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Hydrogen Gas Production Using Water Electrolyzer as Hydrogen Power

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

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

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

***Abstract*— The commonly consumed energy currently comes from fossil fuels that cannot be renewed that decrease over time. The depletion of fossil energy reserves encourages people to find renewable energy sources, and one of them comes from hydrogen fuel. By utilizing water, which is very abundant on earth, hydrogen can be a potential alternative fuel. The process of producing hydrogen from water is called the electrolysis process of water. In this study, a water electrolyzer prototype was designed. The amount of water used in this study is 6 liters varied with variable concentration changes of 10, 20, 30, 40, and 50% NaOH solutions. The optimal production of hydrogen gas achieved at the concentration of 50% NaOH solution to produce a gas of 4.5902 liters and the moll percentage of hydrogen in the product is 78.34%. The results of gas chromatography analysis show that the hydrogen content in the product is 77.85%; 10.86%, nitrogen 11.24%; and carbon dioxide 0.07%. The electrical efficiency obtained reaches 82% with the heat loss of 17.92%.**

Keywords—electrolysis, hydrogen, hydrogen power, water electrolyzer

I. INTRODUCTION

Hydrogen gas can be produced by the electrolysis process of water using metal electrodes. Water can be used as a source for hydrogen production. Hydrogen can be an energy source for electricity generation called fuel cells, vehicle engine fuels, and other application in the 21st century due to its environmental friendliness and ease of conversion [1].

This type of energy is considered environmentally friendly since during the application, hydrogen releases energy in the form of heat, and the waste product is water, and no carbon is emitted. Therefore, the application of hydrogen as fuel much helps reduce to carbon dioxide and carbon monoxide emission, therefore, it simultaneously reduces the green house effect [2,11].

One of the methods to produce hydrogen is water electrolysis. Water electrolysis is the process of decomposing of water compounds (H_2O) into oxygen (O_2) and hydrogen gas (H_2) using electric current through the water. At the cathode, two water molecules react by capturing two electrons, reduced to gas H_2 and hydroxide ions (OH^-) [9]. Meanwhile, on the anode, two other water molecules break down into oxygen gas (O_2), releasing $4H^+$ ions and flowing electrons into the cathode. H^+ and OH^- ions undergo neutralization so that some water molecules are formed again. The overall reaction equal to electrolysis of water can be written as follows

$$2H_2O_{(l)} \longrightarrow 2H_{2(g)} + O_{2(g)} \qquad (1)$$

Hydrogen and oxygen gas produced from this reaction form bubbles at the electrode and can be collected. This principle is then used to produce hydrogen and hydrogen peroxide (H), which resulted in hydrogen vehicle fuel [4, 8].

The research conducted by Putra in 2010 with 4A-6A current regulation, the optimum hydrogen gas was produced in current 6A. However, the experiment device has the disadvantage that if the current is raised, it will be overheated and melt the tube, which made of mica (plastic). For efficient hydrogen gas production, the tube construction must be replaced with components that are resistant to high currents that cause overheating. Water decomposition can be optimized with the use of large currents [5].

The objective of this study is to produce hydrogen gas using water electrolysis by varying NaOH concentration to obtain maximum and optimum hydrogen gas, and at the same time to achieve the high efficiency of water electrolyzer.

II. EXPERIMENTAL DESIGN

Water Electrolyzer Prototype design consists of a cube-shaped plastic compartment to store raw materials to be processed and stainless steel electrodes (pipes) where the electrolysis reaction between the cathode (-) and anode (+) [7]. Electrolysis reaction is to separate H_2 and O_2 gases on the water by the help of electrolyte solution. The electrodes used are five pairs and arranged in parallel. To separate these compounds, electrodes are electrified. The products produced are hydrogen gas and oxygen gas [10].

The produced H_2 gas is channeled to a water reservoir to bind the water content that still exists in hydrogen gas due to the produced gas is not entirely pure. The produced hydrogen gas can be removed by opening the valve opening at the top of the storage tube. The gas pressure inside the tube is indicated by a pressure gauge above the tube as an indicator of the amount of gas in the tube (Fig.1).

