The Production of Hydrogen from Aluminum Waste by Aluminum-Water Methods at Various Conditions

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The Production of Hydrogen from Aluminum Waste by Aluminum-Water Methods at Various Conditions

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Abstract. The production of hydrogen gas from aluminum waste by Aluminum-water methods at various condition has been successfully performed. The hydrogen production is a very important for support the fuel cell application Hydrogen was produced both in the acidic and base conditions at various temperature and using lithium as the activator. The urgencies in this research were effective and cheaper methods. The highest hydrogen production from reaction 0.3 g aluminum with 30 mL hydrochloric acid 2 M at 50 °C in 10 minutes was 348 mL. Meanwhile, the best condition for aluminum water methods for 0.3 g of Aluminum as reactants, were 3 mL water, 5% w/w lithium content and 100 mesh aluminum particle size. Furthermore, using KOH as a catalyst, gave hydrogen product 670 mL with the rate at 67 mL/min.

Keywords: aluminum-water, aluminum waste, hydrogen, activator, lithium.

1. Introduction

Proton Exchange Membrane Fuel Cell (PEMFC) is electrochemical equipment that can convert the chemical energy in hydrogen as fuel and oxygen as oxidant into electrical energy directly [1]. PEMFC is the fuel cell which has been developed for various benefits, such as: high efficiency, low temperature operation and diverse applications [2,3].

The use of hydrogen gas as a fuel in PEMFC make PEMFC as a producer of clean energy and environmentally friendly. Fuel Cell, especially PEMFC convert hydrogen in the anode and oxygen in the cathode to produce water and electricity with zero-emission. In addition, the use of hydrogen will reduce dependence on fossil fuels [4]. Selection of hydrogen as a fuel has many advantages, among others: hydrogen has the highest energy density in all fuels (122 kJ per kg, about 2.75 times greater than other hydrocarbon fuels), hydrogen is believed to be an effective substitute for gasoline as 9.5 kg of hydrogen is sufficient enough to replace 25 kg of gasoline and hydrogen is the lightest of all elements in the world, and hydrogen is the most abundant chemical element comprising about 75% of the earth's elemental mass [5].

Hydrogen is found in abundance in water (H_2O), gas and oil, coal and biomass. However, the availability of hydrogen is not found to be free in nature. Hydrogen gas must be extracted from compounds in nature. This causes hydrogen gas to become a relatively expensive commodity. Hydrogen can be produced in various ways including water electrolysis [6], steam reforming [7], hydrolysis of $NaBH_4$ [8], converting biomass [9–11] and aluminum-water [12–14].

The production of hydrogen from aluminum is one of the interesting production methods. The Methods include production hydrogen with aluminum water with lithium as activator or using KOH as catalyst.

The principle of aluminum water reaction is reaction of aluminum with water to produce oxide/hydroxide aluminum and hydrogen [15]. In this research, the source of aluminum is from aluminum waste. Reaction of aluminum with water is slow due to the formation of a thin oxide layer and coefficient which covered the surface of aluminum, the reaction of aluminum water is needed additive or catalyst. One of the additives is lithium that has a function as an activator.

The important matter of this research is how to supply the hydrogen as the source of new energy carrier for residential or office in the city. The Hydrogen energy is the clean and clear energy for fuel of fuel cell [16].

2. Methods

A parametric experimental study has been conducted in order to find the influence of different operating factors and conditions on the activated aluminum water reaction, measuring the reaction rate and efficiency. Effects of water/aluminum mass ratio, fraction of activator used, water temperature and pressure.

Batch type experiments were conducted in a glass reactor. The aluminum powder + Lithium activator form ball milling system was put in the reactor first, then N_2 was flowed to the reactor and then water was added and a spontaneous reaction started. Since hydrogen has low solubility in water the amount of hydrogen produced from the reaction was measured by water displacement. The hydrogen produced from the reaction was channeled to a glass container filled with water driving the water out from the container to a cup placed. In some experiments the measurements were conducted with a digital mass flow meter. The temperature of the reaction was measured by a digital thermometer.

