International Journal of Smart Grid and Clean Energy

Design of hydrogen reactor based on decomposition of water by aluminum as an alternative to gas fuel

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Abstract

Hydrogen is the most abundant element in the universe which is a source of energy obtained through several processes, one of which is the decomposition of water by aluminum.This reaction aided by NaOH as a binder layer of aluminum oxide on the surface of the aluminum so that the aluminum dissolved with the solution. This study aims to design a hydrogen reactor with a semi-continuous flow system where this system can produce hydrogen gas by refilling aluminum and removing wasted periodically without affecting the hydrogen gas produced. Hydrogen gas produced by semi-continuous hydrogen reactors to be used as fuel in gas stoves, and compared to gas stoves fueled by LPG. The design of hydrogen reactors uses materials that are not affected by the corrosive of NaOH. The hydrogen reactor is consist of several main parts including the reactor made of glass, reservoir, inlet and bubbler made of PVC, and gas storage tubes with iron plate material. The reactor performance was tested by reacting two variations of materials including used aluminum cans and aluminum foil. The first testing using 30 grams of used aluminum cans produces hydrogen gas of 24 liters, while the second testing using 36.54 grams of aluminum foil produced of 49 liters of hydrogen gas. The power produced by hydrogen stove ranges from 1.02 - 1.11 kW with a maximum efficiency of 66.02%, while the LPG stove ranges from 1.18 - 1.27 kW with a maximum efficiency of 80.13%.

Keywords: Hydrogen reactor, semi-continuous flow system, decomposition of water, aluminum, stove

1. Introduction

Hydrogen is one of the most abundant elements with a percentage of 70% of the total elements of the universe and is usually found on earth in the form of water and hydrocarbons such as methane. Hydrogen gas is not available in nature in its pure form, but can be produced through several processes including electrolysis, steam methane reforming, biomass gasification, and others. Decomposition of water using metals is one method for producing hydrogen gas chemically by utilizing the corrosion reaction of several metals such as zinc, magnesium and aluminum in water so that the hydrogen element is separated from the oxygen element that binds it [1], [2].

Aluminum is the most common metal used in the water decomposition process because of its high availability and easy to recycle. The total hydrogen gas produced depends on the mass of aluminum used, where 1 kg of hydrogen gas requires 9 kg of pure aluminum [3], [4]. In previous studies, using aluminum waste as the main ingredient in the process of decomposition of water to produce hydrogen gas, where waste that has a high enough aluminum content can be used to produce hydrogen gas through the water decomposition process [5], [6], [7].

This study aims to design a reactor with a semi-continuous flow system where this system can produce hydrogen gas by refilling aluminum and periodic waste disposal, but it has no effect on the hydrogen gas produced.The system is close to the recommendations of research conducted by Ahmad, F. (2010) [8], which suggests to design a reactor with a continuous flow system that is able to produce hydrogen gas continuously as needed.

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* Manuscript received May 8, 2020; revised December 14, 2020.
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doi: 10.12720/sgce.10.1.8-20

The production of hydrogen gas is generally through several methods which in principle separate hydrogen from other elements in its compounds such as hydrocarbons and water. The production of hydrogen gas is currently dominated by natural gas raw material which is a non-renewable energy source, so that alternative methods are needed to produce hydrogen gas at a cost and scale of production that can compete with natural gas. One method used is the decomposition of water by aluminum.

This study was carried out based on previous study, where study on hydrogen gas about its potential as an alternative energy and its utilization are as follows. Duigou et al. (2005)[1], Wang et al. (2008) [9], Petrovic, and Thomas (2010) [3] conducted research on the production of hydrogen gas from the reaction between aluminum and water to determine the potential and feasibility of a long-term method. Ahmad, F. (2010) [8] designed the hydrogen requirement of the reaction of aluminum with water for fuel cells, investigated the parameters that affect the reaction and recommended to design a continuous flow reactor. Siregar (2010) [5] and Omran et al. (2011) [10] examined the production of hydrogen gas using aluminum beverage cans. Omran et al. (2011) [10] also designed a hydrogen reactor made from polyethylene which is used as an energy source for fuel cells. Kahar (2016) [11] conducted research on hydrogen gas obtained from the reaction between aluminum and water as fuel for a stove or burner. Kahar (2016) [11] also designed a hydrogen reactor to react aluminum foil.