In this study, the efficiency of an electrolyzer can be calculated by:

$$\text{\% Elect Efficiency} = \frac{\text{Energy consumed}}{\text{Energy supplied}} \times 100\% \qquad (2)$$

$$\text{\% Heat Loss} = \frac{\text{Energy supplied} - \text{Energy consumed}}{\text{Energy supplied}} \times 100\% \qquad (3)$$

$$\text{SFC} = \frac{\text{Energy consumed in electrolysis}}{\text{The amount of produced hydrogen mole}} \times 100\% \qquad (4)$$

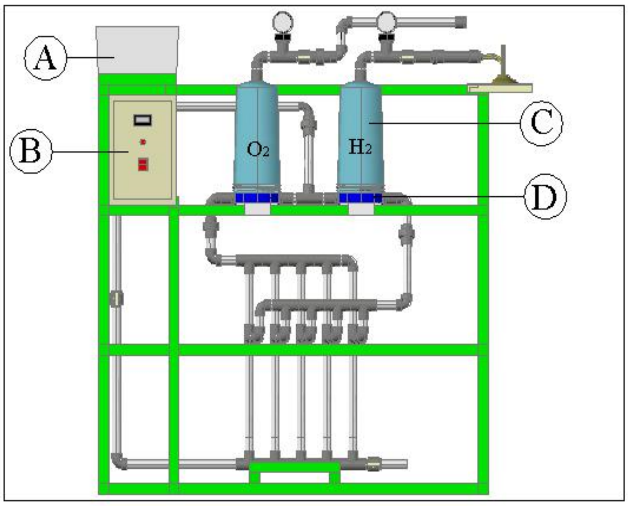

Fig. 1. Water electrolyser design

Where:

A = Raw Material Container

B = Box Panel (Controller)

C = Hydrogen and Oxygen Gas Storage Tube

D = Gas Storage Tube

The Water Electrolyzer Prototype in this research (Fig. 1) is designed to conduct electrolysis process for 20 minutes in producing hydrogen and oxygen gas. The hydrogen and oxygen flow into each gas reservoir. The research variables considered in this study are fixed and changing variables. The fixed variables are the type of electrolyte, the time of electrolysis, the type of electrode, and the amount of raw material (water). The changing variable is the concentration of electrolyte solution (NaOH) which are 10%, 20%, 30%, 40%, and 50%.

III. Result and Discusssion

The experiment was conducted by a prototype Electrolyzer water to produce hydrogen gas as an environmentally friendly fuel. The objective of calculating the amount of produced H2 gas produced, the cell potential needed, electrical efficiency, heat loss, and SFC (Specific Fuel Consumption).

In the process of electrolysis of water with sodium hydroxide electrolytes is called oxidation-reduction process that produces gas. The electrolysis process takes place when electrodes are electrified; therefore, the compounds in the electrolyte break down to form ions. This chemical reaction process is effective and efficient but requires a high electric current during the electrolysis process. Electrodes (cathodes and anodes) will be interconnected when electric current applied. This process due to the electrolyte solution as an electric conductor which causes gas bubbles to emerge. Electrolysis of water with sodium hydroxide by using an electric current that flows through this water is a decomposition of water compounds (H2O) into hydrogen (H2) and oxygen (O2). Gas H 2 and hydroxide ions (OH^-) are obtained by reducing two water molecules that capture two electrons at the cathode. Meanwhile, at the anode, gas oxygen (O2) is formed from two other water molecules that break down, releasing $4H^+$ and flowing electrons to the cathode.

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

In Fig. 2. it can be seen the relationship between the concentration of NaOH electrolyte solution to the volume of hydrogen gas that has been electrolyzed for 20 minutes. Fig. 2 shows that the hydrogen gas produced has a linear increment in the addition of the concentration of sodium hydroxide solution. This condition shows that the higher the concentration of NaOH electrolyte solution, the formed electrons are denser and more numerous, making it easier to transfer electrons from the solution to the electrode [2].

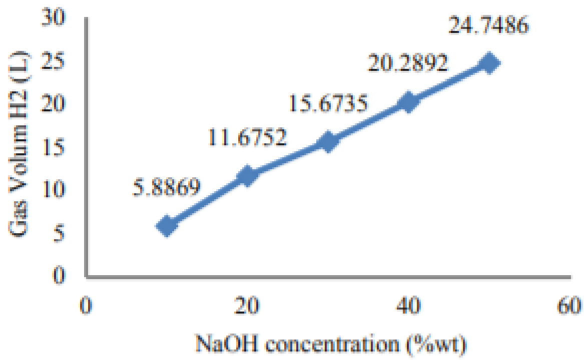

Fig. 2. Literature study on Effect of NaOH Electrolyte Solution Concentration to the Volume of Hydrogen Gas Produced

The process of decomposing water into hydrogen and oxygen will be faster by increasing the conductivity. The increment of conductivity causes the increment of electrical current. This condition can happen if the increase in NaOH concentration is proportional with the increment of hydrogen volume since the more significant amount of sodium hydroxide used, the more Na^+ and OH^- ions are formed and increase the conductivity of the raw material for water.