The production of hydrogen gas using the aluminum water method begins with cleaning aluminum waste as raw material using KOH. Furthermore, aluminum is mixed with lithium in various comparisons and milled in a ball mill system. The mixture is then filtered using different filter sizes (20, 40 and 100 mesh).

The subsequent hydrogen gas production is carried out in reactors with an aluminum mass of 0.3 g in water volume conditions (1; 1.5; 2; 2.5 and 3 mL), aluminum grain sizes (20, 40 and 100 mesh) and lithium activator masses (3; 4; 5; 6 and 7% Al weight) varied. As a comparison material, aluminum is produced by reacting HCl and KOH at various temperatures.

3. Result and Discussion

3.1. Production of H_2 through reaction of aluminum with HCl 2 M

Aluminum will react spontaneously with HCl solution according to equation 1.

$$2\,Al_{(s)} + 6HCl_{(aq)} \rightarrow 2AlCl_{3(aq)} + 3H_{2(g)} \quad (1)$$

The volume of hydrogen gas produced at various temperatures is shown in Figure 1.

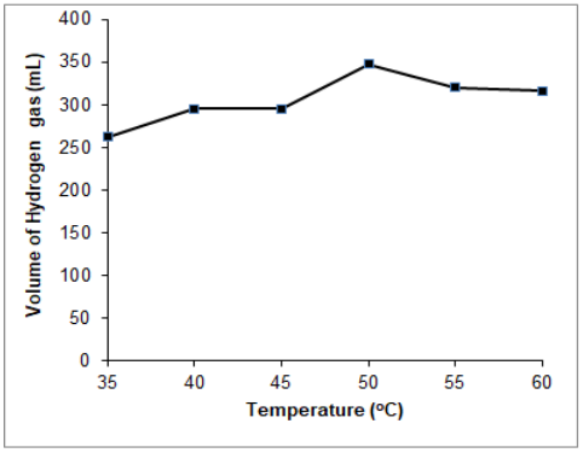

Figure 1. Volume of H_2 from reaction with HCl at various of temperature

The reaction of 0.3 g Al (0.01 mol) with HCl excess will produce 0.0167 mol H_2 stoichiometricaly. At STP conditions, will produce 373.3 mL. Based on the ideal gas equation, volume is directly proportional to the temperature. In this experiment, the highest hydrogen production is 348 mL at 50ºC. The higher temperature, the volume of the generated hydrogen gas is increasing until 50ºC and than decrease. This is evident from Figure 2.

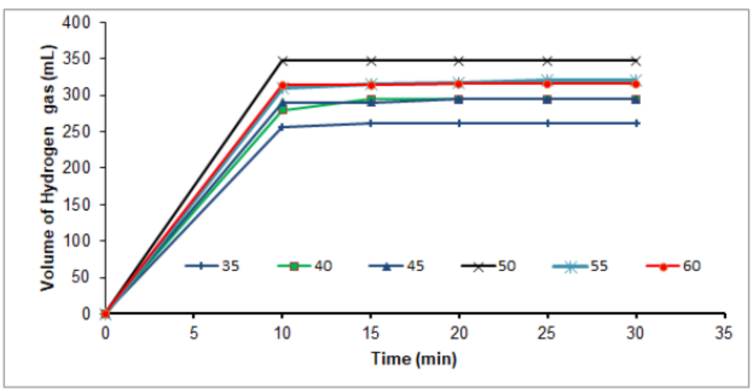

Figure 2. Volume of H_2 from reaction with HCl at various temperature as function of time

Based on Figure 2, hydrogen volumes rose sharply in the first 10 minutes, and thereafter relatively constant. This indicates that the reaction of H_2 formation tends to occur in a span of 10 minutes of the first. It can also be seen from the reaction rate as shown in Figure 3. Figure 3 shows that the reaction rate of H_2 production in the first 10 minutes is the highest rate, and the rate of production of hydrogen at 50°C is the highest rate**.**

