Hydrogen Production from Aluminum Waste with Sodium Activator Using Aluminum-Water Method

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Hydrogen Production from Aluminum Waste with Sodium Activator Using Aluminum-Water Method

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Abstract. The production of hydrogen as one of the fuel cell fuels is a challenge in producing hydrogen with high purity. The production of hydrogen gas from aluminum waste using the aluminum-water method was successfully by adding sodium activator with varying concentrations and NaOH as a catalyst to damage the oxide layer so that aluminum reacts with water to produce hydrogen gas. The best conditions in the aluminum-water reaction are 1 g aluminum with a sodium activator of 1.5 mL water volume, 7 wt% sodium content, and 60 mesh aluminum particle size. The hydrogen production using sodium activator at the best conditions produced hydrogen gas of 502 mL when NaOH catalyst added produced hydrogen gas of 862 mL. The highest reaction rate of hydrogen gas production by adding sodium activator to the selected conditions was 65 mL/min, while NaOH as catalyst was 160 mL/min.

INTRODUCTION

The high population growth and rapid economic development in the world cause the world to need more and more energy. As energy demand increases, energy availability, especially energy from fossil fuels, decreases, and there are emissions of combustion products that are not environmentally friendly [1]. This is because the energy needs in Indonesia are still primarily dominated by the use of fossil fuels (coal and oil). To overcome this problem, this study seeks to find alternative fuels that have a clean energy concept [1].

Hydrogen is one of the energy carriers that has been widely developed to date. Hydrogen is also considered the best clean energy carrier due to its lightweight, high-energy density, and non-polluting process [2]. Hydrogen can be produced in various ways, including electrolysis, steam reforming, metal-acid reaction, and aluminum-water reaction (aluminum-water reaction). However, all hydrogen production methods have various drawbacks. For example, direct decomposition requires high temperatures and produces significant amounts of CO and other by-products [3].

Hydrogen production carried out by the aluminum-water method (reaction of aluminum with water) produces aluminum oxide and hydrogen gas. The aluminum-water reaction is considered more efficient and environmentally friendly. Al-H_2O reaction as hydrogen sources becomes economically attractive because aluminum comes from

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aluminum waste [4]. Aluminum is a metal with a relatively high selling value. Most of its waste is rarely recycled; hence, in this study, aluminum waste was reused for hydrogen production through the aluminum-water method [1].

The reaction between aluminum and water is relatively slow due to the formation of a thin oxide layer that covers the surface of the aluminum metal. Therefore, the aluminum-water reaction is assisted by additives or catalysts [5]. Research conducted by Ihsan (2017) reacts aluminum with water with lithium activator relatively very slowly so that other activators are needed that aim to increase hydrogen production [6]. To overcome these weaknesses, this study uses another activator in the form of a sodium activator. This is because sodium is an alkali metal that is very reactive and has very low ionization energy. It is very easy to form positive ions and react to form compounds [7]. Besides the activator, a catalyst is also used to destroy the thin oxide layer that covers the surface of the aluminum metal. NaOH as a catalyst can increase hydrogen production by up to 20% [8].

In this study, we also calculate the rate of hydrogen production and analyzes the effect of several parameters such as the particle size of aluminum, the volume of water, the content of sodium activator and NaOH catalyst to the volume of hydrogen production, and then the characterization of the by-product resulting from the hydrogen production reaction.

MATERIALS AND METHOD

The materials used were distilled water, 5 M sodium hydroxide solution, aluminum waste, and sodium powder. Preparation of aluminum waste includes collection, separation, cleaning, drying. The aluminum formed is in the form of aluminum powder.

Production Hydrogen Gas with Sodium Activator Using the Aluminum-Water Method

Aluminum and activator with various concentrations (3, 5, and 7 wt%) are mixed and milled using mechanical alloying. The milling process was carried out for 15 minutes and then filtered with various sizes of sieves (20, 40, and 60 mesh). The synthesis of an alloy between 1 g aluminum and 3wt% sodium was carried out using a mechanical alloying method using HEM (High Energy Milling equipment with a BPR (ball to powder ratio) 1:5, and 10 minutes of grinding time. Furthermore, as much as 1 g of the sodium-aluminum alloy is put into a glove box, and N_2 gas is flowed into the reactor to remove oxygen gas/air.

