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Effect of Sodium Chloride Solution Concentration on Hydrogen Gas Production in Water Electrolyzer Prototype

Rusdianasari
Chemical Engineering Department
Politeknik Negeri Sriwijaya
Palembang, Indonesia
rusdianasari@polsri.ac.id

Yohandri Bow
Chemical Engineering Department
Politeknik Negeri Sriwijaya
Palembang, Indonesia
yohandribow@polsri.ac.id

Tresna Dewi
Electrical Engineering Department
Politeknik Negeri Sriwijaya
Palembang, Indonesia
tresna_dewi@polsri.ac.id

Ahmad Taqwa
Electrical Engineering Department
Politeknik Negeri Sriwijaya
Palembang, Indonesia
a_taqwa@yahoo.com

Lin Prasetyani
Mechatronics Department
Politeknik Manufaktur ASTRA
Jakarta, Indonesia
lin.prasetyani@polman.astra.ac.id

***Abstract*— Energy is an essential component of human life because all human activities require energy. The current consumed energy comes from fossil fuels that are not renewable in a short time; therefore, they are decreasing over time. The current research shows the possibility of producing energy source from water in which Indonesia as an archipelago country has an abundant source of water. Therefore, Indonesia has a high possibility of developing renewable energy sourced from water. The process of getting hydrogen from water is called the electrolysis process of water. In this study, a water electrolyzer prototype was designed, and an experiment in producing hydrogen was conducted. The water used in this study is 6 liters with a variable that changes the concentration of sodium chloride solution (NaCl) starting from 10, 20, 30, 40, and 50%. The optimal production of hydrogen gas is at the concentration of 50% NaCl solution with the amount of gas produced at 11.29 liters and the mol percent of hydrogen in the product which is 78.45%.**

Keywords—electrolysis, hydrogen, sodium chloride solution, water electrolyzer

I. INTRODUCTION

Some solutions are offered in facing energy deficiency by researching and developing renewable energy such as nuclear, solar, wind, and tidal power. Those emerging renewable energies come with advantages and disadvantages in their applications. One of the new energies that have sound potential is hydrogen [1, 11].

Hydrogen fuel is energy composed of a single element called hydrogen H_2. This energy is environment-friendly energy whose emission is water. With the right developing technology, this energy has great potential and economically beneficial with almost zero pollution [4].

Hydrogen gas is formed by electrolyzing water using metal electrodes. Indonesia is an archipelago country whose 2/3 territory is the ocean; therefore, Indonesia has a great potential in developing hydrogen fuel to solve energy deficiency in Indonesia [11].

It is predicted that hydrogen becomes the primary energy supply for electricity generation known as hydrogen fuel. This hydrogen fuel can be used for transportation and domestic due to its environmentally friendly nature and easiness to produce.

During the electrolysis process, hydrogen will be produced in cathode; the electrode connected to negative pole and oxygen will be in anode; the electrode connected to the positive pole. The amount of hydrogen produced is twice as the amount of the produced oxygen, and both produced elements are proportional with electric power used in generating them. The electrolysis of water takes a long time to complete [5].

The rate of water electrolysis in producing hydrogen and oxygen can be increased by adding electrolyte material such as salt, base, acid. Those electrolytes are added to the water to increase the solution conductivity. The most used salt is Sodium Chloride due to its low price and easiness to solute in water. The electrolysis chemical reaction is: [6]

$$\text{Energy (Electricity)} + 2H_2O \longrightarrow O_2 + 2H_2 \quad (1)$$

Electric pressure is applied to the negative electrode (cathode) pushing electrons to the water, and in the anode (positive electrode) in absorbing electron. The water molecule in cathode consists of positive hydrogen ion (H^+) and hydroxide (OH^-).

$$H_2O \longrightarrow H^+ + OH^- \quad (2)$$

H^+ is an open proton, free to capture electrons from the cathode, then into ordinary and neutral hydrogen.

$$H^+ + e^- \longrightarrow H \quad (3)$$

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The hydrogen atom is assembled with other hydrogen atoms and make molecules in the gas to bubble and then rise to the surface.