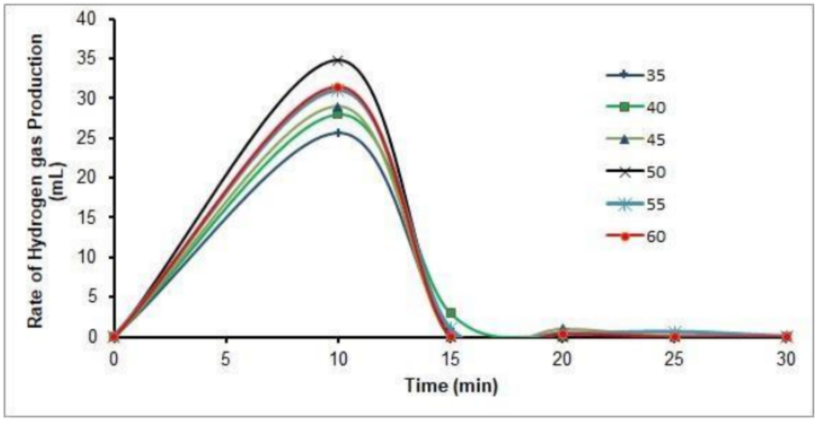

Figure 3. The rate of hydrogen production from reaction aluminum with HCl 2 M

3.2. Production of H_2 through aluminum-water reaction

Aluminum-water method is a method of hydrogen production by using aluminum treated with water. Because the existing coated aluminum oxide, aluminum reacts slowly with water. Therefore, in this study used lithium as an activator and the second method is used also KOH as a catalyst.

The principle of the aluminum water reaction is the reaction of aluminum with water at various trigger conditions / promoter to produce H_2. Stoichiometric reaction of hydrogen gas production with aluminum water method is as follows:

$$2/3Al + 2H_2O \rightarrow 2/3Al(OH)_3 + H_{2(g)} \quad (2)$$

In thermodynamics, reaction of aluminum with water will take place spontaneously. However, the fact that aluminum does not react at room temperature or high temperatures. This is because aluminum is coated by a thin layer of aluminum oxide coherent and stable. Therefore, the presence of promoters intended to damage the aluminum oxide layer and subsequently reacts with water spontaneously.

3.2.1. Production of H_2 with lithium as activator

Hydrogen production using aluminum activator is one method used by utilizing the activity of lithium in the water. In this regard, lithium serves to disrupt/destroy the oxide layer of aluminum so that the aluminum can react quickly. In addition, the presence of lithium diffuses into aluminum structure so as to modify the structure of the oxide / hydroxide of aluminum which causes aluminum surfaces are not protected anymore [17].

The production of H_2 using lithium depends on several conditions, among others, the volume of water used, the percentage litihium and temperature. In this study, factors other than the water volume, the content of lithium and temperature, also studied the effect of different types and sizes of samples of aluminum.

a. Effect of volume of water

The volume of water as a reactant affects the production of H_2. If the volume of water does not reach equilibrium stoichiometry, the volume of H_2 produced will not be maximized. Conversely, if too much volume of water will hydrate alumina (Al_2O_3) resulting from the merger of $Al(OH)_3$ becomes bemit (AlOOH) and further hydrolyzed into bayerit ($Al(OH)_3$) [18]. The presence of bayerit make the reaction of H_2 production is inhibited. This condition can be seen in Figure 4.