The Effect of Adding Water Volume

After the alloy of 60 mesh size, Al powder was successfully synthesized, it was ready in the reactor, and then water was added to the reactor with varying volumes (1; 1.5; 2; 2.5 and 3 mL).

The Effect of Aluminum Particle Size

After obtaining the optimum water volume, hydrogen production was continued with various aluminum powder sizes (20, 40, and 60 mesh).

The Effect of Sodium Activator Mass

Aluminum with an optimum particle size of 1 g was mixed with sodium with a mass ratio variation of 3; 5; and 7wt% by weight of Al, then ground using ball milling.

For all parameters, time is recorded from the beginning of the addition of water until the first gas is formed. The recording of time is continued until the gas production stops. The hydrogen volume equals the volume of water that comes out of the bottle into the measuring cup.

Using NaOH as a Catalyst

One g of aluminum with a size of 60 mesh was put into the reactor, and N_2 gas was flowed into the reactor to remove oxygen gas. Add 2.5 mL of 5 M NaOH solution to the reactor. We record the time starting from the addition of NaOH until the gas is first formed and recording the time until the gas production stops. The volume of hydrogen gas is measured as described above.

RESULTS AND DISCUSSION

Hydrogen Gas Production with Sodium Activator Using the Aluminum-Water Method

The Effect of Added Water Volume

The effect of water volume on the hydrogen gas production rate is shown in Figure 1. The maximum volume of hydrogen gas occurs at the addition of 1.5 mL of water volume with a volume of 367 mL of hydrogen gas and a reaction rate of 52.5 mL/min. The effect of the volume of water added depends on the achievement of the stoichiometric equilibrium reaction.

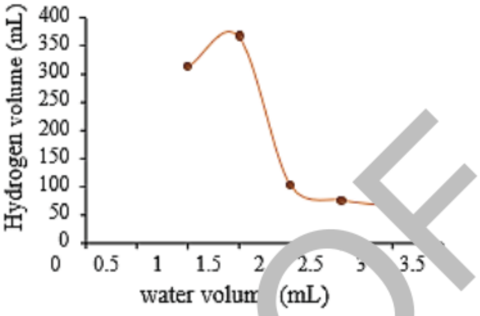

FIGURE 1. Hydrogen gas production curve at various volumes of water

Figure 1 shows the curve of each volume of hydrogen produced at various volumes of water added for 20 minutes. The resulting hydrogen gas undergoes an increase because the volume of water added is increasing. The volume of hydrogen gas increases with the addition of 1 to 1[illegible] mL of water so the best hydrogen gas volume occurs at 1.5 mL of water. This also corresponds to the stoichiometric equilibrium condition. Theoretically, 1 mole of aluminum can react optimally with 3 moles of water. In this study, the [illegible] of aluminum was weighed as much as 1 g (0.037 mol) and could react optimally with 0.1 mol of water (±1.8 mL). At the addition of 2 mL of water volume, the production of hydrogen gas began to decrease. This is because [illegible] addition of the volume of water is more than the stoichiometric equilibrium condition, so the volume of hydrogen gas produced is not optimal. The addition of an excessive volume of water will hydrate alumina (Al_2[illegible]), resulting in by-products such as bayerite ($Al(OH_3)$), bemite ($AlOOH$), or a mixture of both [9]. The presence [illegible] bayerite inhibits the hydrogen formation reaction. Hydrogen gas production increases with increasing time.

FIGURE 2. Bubbles produced by hydrogen gas

Figure 2 shows bubbles produced by hydrogen gas with various water volumes added to hydrogen gas produced for 20 minutes.

The Effect of Aluminum Particle Size

The particle size of aluminum is one of the things studied in this study. Kumar and Muthukumar (2020) explained that milling with the High Energy Milling system to obtain powder particles of a specific size could affect the morphology and structure of aluminum particles [9]. The effect of aluminum particle size on hydrogen production is shown in Figure 3.