$$H + H \longrightarrow H_2 \quad (4)$$

Positive electrodes have caused hydroxide ions (OH^-) to move to the anode. When it reaches the anode, the anode releases excess electrons taken by the hydroxide from the previous hydrogen atom, then the hydroxide ion joins with another hydroxide molecule and forms 1 molecule of oxygen and 2 molecules of water:

$$4\ OH^- \longrightarrow O_2 + 2H_2O + 4e^- \quad (5)$$

This oxygen molecule is very stable, and then the bubble rises to the surface, and the process is repeating. The reactions at the cathode (reduction) depend only on the type of cation in the solution. If the cation comes from metal with a lower electrode potential, then the water will be reduced [7].

In the process of electrolysis, electrodes are electrified (by DC current) so that the compounds in the electrolyte break down to form ions, and the oxidation-reduction process occurs to produce gas. The electrolysis process requires a high electric current to ensure the chemical reaction process becomes effective and efficient [8].

If both electrode poles (cathodes and anodes) are electrified by electric current, the electrodes will be interconnected since the electrolyte solution becomes a conductor that causes gas bubbles to emerge in electrodes. The electrolysis process states that oxygen atoms form a negatively charged ion (OH^-) and a hydrogen atom forms a positively charged ion (H^+). At the positive pole, the H^+ ions are attracted to the negatively charged cathode pole; therefore, the H^+ ion converges to the cathode. Hydrogen atoms will form hydrogen gas shown as gas bubbles at the cathode which floats upward. The same thing happens to OH^- ions which fuse at the anode then form oxygen gas in the form of gas bubbles. In the Electrolyzer Water Prototype, various concentrations of NaCl solution are used to be the starters and function to increase the number of ions in the feed solution to produce more hydrogen gas [9, 10].

II. Experimental Design

In general, the design of the prototype is divided into three parts; container feed water reservoir, H_2, and O_2 gas storage tube, and electrode pipe. The feed water container has a length of 27 cm, a width of 13 cm, and a height of 17 cm. The container for feed water is made of plastic with the form of a beam. The bottom of the feed container consists of two outputs. The first is the output for the feed stream to the electrode pipe, and the second one is the output to the product storage tube. This second output hole is made slightly upward because the feed must first come out through the first output hole. The flow leading to the electrode pipes is connected to a pipe with 100 cm vertically and 85 cm horizontally as the entry point for feed water.

Electrodes are 40 cm stainless steel with 40 cm for the cathode and 8 cm for the anode. Cathodes and anodes are connected using a tee. This tee connection is installed parallel with another pipe as a pathway for the produced hydrogen and oxygen gas that comes out from the top of the anode. The pipe is connected to each storage tube. The electrodes used are 5 pairs and arranged in parallel. The cables are connected between the anode and cathode and then to the regulator. At the bottom of the electrode pipe, an outlet is placed to remove the remaining water after the electrolysis process and as a place for cleaning/draining tools.

For H_2 and O_2 gas storage tubes, two expenditure streams are made. The first flow is located at the bottom of the tube and connected directly to the container of water (the raw material). The second flow is on the top of the tube, which is given a pressure gauge and a check valve as a safety valve. The H_2 and O_2 gas storage tubes are 27 cm in height and 9 cm in diameter. At the end of the pipe, a nozzle is installed to ensure the gas can be burned directly.