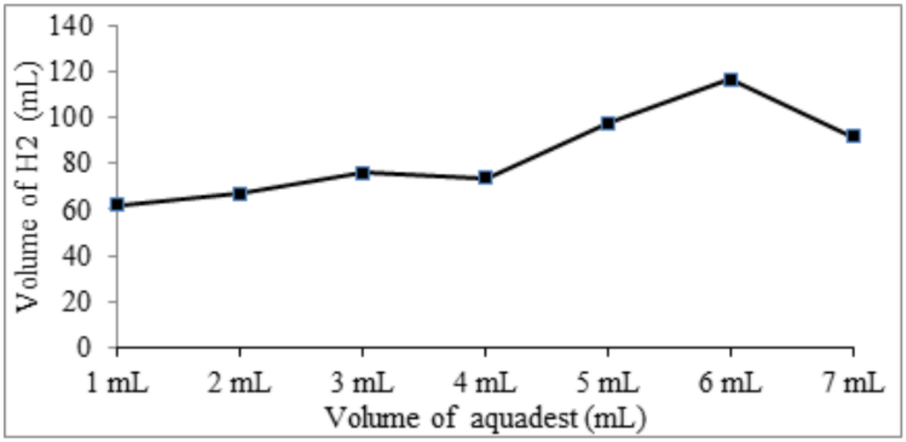

Figure 4. Production of H_2 at various volume of aquadest

b. The effect of kinds and sizes of sample

Type the source of aluminum and aluminum grain size is one that is to be assessed in this study. The influence of the type of source and size of the aluminum particles is presented in Figures 5 and 6.

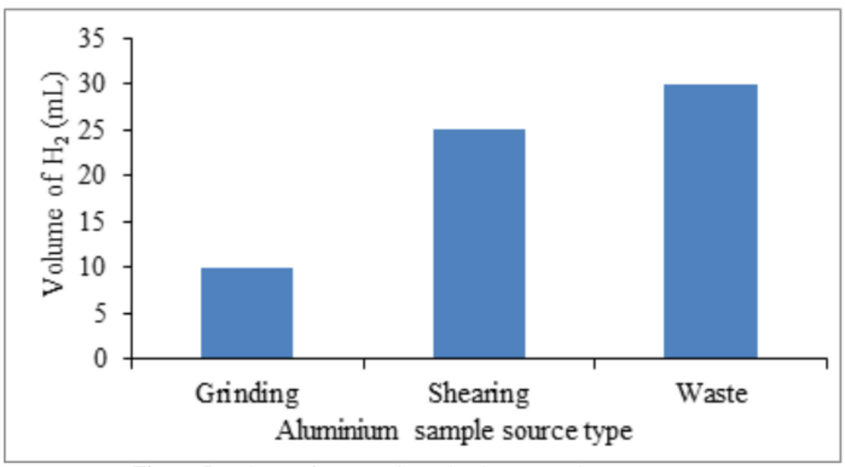

Figure 5. Volume of H_2 at various aluminum sample source type

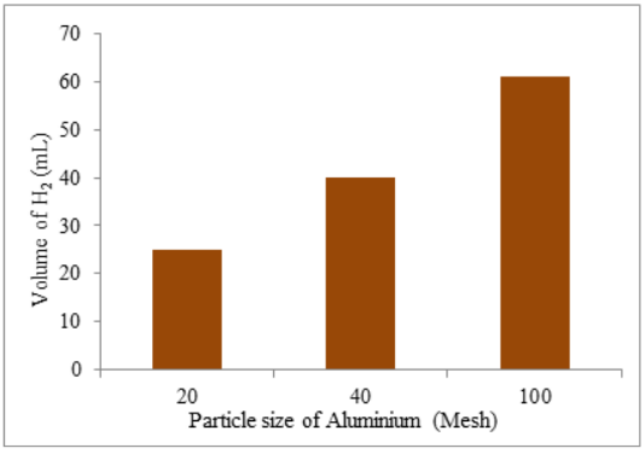

Figure 6. Volume of H_2 at various particle size of aluminum

Aluminum sample types of waste cutting aluminum based image 5 produce more H_2 than the aluminum using grinding and cutting results using scissors. It is associated with a grain size of aluminum from aluminum waste cutting results are more subtle than the result of shearing or cutting with grinding. The smaller the particle size, the greater the surface area and can increase the production of H_2. It is also evident from Figure 6. Aluminum with a grain size of 100 mesh produce more hydrogen than aluminum with a grain size of 20 and 40 mesh.

c. The effect of lithium content

The content of lithium as an activator effect on the productivity of H_2. Based on the Figure 7 and 8 can be seen that the production of H_2 increases with increasing of lithium content up to 5 wt% and then decreases again. According to some literature, effective lithium content is from 1 to 5 wt% [12,17].