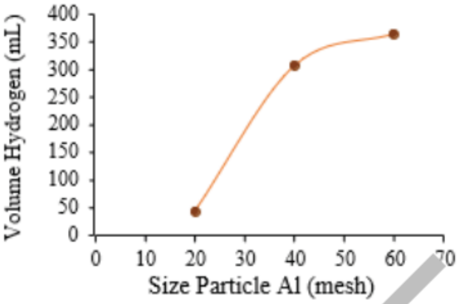

FIGURE 3. Hydrogen gas production curve for variations of aluminum particle size

Based on Figure 3, the highest hydrogen volume is produced from the aluminum particle size of 60 mesh. Hydrogen gas produced from the best particle size (60 mesh) was 367 mL for a specific period of time. Meanwhile, for the reaction rate, the maximum obtained was 52.5 mL/min. In Figure 3, the smaller the aluminum particle size, the higher the volume of hydrogen gas produced. The smaller the particle size, the wider the surface area of aluminum, so it is more active to react, producing more hydrogen gas. This agrees with hsan's report (2017), which compares hydrogen production with the highest range of aluminum [illegible] [6]. According to Wang et al. (2011), the smaller the particles of a substance, the wider the surface area [3]. Particles with a large surface area will speed up the reaction rate because they have a wider contact area to make more collisions.

The Effect of Sodium Activator Mass

The content of sodium as an activator is exceptionally influential on the productivity of hydrogen gas. The effect of sodium content on hydrogen production can be seen in Figure 4. The sodium content of 7wt% is the best result with 502 mL hydrogen gas production for 20 minutes and a reaction rate of 65 mL/min.

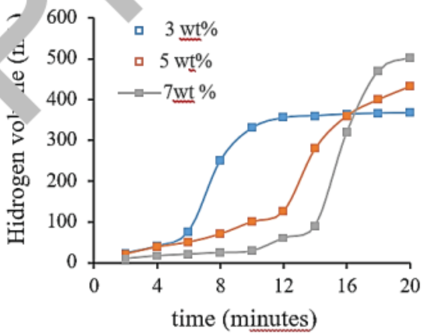

FIGURE 4. Hydrogen gas volume on the mass variation of sodium activator as a function of time

Figure 4 shows that the production of hydrogen gas increases with increasing sodium content according to experimental variations. The more activator is added, the oxide layer on the aluminum will be destroyed so that the pores of the substance will open and cause the reaction between aluminum and water to occur quickly. This affects the hydrogen production yield will be more and more [8].

Ihsan (2017) has conducted research using different activators, where the activator used is lithium with hydrogen gas produced by 138 mL [6]. It can be concluded that the sodium activator reacts faster and produces more hydrogen gas than the lithium activator.

Production of Hydrogen Gas with the Addition of NaOH Catalyst Using the Aluminum-Water Method

Data on the production of hydrogen gas using the aluminum-water method using a NaOH catalyst within a certain time can be seen in Figure 5.

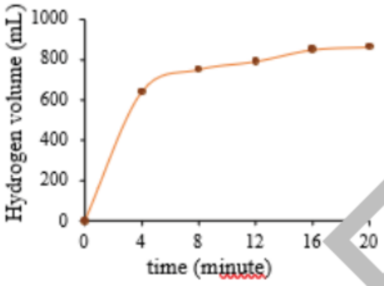

FIGURE 5. Hydrogen gas production curve with NaOH catalyst

Based on Figure 5, the rate of hydrogen gas production increases sharply for the first 10 minutes, and after 10 minutes, the hydrogen gas formation tends to be constant. This condition indicates that the effective reaction rate for hydrogen gas production with NaOH occurs in the first 10 minutes with the addition of a catalyst. Meanwhile, the highest volume of hydrogen gas produced was 86[illegible] mL, and the reaction rate was 160 mL/min. The volume of hydrogen produced is not maximal because the number of moles of NaOH added does not match the stoichiometric calculations. Stoichiometrically, 1 g (0.333 mol) of aluminum used in this study required a comparable number of moles of NaOH. Meanwhile, in this study, the number of moles of NaOH used was 0.0125 moles.

