure the volume of gas produced by a chemical reaction that based on the reduced volume of water in the test tube. The technique of analyzing the data in this study was descriptive quantitative. After the volume of hydrogen gas, it is known from the water displacement method. Then, the calculation of the hydrogen gas production rate was carried out by dividing the resulting volume of hydrogen gas obtained by the time required for electrolysis [19].

Results and Discussion

Table (1) the volume and rate of hydrogen gas production Measurement using copper electrodes in the electrolysis of seawater

No	Voltage	Current (A)	Volume of Hydrogen (ml)	Production Rate of Hydrogen (ml/min
1	2	0.7	0.5	0.04
2	2.5	0.09	0.7	0.06
3	3	0.13	0.1	0.07
4	4	0.17	1.2	0.09
5	5.5	0.19	1.6	0.12
6	7	0.22	1.8	0.2
7	8.5	0.24	2	0.27
8	10	0.27	2.4	0.35
9	12	0.29	2.7	0.46
10	14	0.35	3	0.52
11	15	0.38	3.5	0.6
12	17	0.42	4.4	0.68
13	20	0.47	5.8	0.78
14	22	0.55	6	0.85
15	25	0.6	7.5	0.75
16	27	0.53	8.6	0.77

Table (2) the volume and rate of hydrogen gas production Measurement using graphite electrodes in the electrolysis of seawater

No	Voltage	Current (A)	Volume of Hydrogen (ml)	Production Rate of Hydrogen (ml/min
1	2	0.04	0.3	0.03
2	2.5	0.065	0.4	0.05
3	3	0.085	0.55	0.560
4	4	0.9	0.8	0.07
5	5.5	0.12	0.96	0.19
6	7	0.16	1.5	0.24
7	8.5	0.19	1.9	0.35
8	10	0.21	2.5	0.4
9	12	0.24	3.6	0.43
10	14	0.3	4.5	0.47
11	15	0.34	5.8	0.53
12	17	0.45	7	0.58
13	20	0.6	8.3	0.62
14	22	0.65	9.3	0.73
15	25	0.7	9.7	0.59
16	27	0.54	8.9	0.77

Tables have been showed that volume of hydrogen gas that produced by the electrolysis of seawater at different voltages for different type of electrode in a constant processing time of 10 mins. The volume of hydrogen gas produces hydrogen gas productivity coefficient of 0.41 ml/ minute (R^2 = 0.97) when using copper electrodes. However, the use of a graphite electrode resulted in a volume productivity coefficient of 0.32 ml/ mins (R^2 = 0.93). The results showed that graphite electrodes can produce a low volume of hydrogen gas compared to copper electrodes.

The tab.1 has been shows that the higher voltage that used in the electrolysis for each types of electrode has an influence on the increase in the volume of hydrogen that produced through the process. There is a strong relationship between dependent variable Y (volume of hydrogen) and independent variable X (voltage variation) with the value of R2 > 0.7. Therefore, volume of hydrogen gas that produced will increased. The value of b in the linear regression equation serves to show the magnitude of the change in the amount of Y (production of hydrogen gas) due to changes in the amount of X (voltage variation) that given to the electrolysis of seawater. It can be see that the type of electrode has more optimal performances in production rate and volume of hydrogen gas at different voltages that used. But, at the voltage variations rang 25 to 27 volts, using the two types of electrodes has decreased the volume of hydrogen gas produced by the electrolysis process. This can be understood that chlorine content in seawater causes a decrease in function, thereby accelerating the damage to the metal electrodes [12]. It has been decreased as results of hydrogen gas which was produced.

Tab2 has been showed that the rate of hydrogen gas production against the voltage variations for different type of electrode that used in the electrolysis. Using of copper electrodes process resulted in the hydrogen gas production value of 0.041 ml / minute (R2 = 0.97), while the graphite electrode produce a hydrogen gas production value of 0.032 ml/ minute (R2 = 0.93). These results have been showed that using copper electrode can be producing a higher hydrogen gas production value than using the graphite electrode. Table 1 and 2 have been indicated that the greater the applied voltage, the greater the production rate

of hydrogen gas produced through the electrolysis of seawater. The results agreed with of Jumiati et al. (2013) [20] who has explained that the greater the voltage causes, the electric current was greater. The reaction of decomposition of seawater that occurs will be also be greater and gas formation of will get faster and bigger. Also, the results have agreed with N Bellel and M Sahli (2011) [21] which indicate that the variations of the hydrogen gas produced will continue to increase with the increasing of variations in the voltage that used. It can be found that at variation of the voltage 25 to 27 volts, using copper electrodes has been decreased the production rate of hydrogen gas. However, using graphite electrodes shows that the hydrogen gas production rate has been only decreases when the voltage was 27 volts. This decrease in the hydrogen gas production rate was understandable because the copper electrodes were fewer resistances to chlorine than graphite electrode. For the chlorine in seawater, the copper electrodes are corroded that causing a decrease in the effectiveness of the copper electrode. These results have agreed with NH Saputra, et al. (2020) [22] who have indicated that the electrodes that experience corrosion due to seawater can be cause a decrease in the effectiveness of such electrodes in conducting electricity. But, the results of the study have been showed that the use of copper electrodes was better than the use of graphite electrodes in producing hydrogen gas through the electrolysis of seawater. Thus, use of copper electrodes produce a larger volume of hydrogen gas compared to use of graphite electrode in the electrolysis of seawater.

The results of the study have accordance with the results by Slama (2013) [23] who conducted research to test different types of electrode materials in producing hydrogen gas in the electrolysis process. Slama's study using NaCl solutions in the electrolysis process has concluded that the copper electrode was first, bronze was second, stainless steel was third and graphite was last. The results of the study using copper electrodes have been showed that the largest volume of hydrogen gas produced using the electrolysis of seawater occurs at a voltage of 22 volts. For the 22 volt voltage difference, the volume of hydrogen gas have produced through the electrolysis of seawater using copper electrodes was 5.8 ml with a production rate of 0.85 ml/ min. This result was greater than the volume of hydrogen gas produced in the electrolysis of seawater using a graphite electrode at a voltage difference of 9.7 ml of 25 volts and a production rate of 0.73 ml/min. The results indicate that the productivity hydrogen gas produced rate through the electrolysis of seawater using copper or graphite electrodes has different results compared to the results that found by N Bellel and M Sahli (2011). As it is known that N. Bellel, and M. Sahli has been showed that the best voltage to produce the largest hydrogen gas production rate up to 1.8 ml/ min was obtained through the electrolysis of brine using a graphite electrode at a voltage of 17 volts. This can be said that there are differences in salinity variations and voltage and in the electrolyte solution.

5. Conclusion

The study has concluded that the variations in the voltage and type of electrode have an influence on the volume and hydrogen gas production rate through the electrolysis of seawater. Copper electrode in the electrolysis of seawater has a greater effect on the productivity of hydrogen gas. The volume and the hydrogen production rate were 5.8 ml (R2 = 0.97) and 0.58 ml / min (R2 = 0.97) respectively, that occurred when using copper electrodes with a variation of 22 volts.

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