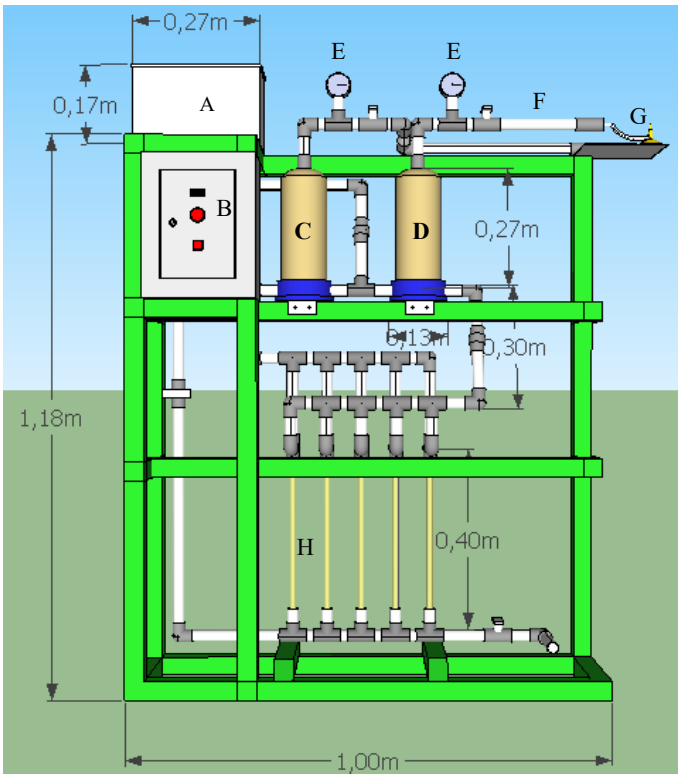

Fig. 1.Water electrolyzer design

Where:

A: Water storange
B: Panel Box
C: O_2 gas storage
D: H_2 gas storage
E: Pressure Gauge
F: Arestor Flashback
G: Nozzle Burner
H: Electrodes (Stainless Steel)
I: Drain

III. Result and Discussion

A. *Literature study on Effect of NaCl Electrolyte Solution Concentration to the Volume of Hydrogen Gas Produced*

The relationship of the concentration of NaCl electrolyte solution to the volume of electrolyzed hydrogen gas for 20 minutes can be seen in Fig 2. It shows that hydrogen gas production has a linear increase in the concentration of sodium chloride solution. This condition shows the greater the concentration of NaCl electrolyte solution, the more significant electrons formed and denser to facilitate the transfer of electrons from the solution to the electrode [2].

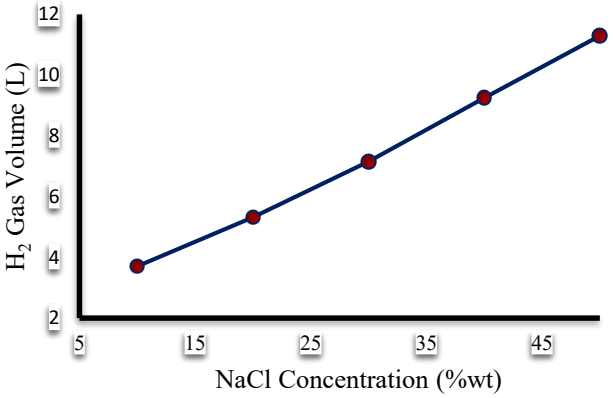

Fig. 2. Literature study on Effect of NaCl Electrolyte Solution Concentration to the Volume of Hydrogen Gas Produced

The increment of NaCl concentration is proportional to the increase in hydrogen gas volume. The more sodium chloride is used, the more Na^+ and Cl^- ions have formed that increase the conductivity of the water. With the increase in conductivity, this makes the electric current also produced primarily. Thus, the process of decomposing water into hydrogen and oxygen becomes faster.

Electrolysis proses in this study used stainless steel electrodes. A direct electric voltage is applied to the electrode to create a potential difference between the two electrodes. This potential difference creates ions in the electrolyte solution migrate towards the electrode opposite the charge with the ion. In this research, the ions in solution come from the dissociation of NaCl. The dissociation that occurs in the NaCl solution produces Na^+ and Cl^- ions. Positively charged ions such as sodium ions (Na^+) and hydrogen ions (H^+) in electrolyte solutions migrate towards the cathode. Negatively charged ions such as chloride ions (Cl^-) and hydroxyl ions (OH^-) migrate to the anode. Migration of these ions creates an electric current in the solution, giving rise to a redox reaction on the electrode.