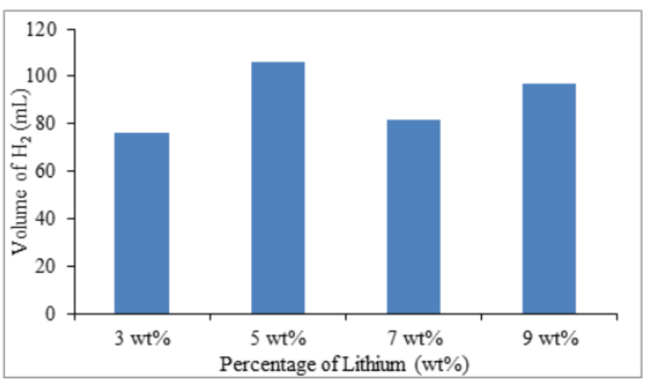

Figure 7. Production of H_2 at various of lithium content

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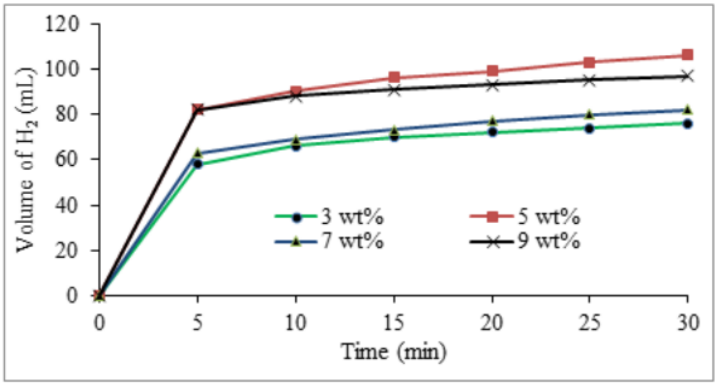

Figure 8. Volume of H_2 at various lithium content as function of time

The H_2 volume increases with increasing lithium content of up to 5 wt% content. A clearer picture can be seen in Figure 8. The lithium content of 5 wt% is the highest lithium content.

d. The effect of temperature

In general, H_2 production will increase with increasing temperature. This is in line with the increase in kinetic energy. Data effect of temperature on H_2 production is presented in Figure 9.

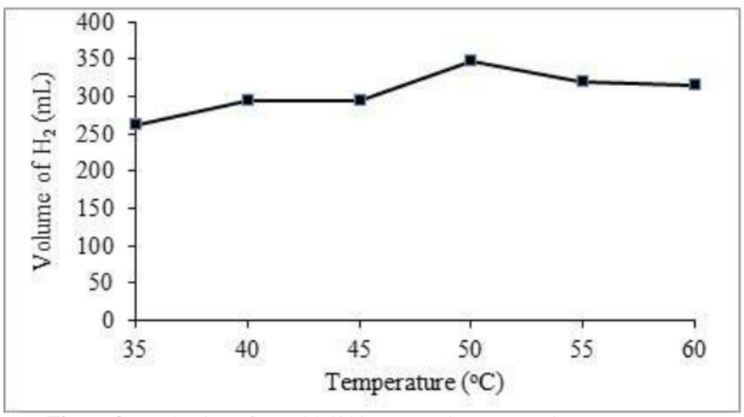

Figure 9. Production of H_2 with lithium as activator at various temperature

Based on the pictures 9 shows that the production of hydrogen increases with increasing temperature up to 50°C.

3.2.2. Production of H_2 with KOH as catalyst

The addition of KOH in H_2 production through the aluminum-water method because KOH can destabilize oxide layer that covers Al. Unlike the HCl, the addition of KOH serves as a catalyst. Taking the analogy of the use of NaOH as catalyst [18], then the conditions that occur in KOH followed the equation:

$$2Al + 6H_2O + 2KOH \rightarrow 2KAl(OH)_4 + 3H_2 \quad (3)$$

$$2KAl(OH)_4 \rightarrow 2KOH + 2Al(OH)_3 \quad (4)$$

$$\text{Overall} \quad : 2Al + 6H_2O \rightarrow 2Al(OH)_3 + 3H_2 \quad (5)$$

Because the overall reaction was no KOH, the role of KOH in the above reaction serves as a catalyst.