This study aims to design a hydrogen reactor and gas storage based on recommendations from Siregar (2010) [5], ie the hydrogen gas produced can be used when needed. This study will analyze hydrogen gas produced from the decomposition reaction of water by aluminum so that it can be identified as an alternative fuel on a gas stove.

2. Methodology

The design of this reactor has main components namely reactors, reservoirs, and gas storage tubes. The reactor is where the reaction between aluminum and NaOH solution, with a semi-continuous hydrogen production system that requires the reactor to be easily removed and installed from the system. The reactor is also required to be able to withstand the corrosive nature of NaOH and the heat generated when the reaction occurs. In addition, to making it easier, simple materials are used but can function according to problems that will arise when producing hydrogen gas.

The reactor used was a glass drink bottle with a volume of 620 ml. The selection of beverage bottles as reactors is based on the type of material, which is glass that is not easily corroded and the nature of the glass which is able to withstand the heat from the reaction of aluminum with water. The glass bottle will be connected to a 1" pipe that has been heated before being installed at the mouth of the bottle. The pipe at the mouth of the bottle is then glued to the union socket with a 1" outer thread. The reactor design can be seen in Fig.1.

Reservoir is a storage area of NaOH solution which is a strong base, so material selection is prioritized for materials that are resistant to the corrosion properties of NaOH, and PVC is chosen as the reservoir material [12], [13]. PVC pipe is very suitable as a raw material for reservoirs because it has the shape of a tube with various sizes. The reservoir is connected to the inlet which is limited by a valve/ball valve which aims to keep the production of hydrogen gas water and hydrogen gas not flowing into the inlet. The reservoir is designed to be able to accommodate 2500 ml of water volume.

Fig. 1. Reactor design with union socket 1"

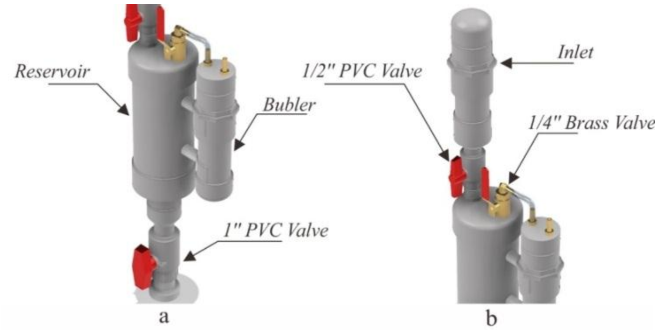


Fig. 2. Design of reservoir and bubler (a) and design of inlet (b).

At the inlet on the reservoir there is a lid and faucet which aims to enter the NaOH solution into the reservoir even though the reactor is reacting. The inlet is designed to minimize the incoming water so that hydrogen gas does not mix with water from outside. The bubler is designed to condense water vapor that is formed during the reaction and to be easily assembled at a reservoir and easy to replace water for condensation. The reservoir, bubler and inlet designs can be seen in Fig. 2.

Gas storage tube is a storage place for gas produced from hydrogen gas before the gas is used as fuel on the stove [14], [15]. The type of gas storage used is a floating tank that will float if filled with hydrogen gas. This gas storage tube has a volume indicator on the outside to find out the volume of gas produced, and there is a faucet to regulate the incoming gas flow and gas flow to be used. The design of hydrogen gas storage tubes can be seen in Fig. 3.

Hydrogen reactors are designed by combining all components, namely reactors, reservoirs, and gas storage tubes [16]. Combining these three components requires a brass hose and connector and several faucets so that the system runs according to the previous plan. This hydrogen reactor has a buffer to uphold all components, so the reaction process and data retrieval can be done easily. The overall design of this hydrogen reactor can be seen in Fig. 4.