In this study, stainless steel was used as an electrode in the electrolysis process. Direct voltage is applied to generate a potential difference between the two electrodes. This potential difference makes ions in the electrolyte solution migrate towards the electrode charged with opposite ion. Ions formed in this study come from the dissociation of NaOH. The dissociation that occurs in the NaOH solution produces Na^+ and OH^- ions. In the electrolyte solution of sodium (Na^+) and hydrogen (H^+) ions which are positively charged migrate towards the cathode, while negatively charged hydroxyl (OH^-) ions migrate to the anode. At the electrode, a redox reaction occurs due to the migration of these ions and causes an electric current to flow in the solution.

The amount of water used as a raw material in this process is 6 liters. The calculation of hydrogen gas volume is conducted by the equation reaction of water with sodium hydroxide. To calculate the reactant moles and the produced moles, temperature, molecular weight, and density data are needed. This mole data is used to calculate the volume of hydrogen.

The experiment shows that the volume of hydrogen gas produced is higher when the NaOH solution is used. Fig. 2 shows that the volume increment due to the concentration of the NaOH solution used as an independent variable. The amount of NaOH solution is 10 grams for each concentration, and the increment is not apparent; therefore, the increment is not very significant.

B. *Experiment Result on Effect of NaOH Electrolyte Solution Concentration to the Volume of Hydrogen Gas Produced*

Fig. 3 shows the difference in NaOH concentration used in the electrolysis process of hydrogen water produced relative to the increment of raw material (water). Water fills the storage tube used to process the hydrogen and oxygen gas during the electrolysis process. Gas will fill the reservoir tube when the first 20 minutes of electrolysis time has been reached. Based on observations made during the process, in the 20th-second hydrogen gas has begun to appear.

The experiment shows that s hydrogen gas level increase, the water level decrease. Therefore, the gas level indicated by for the gas height data in the tube, and by using the cylindrical volume equation (cylindrical reservoir tube), the volume of gas formed can be calculated. In the literature review, the amount of produced hydrogen gas is influenced by the concentration of the NaOH solution. Information on the effect of the concentration of NaOH solution on the volume of hydrogen gas produced can be seen in Fig. 3.

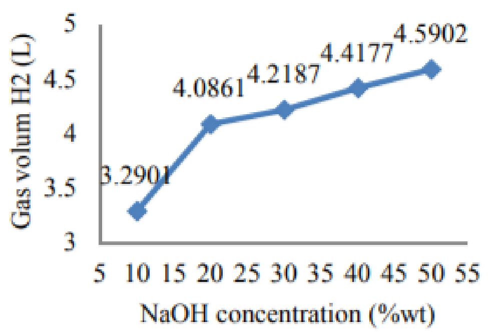

Fig. 3. Research study on Effect of NaOH Electrolyte Solution Concentration to the Volume of Hydrogen Gas Produced

Based on variations in the concentration of the NaOH solution used, namely 10, 20, 30, 40, and 50 %, the data collection process was carried out in five experiments. From the experiment result, it can be seen that the hydrogen gas produced increases with the increment variation in the concentration of the NaOH solution used. In the first run (concentration of 10% NaOH solution), the volume of hydrogen gas was 3.2901 liters, whereas in the second run the volume of hydrogen was 4.0861 liters. The increase in the volume of hydrogen is not too high at around 0.8 liters. In the next run, an increase of hydrogen gas occurs only around 0.1 Liter. Hydrogen gas production still increases from the previous run, but the increment is less than the first and second run. The function of a NaOH solution as an electrolyte solution in this process is still quite optimal. However, based on experiments that have been conducted, the use of electrolytes containing sodium (Na) will form flocs, which can be seen in gas storage tubes. They can clog the electrode pipeline the site of the reaction and decomposition of water into hydrogen and oxygen.

The formation of atrial salt floc in the electrode pipe causes the gradual decrement of the production of hydrogen gas. This phenomenon can be observed in Fig. 3 as the result of the next run during the producing of hydrogen gas with an increase of only about ± 0.2 liters each time the addition NaOH concentration solution which is very different from the first run because the experiment advice still has not experienced accumulation of sodium salt floc.