Data from the reaction of hydrogen gas production using the aluminium water method at various temperatures using KOH as a catalyst are shown in Figures 10 and 11. Based on Figure 10 it can be seen that at 40°C hydrogen production has decreased. This is caused by the inhibition that occurs because the temperature rise of the exothermic spontaneous reaction that occurs in the tube is hampered by the temperature outside [19,20]. Meanwhile, the reaction that occurs at a temperature of 35°C is the reaction in ambient (room) condition. Therefore, the volume of hydrogen gas produced at room temperature is the highest compared to other temperatures.

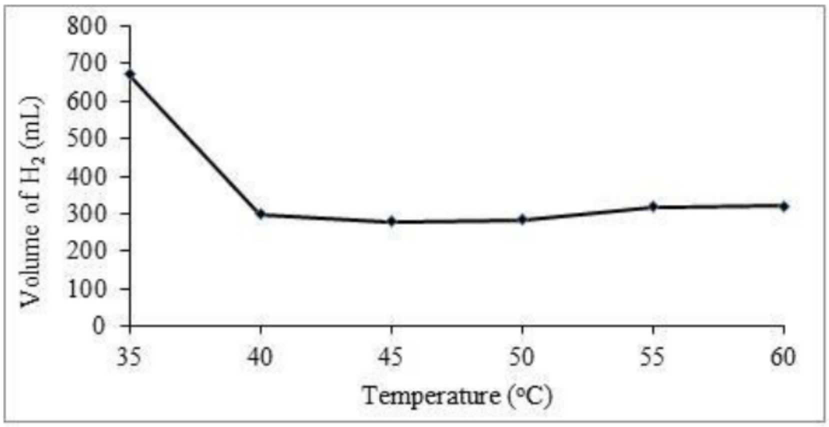

Figure 10. Production of H_2 with KOH as catalyst at various temperature

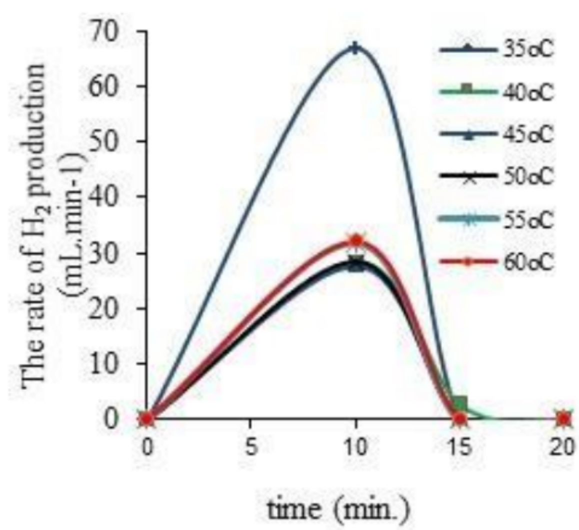

Figure 11. The rate of hydrogen production with KOH as catalyst at various temperature as function of time

Based on Figure 11, it can be seen that the rate of hydrogen gas production increases until the first 10 minutes and after 10 minutes it decreases. This condition shows that the effective reaction rate for hydrogen gas production with KOH occurs in the first 10 minutes. From Figure 11 can also be seen that the formation of hydrogen gas at a temperature of 35°C has the highest reaction rate compared to the reaction rate at other temperatures. This shows that the effective temperature occurs at 35°C with a volume of 670 mL and the reaction rate of 67 mL/minute within 10 minutes.

4. Conclusions

The production of hydrogen by the aluminum water method is one method that is quite effective and inexpensive. The effectiveness of the aluminum water reaction depends on the amount of water added, the mass of the activator and the size of the aluminum particles. In general, the more activators, hydrogen production increases, while the amount of water added must match the reaction stoichiometry.

5. Acknowledgements

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