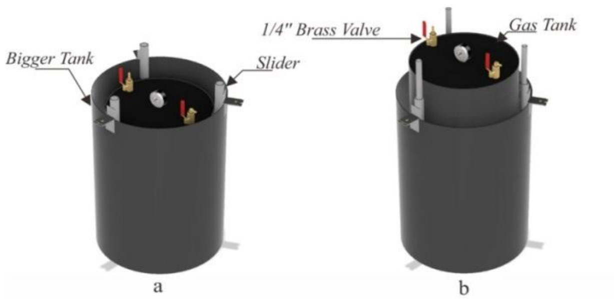


Fig. 3. Hydrogen gas storage tube design: (a) the tube sinks empty and (b) the tube floats when filled with gas.

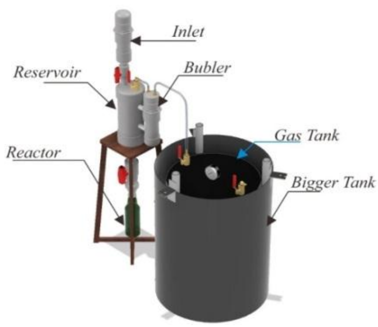


Fig. 4. All components of hydrogen reactor

The hydrogen reactor test was conducted to determine the feasibility of the condition of the reactor to be used. Reactor testing is divided into two tests namely functional testing and performance testing. The following of the testing process are:

2.1. Functional test

The hydrogen reactor functional test is a measurement process carried out to determine the condition of the reactor before the tool works. Functional tests carried out are leakage and connection strength tests on hydrogen reactors as well as on hoses and their connections. Leakage tests on hydrogen reactors can be carried out by applying air pressure using a compressor at the bubler output with all faucets open, then immersed in water and observed in the part or connection that is leaking. Pressure test on the hydrogen reactor is to determine the strength of each connection in the hydrogen reactor. If there is no leakage or loss of connection, it will be continued with the next test.

2.2. Performance test

Performance testing of the hydrogen reactor is divided into 2 steps, including testing and observing the reactor during action and testing with the Water Boiling Test.

- Test and Observation of Reactor

The reactor test was carried out by reacting 30 grams of used aluminum cans and 36.54 aluminum foil to the reactor with a volume of 2500 ml base solution with 1 M NaOH concentration. The reactor was tested while observing the temperature rise in the reactor and the volume of gas in the storage tube.

- Water Boiling Test

Water Boiling Test (WBT) is generally used to test the performance of the stove used. WBT test in this study aims to determine the ratio of time and volume/mass of fuel needed to heat 500 grams of water to the boiling point of water (100 ℃) using variations of hydrogen fuel and LPG fuel. The consumption of each fuel on the stove and the time ratio of the two fuels are used to find the required power or the value of the heat intake from the stove to heat the water to its boiling point. This test refers to research conducted by Sudano and Fadelan (2015) [17] to find heat intake from stoves SNI 7368: 2007.

Observation parameters in this study:

- Hydrogen Gas Discharge

Hydrogen gas discharge is the amount of hydrogen gas produced at any given time, hydrogen gas discharge can also be said to be the rate of hydrogen gas production obtained from the following equation:

$$Q = \frac{V}{t} \quad (1)$$

Where:

Q : discharge of hydrogen gas production (m^3/s)

t : hydrogen gas production time (s)

V : measured gas volume (m^3)

- Volume of Hydrogen Gas

The volume of hydrogen gas produced can be determined by observing the final result when the aluminum reacts. For the volume of hydrogen gas needed in the WBT test can be determined by calculation according to equation:

$$\Delta V = V_0 - V_1 \quad (2)$$

Where:

ΔV : volume of hydrogen gas used (m^3)

V_0 : hydrogen gas volume before testing (m^3)

V_1 : volume of hydrogen gas after testing (m^3)

- Power Needed to Heat Water

The power needed can be said as heat intake which is the capacity of a stove to transfer heat to the pan

which is directly proportional to the rate of fuel consumption. Stove power with variations of hydrogen and LPG fuels can be determined by using equations (3) and (4) [17], [18].
Power cookers use LPG fuel:

$$P = \frac{m_f \cdot LHV_{LPG}}{\Delta t} \tag{3}$$

Power cookers use hydrogen fuel:

$$P = \frac{V_f \cdot LHV_{H_2}}{\Delta t} \tag{4}$$

Where:

P	: Stove power (kW)
m_f	: Mass of LPG fuel used (kg)
LHV_{LPG}	: LPG net calorific value (46.28 MJ/kg)
V_f	: Volume of hydrogen gas used (m^3)
LHV_{H_2}	: Net calorific value of hydrogen gas (10.05 MJ/m^3)
Δt	: Time taken during reaction (s)

- The Efficiency of Stove

The efficiency of the stove can be calculated by comparing the energy used during the test with the energy absorbed to raise the temperature of the air during the test.
The efficiency of the stove uses LPG fuel:

$$\eta_{LPG} = \frac{m_w \cdot c_w \cdot \Delta T + m_u \cdot H}{m_f \cdot LHV_{LPG}} \times 100\% \tag{5}$$

The efficiency of the stove uses hydrogen fuel:

$$\eta_{H_2} = \frac{m_w \cdot c_w \cdot \Delta T + m_u \cdot H}{V_f \cdot LHV_{H_2}} \times 100\% \tag{6}$$

DWhere:

η_{LPG}	: Efficiency of LPG fuel stoves (%)
η_{H_2}	: Efficiency of H_2 fuel stoves (%)
m_w	: Mass of heated water (kg)
c_w	: Specific heat of water (kJ/kg ℃)
m_u	: The mass of steam produced (kg)
H	: Latent heat of water evaporates (2257 kJ/kg)
ΔT	: Increase the temperature of the water during the test (℃)

3. Results and Discussion

3.1. Hydrogen reactor manufacturing results

The hydrogen reactor is a reactor with a semi-continuous flow system with aluminum filling and regular disposal of waste, the resulting hydrogen gas can still be used even in the process of refilling aluminum into the reactor. The reactor that has been made is also resistant to the corrosive nature of NaOH solution which is a strong base and resistant to high temperatures when aluminum reacts with NaOH solution.The manufacturing process is carried out through stages that have been planned so that the manufacturing process becomes more efficient. The stages in the hydrogen reactor manufacturing process begin with the design, reactor manufacturing process, reservoirs, floating tanks, and gas stove modification processes.

The reactor is where the reaction between aluminum and NaOH solution takes place. The reactor was made by using a glass bottle with a volume of 620 ml, which was connected with a 1" PVC pipe that had been heated and glued together with clamps when the PVC pipe was hot and then the PVC pipe was glue with union socket 1". The glass material was chosen because it is resistant to corrosion and high temperatures, but it also can monitor the reaction of the formation of hydrogen gas. The reactor that has been made can be seen in Fig. 5

Reservoir is a place to contain NaOH solution that is used before reacting with aluminum. Reservoirs are made using 4", 2" and 1" PVC pipes, 4" end caps, 1" faucets and 4" × 2"and 2" × 1" reducers arranged according to the design that has been made. The 4" PVC has a length of 25 cm to be able to contain NaOH solutions up to 2500 ml.

The reservoir also has an inlet that is used to insert the NaOH solution into the reservoir. The inlet in this reservoir is made of a 2" PVC pipe which is connected at the top with a 2" deep drat socket and at the bottom connected with a 2" × 1/2" reducer. The inlet cover is made using a 2" outer thread socket connected to a 2" PVC end cap. At the bottom of the inlet there is also a 1/2" faucet that functions to regulate the NaOH solution when refilling. The faucet is connected with a 4" PVC end cap that has been perforated and glued to the socket 1/2" from the outside and inside. The output of hydrogen gas from the reservoir will be flowed to the bubler to condense the vapors formed during the reaction.

Fig. 5. The hydrogen reactor used glass bottle with a volume of 620 ml

The bubler is made using a 20" PVC pipe with a length of 20 cm with the bottom covered with an end cap, while the top of the pipe has a lid that can be disassembled like an inlet, but the bubler lid has been perforated with 2 holes and installed with a hose fitting with outer size measuring 1/4". In one of the holes that function as an inlet hole to the bubler there is a long hose until it reaches the bottom of the bubler, this aims to make the vapor carried with hydrogen gas directly condensed so that the hydrogen gas produced is not mixed with water vapor. The reservoir also has a buffer made of PVC pipe 1" along the length of 3 cm, and PVC pipe 2" longitudinally cut. Reservoirs, inlets and bublers that have been created can be seen in Fig. 6.