The longer the use of experiment tool in the electrolysis process with NaOH solution as a catalyst solution, the performance of the water electrolyzer prototype keeps on reducing. The formation of sodium salt floc in the electrode pipe was identified by the suspension floating in the hydrogen and oxygen gas storage tubes. The formation of sodium salt floc can reduce the performance function and reactivity of the electrode; therefore, the hydrogen production will tend to decrease.

By comparing hydrogen gas produced in laboratory experiment and literature study is that unlike the result in literature study, where the obtained data that are linear with the increase in volume, in contrast, the experiment result shows the tendency of decreasing. Based on the literature review, the maximum hydrogen produce is 24.4786 liters, while from Fig. 3 it can be seen that the highest hydrogen volume is 4,5902 Liter.

The difference that occurs is noticeable, at a concentration of 10% theoretically the volume of hydrogen is 5.8869 liters, while practically the volume of hydrogen is 3.2901 liters. This difference is not very significant because the electrode pipe is still functioning correctly and not contaminated.

In the second experiment result, which is at 20% NaOH concentration, the difference starts to occur a little bit, which is 11.6752 Liter in theory and 4.0861 Liter in the experiment. The difference between the theoretical and experimental results occurred until the 5th run, at the concentration of 50% NaOH solution. Theoretically, the results are 24.7486 liters, while in experiments are 4.5902 liters. The difference is around 20 liters. The loss of the volume of hydrogen as much as 20 liters in the experiment is due to a decrease in the performance of the electrode, which is increasingly saturated. Repair or curative action is essential on the part of the contaminated equipment to reduce the inhibition that occurs, the more inhibitors, and the less hydrogen gas is produced.

C. *Cell Potential Value used in the Electrolysis Process*

Theoretically, the equilibrium voltage of the electrolysis process of water is 9.08 V and based on the calculation by reviewing the variation of NaOH concentration the different potential cell values are obtained, ranging from 12.04 volts to 12.07 volts, but this electrolysis process requires voltage which is much higher than the equilibrium voltage. In the experiment tool panel, the voltage set is 13.1 volts while in reality, is not much different, only 13.3 volts. This condition occurs due to the measurement of the 9.08 V equilibrium voltage is in a standard state that cannot be achieved, and the process always overpotential on the system. Overpotential causes the working voltage to be far higher than the equilibrium voltage. The working voltage is determined by varying the source voltage so that there are several currents whose magnitude does not change even though the voltage continues to be increased. The minimum voltage when a constant starting current is called working voltage. This actual cell potential value is more, and this means that the cell potential needs of each reaction and variation in concentration can be achieved because it has passed the cell potential limit in theory.

D. Effect of % Heat Loss, Electric Efficiency, and (Specific Fuel Consume) on Hydrogen Gas Produced

Current, voltage and the number of electrodes are not affecting the calculation of heat loss for the water electrolyzer prototype tool. In this process, heat loss is influenced by efficiency, the higher the efficiency of the gas produced, the lower the heat loss that occurs because heat loss is inversely proportional to efficiency. Therefore, in this process, the heat loss value tends to be constant, which is around 17.9198% because all runs use the same operation, and the comparison of each run cannot be reviewed. Theoretically, the electric power used in the process is around 79.8 Watts with a 13.3 Volt voltage setting, 6 A current, and 20 minutes, while the actual conditions that occur are the power used is 65.5 Watts, 13.1 Volt, 5 A, and 20 minutes. With this difference, the heat loss can occur because of the lack of operating conditions when setting the device with the actual conditions that occur.

By reviewing the differences in operating conditions, electrical efficiency can also be calculated. Based on the calculation, electrical efficiency is 82.0802%. This is good since, in general, electrolysis efficiency is theoretically 80%. This value only refers to the efficiency of converting electrical energy into hydrogen chemical energy [3, 12].

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, the more significant 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, for each variation in the concentration of NaOH solution, different SFCs are needed. This SFC value is directly proportional to the volume of hydrogen gas produced both theoretically and practically. It is noted that the value of SFC tends to decrease with the increasing volume of hydrogen gas produced. It is the same as the performance of electrodes described in the previous discussion. The performance or function of the electrode pipe begins to saturate and results in a decrease in the value of SFC. Therefore, even though the volume of hydrogen produced is still increasing, the SFC given decreases. Information on gas volume comparison data in theory and practice versus SFC can be seen in Fig. 4.