Theoretically, the volume of hydrogen gas is obtained by calculating using the equation of the reaction of water with sodium chloride. The amount of water as the raw material used in this process is 6 liters. By knowing the temperature, molecular weight, and density data, the moles of water can be determined to calculate the moles of reactants reacting and the moles of the product produced. This mole data is used to calculate the volume of hydrogen.

Based on the results of the calculation, the higher the concentration of the NaCl electrolyte solution used, the greater the volume of hydrogen gas produced. Fig. 2 shows the tendency increment. This trend is caused by the variation in the concentration of NaCl solution is in a short rance, which is only 10 grams difference; therefore, the difference in the increment in yield of hydrogen volume produced is not too significant; ± 2 liters.

B. *Experiment results on Effect of NaCl Electrolyte Solution Concentration on Hydrogen*

Hydrogen gas production increases proportionally with the difference in NaCl concentration used in the electrolysis process of water. When the electrolysis process takes place, water fills the hydrogen and oxygen gas storage tubes. After the electrolysis time is reached, which is 20 minutes, the gas fills the gas storage tube. Based on observations made during the process, hydrogen gas is formed quickly enough that it starts to appear at around the 20th second. The increment of hydrogen gas level indicates the decrease in water level. From the gas height data in this tube, the volume of gas formed can be calculated using the cylinder volume equation (cylindrical reservoir tube)

In line with the literature study, the formation of hydrogen gas in the experiment is affected by the concentration of NaCl. The effect of NaCl solution concentration on the produced hydrogen gas is shown in Fig. 3.

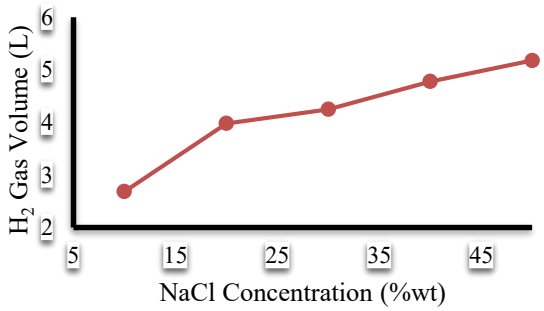

Fig. 3. Effect of NaCl Solution Concentration on the Volume of Hydrogen Gas Produced in Experiment

The data collection process was carried out five times according to variations in the concentration of NaCl solution used; 10, 20, 30, 40, and 50%. From the experiment data, it can be seen that the higher the concentration of NaCl solution is used, the more hydrogen gas is produced. In the first round (the concentration of 10% NaCl solution) the hydrogen gas volume is 2.68 liters, while in the second round the volume of hydrogen is around 3.98 liters. This increase in hydrogen volume is quite high, which is around 1.3 liters. Unlike the next round, the increase in hydrogen gas is only about 0.3 liters. Hydrogen gas production is still increasing from the previous round, but the increase is less than before. The function of NaCl solution as an electrolyte solution in this process is still quite optimal, but based on experiments that

have been carried out, the use of electrolytes containing sodium (Na) will lead to crystallization of sodium salt in the electrode pipeline where reaction and decomposition of water molecules into hydrogen and oxygen [2].

The formation of sodium salt in the electrode pipe results in the production of hydrogen gas gradually decreasing. This condition can be observed in Fig. 3. On the next process, the produced hydrogen gas is only about ± 0.5 Liter increment for different NaCl concentration solution. This condition is very different from the first round because the tool still has not accumulated sodium salt.

At the specific application time of electrolysis, the performance of the prototype water electrolyzer tool is reduced due to the accumulation of sodium salt in the electrode pipe. This accumulation can be identified by changing the color of the water in the hydrogen gas and oxygen storage tubes becoming red brick color due to the nature of sodium when dissolved in water, and it will change color. The deposition of sodium salt can result in reduced work function and electrode reactivity; therefore, hydrogen production will tend to decrease.

The volume of the produced hydrogen gas achieved from the experiment is compared to literature study. In the literature study, the increment is linear and constant, while in the experiment, there is a tendency of decreasing the production of hydrogen gas. Fig. 3 shows that the highest hydrogen volume is 5.17 Liter, while in literature study, the highest hydrogen volume produced is 11.29 Liters.