Ilyin (2019) revealed that the reaction of aluminum with water to produce hydrogen gas uses a temperature of 700 °C, and the aluminum powder is not completely oxidized [10]. The oxidation of aluminum requires heating to a temperature of 1250 °C. Therefore, to accelerate the process of hydrogen gas formation, alkalis such as KOH, NaOH, and $Ca(OH)_2$ are used as catalysts. The use of NaOH as a catalyst for the reaction of aluminum with water is better than KOH as done by previous researchers because KOH has enormous activation energy so that the current density is small and the corrosion process takes place more slowly than NaOH [11].

The production of hydrogen gas in this study also uses pure aluminum as a comparison. The volume of hydrogen gas produced for 20 minutes is 1[illegible]52 mL. This shows that the use of pure aluminum produces more hydrogen gas than aluminum waste. This research uses aluminum waste that has been contaminated to form alumina compounds so that the outer layer inhibits the reaction of aluminum with water to produce less hydrogen gas.

X-Ray Diffraction Analysis

XRD analysis in this study was conducted to identify the presence of aluminum hydroxide ($Al(OH)_3$) and unreacted aluminum products. To see the difference in the diffractogram before and after the reaction, in this study, an analysis of aluminum alloy and aluminum-water reaction products was carried out under selected conditions. The XRD spectral data before and after the reaction are shown in Figure 6.

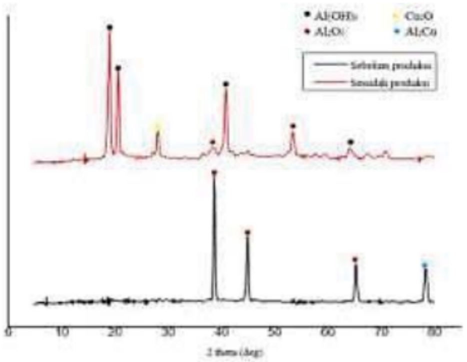

FIGURE 6. Diffractogram before and after hydrogen production

The XRD analysis shows a diffraction pattern of $Al(OH)_3$ and alumina (Al_2O_3) scattered at various angles at the optimum condition (1.5 mL water volume, 60 mesh aluminum particle size, 7wt% sodium content, and 25° C). Based on the results, the compounds contained in the aluminum waste before being reacted with the activator and water were alumina compounds (Al_2O_3). The alumina diffraction pattern obtained is at angles of $2\theta = 38.662°$, 44.90°, and 65.17°. These results are consistent with JCPDS data 00-010- 0425 which shows the diffraction peaks of Al_2O_3 are at angles of $2\theta = 37.8°$, 43.36°, and 66.55°. Meanwhile, after reacting with activator and water, the compound contained in aluminum waste is $Al(OH)_3$, which produces a diffraction pattern at angles of $2\theta = 19.032°$, 20.60, and 40.84°. This result is supported by JCPDS data 00-0120-457 which shows the diffraction peaks at angles of $2\theta = 18.78°$, 20.35°, and 40.798°. Based on the XRD results, the compounds produced after the reaction are $Al(OH)_3$ compounds formed and compounds (Al_2O_3), so it can be concluded that the aluminum powder waste is not finished reacting. The diffraction pattern produced in this study also has similarities with the research conducted by Matori et al. [12]. which shows the pattern alumina diffraction is seen at position $2\theta = 2$[illegible] - 68°.

CONCLUSION

The optimum condition of hydrogen production using the aluminum-water method in the reaction of 1 g of aluminum with water using a sodium activator at a volume of 1.5 mL of water, the sodium content of 7 wt%, and an aluminum particle size of 60 mesh [illegible] produce 520 mL of hydrogen. The percentage of hydrogen gas produced to the theoretical hydrogen production under the same conditions was 38.348%. The addition of NaOH catalyst resulted in 862 mL of hydrogen gas. The highest reaction rate of hydrogen gas production with the addition of sodium activator under selected conditions was 65 mL/min, while the addition of NaOH as a catalyst was 160 mL/min.

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