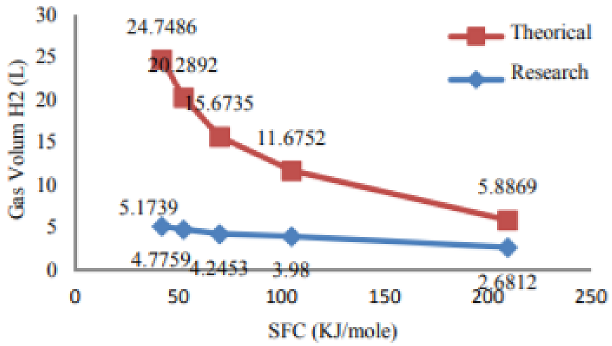

Fig. 4. The Relationship of SFC (Specific Fuel Consume) to the Volume of Hydrogen Gas produced by Theory and Research

Fig. 4 shows there was a significant decline due to the energy needed to produce hydrogen gas in the second run and after that is not as much as the first run; therefore, this process requires energy which is not as much as the first run.

E. Effect of NaOH Concentration on the Composition of Hydrogen Gas Content by Gas Chromatography Analysis

In the previous discussion, it was described that the higher the concentration of NaOH solution, the higher the amount of hydrogen gas produced. This condition is also proven by doing product analysis using gas chromatography. Information about the effect of the concentration of NaOH solution on the composition of hydrogen gas and impurity gases can be seen in Fig. 5.

Analysis of gas products using gas chromatography is carried out with the principle of separating the mixture into its components 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 there are other gas components such as carbon dioxide, oxygen, and nitrogen so that the hydrogen produced is not 100% pure. These contaminants can come from the air that enters during the product storage process in the sample bag. Air is a mechanical mixture of various gases. Typical 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 [6].

The problem with the design of this tool is the absence of a vacuum system. Therefore it can eliminate the air content in a room and causes the hydrogen gas produced still contains other gas components, but during the product storage process it has been tried and carried out as much as possible so that it does not come into direct contact with air. When the process takes place, the hydrogen gas storage tube is filled with water but is not 100% full so that there is residual space filled with air. When hydrogen gas begins to fill the reservoir tube, then a little air is mixed with hydrogen. The gas product output valve is opened to remove some of the gas into the air but does not rule out the possibility that there is still homogenized air with hydrogen, and it causes the analysis results for gas composition using gas chromatography still containing other components.

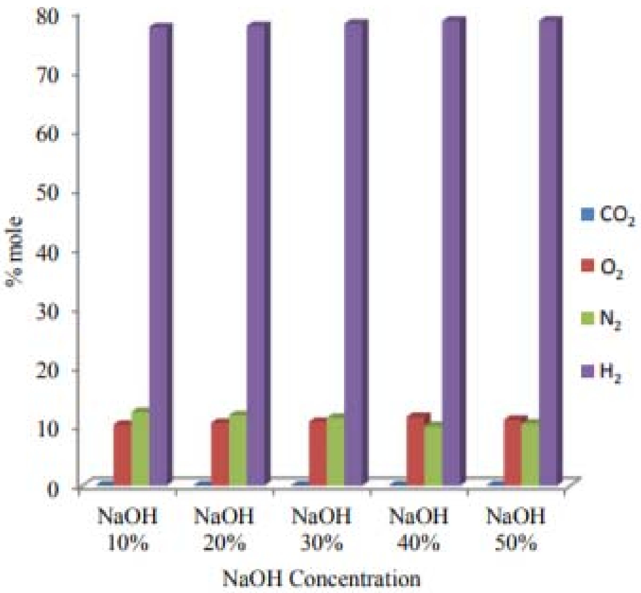

Fig. 5. Effect of NaOH Concentration on Hydrogen Gas in Gas Chromatography Analysis

IV. CONCLUSION

The prototype water electrolyzer experimental tool designed in this study has a capacity of 6 liters of raw material, each hydrogen and oxygen gas storage tube is 3.58 liters, into hydrogen and oxygen gas with various concentrations of NaOH. In this process, hydrogen gas produced with the highest volume produced in the electrolysis process is 4,5902 liters. Therefore the optimum NaOH 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 77.85%; 10.86%, nitrogen 11.24%; and carbon dioxide 0.07%.

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