The difference that occurs is quite apparent, at the concentration of 10% NaCl solution. Theoretically, the hydrogen volume is 3.71 Liter, while in the experiment, the hydrogen volume is 2.68 Liter. This difference is not so far in the first use of experiment tools that the electrode pipe used is clean. In the results of the second experiment, at a concentration of 20% NaCl, the difference began to occur a little bigger; 5.32 Liter in theory and 3.98 Liter in the experiment. This difference is increasing until the concentration of NaCl solution used is 50%. The highest difference is at the 5th round, which is 11.29 Liter in theory and 5.17 Liter in the experiment; the difference is around 6 liters. The loss of the volume of hydrogen is as much as 6 liters in the experiment. This loss is due to a decrease in the performance of the electrode, which is increasingly saturated. This condition occurs because more sodium salt is formed and heaps on the tool components. This inhibition if no corrective action is taken or repairs on the part of the contaminated equipment, will make hydrogen production increasingly inefficient and not maximum.

C. *Effect of NaCl Concentration on Hydrogen Gas Composition*

Fig. 4 shows the result of chromatography gas to show the effect of the concentration of NaCl solution on the composition of hydrogen gas and impurity gases.

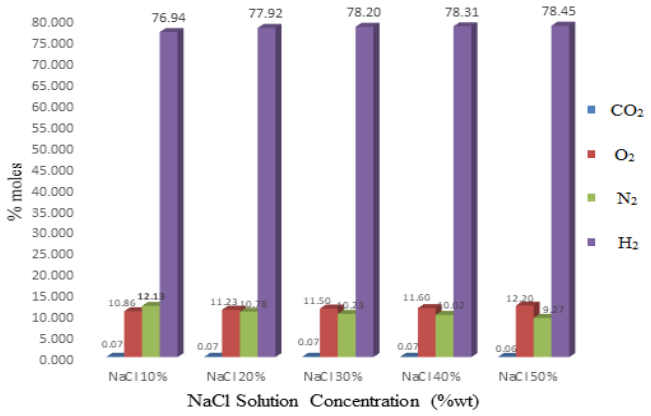

Fig.4. Effect of NaCl Concentration on Hydrogen Gas in Gas Chromatography Analysis

The analysis of gas products using gas chromatography is carried out by the principle of separating the mixture into its components. This analysis is conducted by using gas as a moving phase that passes through a layer of absorption (sorbent) that is stationary. The results of the analysis show that not only hydrogen gas is contained in the gas product, but also other gases are formed; therefore, the hydrogen produced is not 100% pure. Other components include carbon dioxide, oxygen, and nitrogen.

The presence of other gases causes hydrogen gas to become impure. Other gas contaminants in the form of carbon dioxide, nitrogen, and oxygen can come from the air that enters during the product storage process in the sample bag. Air is a mechanical mixture of various gases. Average air composition consists of nitrogen gas 78.1%, oxygen 20.93%, and carbon dioxide 0.03%, while the rest is argon, neon, krypton, xenon, and helium [12].

At the time of the product, the shelter process has been carried out and endeavored as much as possible, to ensure no direct contact with air. The problem in tool design is an absence of a vacuum system to eliminate the air content in a room. When the process takes place, the hydrogen gas storage tube is filled with water but is not 100% full, leaving a residual space filled with air. When hydrogen gas begins to fill the reservoir tube, then a little air is mixed with hydrogen. When the gas product valve is opened, some of the gas is discharged into the air but does not rule out the possibility that there is still homogenized air with hydrogen. Therefore, by using gas chromatography, the existences of other gasses are still detected.

D. *Effect of% Heat Loss, Electric Efficiency and SFC (specific fuel consume) on hydrogen produced*

The heat loss in the water electrolyzer water prototype is not influenced by electric current, electric voltage, and the number of electrodes because those three components are fixed variables in this study. The value of efficiency can influence heat loss in this process, the higher the efficiency of the gas produced, the lower the heat loss that occurs since the heat loss is inversely proportional to efficiency. In this process,

the heat loss value tends to be constant, which is around 17.91%, and this condition can be stated for each rotation since all rounds use the same operating conditions. In the literature study, the electric power used in the process is around 79.8 W with a 13.3 V voltage setting, 6 A electric current, and 20 minutes, while the actual conditions that occur are the power used is 65.5 W, 13, 1 V voltage, 5 A electric current, and 20 minutes. With this difference, the heat loss can occur due to the difference in operating conditions during the device setting, referring to the actual conditions.

By reviewing the differences in operating conditions, electrical efficiency can also be calculated. Based on the results of the calculation of electrical efficiency in this water electrolyzer is 82.08%. This is still said to be good because in general, electrolysis efficiency is theoretically 80%. This value only refers to the efficiency of converting electrical energy into hydrogen chemical energy [3, 12].

Electrical efficiency can be calculated by using the differences in operating condition, and in this research, the electrical efficiency achieved is 82.08%. This efficiency is sufficient, more than the standard of 80%. This value only refers to the efficiency of converting electrical energy into hydrogen chemical energy [3].

Energy requirements in the electrolysis process of water are determined by calculating the amount of energy needed in electrolysis per number of moles of H_2 gas produced. Based on the literature study, the higher the concentration of electrolytes, the conductivity will increase; therefore, the energy requirements per gas volume of H_2 produced will be smaller.

Water electrolysis requires a minimum of 286 kJ of electrical energy input to separate each mole [3]. Water electrolysis does not convert 100% of electrical energy into hydrogen chemical energy. This process requires more extreme potential than what is expected based on the reversible cell number reduction potential.

In this electrolysis process, SFC is needed, which varies in the concentration of NaCl solution. This SFC value is directly proportional to the volume of hydrogen gas produced both theoretically and in the experiment. It should be noted that the results of this SFC calculation are that the SFC value tends to decrease with the increasing volume of hydrogen gas produced. The condition is the same as the electrode performance described in the previous section. This decrease in SFC value is due to the function or performance of the electrode pipe which begins to experience saturation, where even though the volume of hydrogen produced is still increasing, the SFC given is decreasing. Information on gas volume comparison data in theory and practice versus SFC can be seen in Fig. 5 Fig. 5 indicates that there was a significant decrease which occurs due to the energy needed to produce hydrogen gas in the second and subsequent rounds is not as much as in the first round; therefore, this process requires energy that is not as much as the first round.

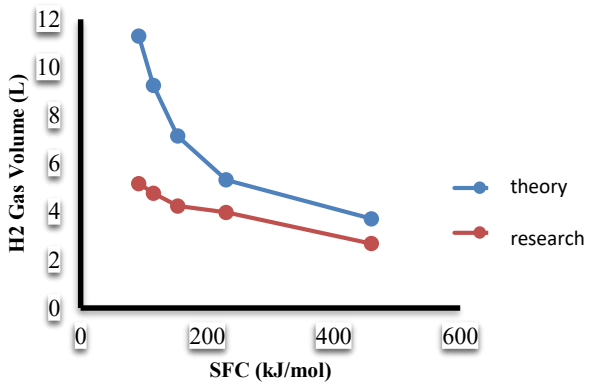

Fig. 5. Graph of SFC (Specific Fuel Consume) Relationship to Hydrogen Gas Volume Generated in Theory and Experiment

IV. Conclusion

The water electrolyzer prototype designed in this study has a capacity of 6 liters of raw material, each hydrogen and oxygen gas canister is 3.58 liters, into hydrogen and oxygen gas with various NaCl concentrations. In this process, hydrogen gas produced with the highest volume produced in the electrolysis process is 11.29 liters, so the optimum NaCl concentration in this study is 50%. The results of gas chromatography analysis show that on average for 5 samples of hydrogen content in the product is 77.96%; oxygen 11.48%, nitrogen 10.49%; and carbon dioxide 0.07%.

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