Hydrogen gas storage tanks of the floating tank type are made using 2 iron tubes with different diameters. A tube with a diameter of 50 cm serves to hold water, and a tube with a diameter of 40 cm functions as a gas storage tube. The gas storage cylinder is calibrated and a volume indicator is provided on the outside. The calibration process is carried out by inserting water into the tube every 1 liter, and marking any increase in water level as an indicator of the volume of the tube.

The floating tank system requires the tubes to float upright, so that in this design the tubes are supported like rails. This gas storage tube has 2 pieces of brass faucet measuring 1/4" as a regulator of gas entering and exiting the tube, this faucet will also be a regulator of the size of the fire on the gas stove. The hydrogen gas storage tube that has been made can be seen in Fig. 7.

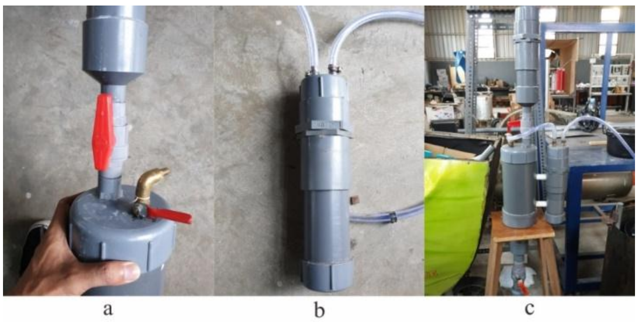


Fig. 6. Reservoir (a) inlet and outlet faucets; (b) bubler; (c) the reservoir has been assembled.

Fig. 7. Hydrogen gas storage tubes (a) the tubes sink empty; (b) the tube floats when filled with gas.

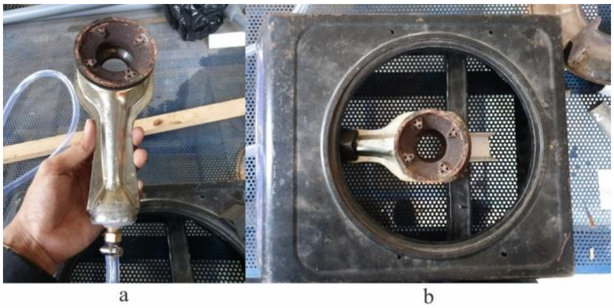


Fig. 8. Modified SNI 7368: 2007 stove, (a) burner modification, (b) modified stove.

The stove used is a gas stove SNI 7368:2007 which generally has a mixing chamber for gas and air that utilizes the Bernoulli principle. This stove has a nozzle that serves to change the high pressure on the gas cylinder into a high gas flow velocity so that the surrounding air is absorbed and mixed with fuel to the burner. This stove uses high gas pressure as fuel, because the pressure on the storage tube is not like the LPG gas tube, the gas stove SNI 7368: 2007 must be modified in order to work at low gas pressure. The modification process is removed the nozzle and connected the gas storage tube output hose directly to the burner. In addition, hydrogen gas is explosive when mixed with oxygen so that the stove modification also aims to make the process of mixing fuel with air occur outside the burner. Setting the rate of gas output or the size of the resulting flame can be controlled by adjusting the opening of the output valve on the gas storage tube.The results of the stove modification can be seen in Fig. 8.

3.2. Hydrogen reactor test results

The hydrogen reactor test was conducted to determine the performance of the design and manufacture of hydrogen reactors. Reactors with semi-continuous flow systems are tested through several steps of testing so that the testing process runs systematically and minimizes errors made during testing. Hydrogen reactor testing using used aluminum cans was carried out for 3 repetitions with different results. Before testing begins, the storage tube must be ensured immersed in water so that there is no water left in the gas storage tube.

The first test was carried out by reacting 30 grams of used aluminum beverage cans with a very long gas production rate, so data on gas production rate could not be retrieved due to time constraints. The final volume of hydrogen gas after more than 12 hours of reaction takes place and is read in a storage tube of 19 liters (a total of 24 liters if added to compressed gas). The results obtained are certainly very different from the calculations carried out in hopes of producing 40 liters of hydrogen gas. This is because the material used has a plastic layer on the inside and a layer of paint on the outside of the surface so that the surface area of the reacting aluminum is very small. This is proven by the results of the reaction in Fig. 9.

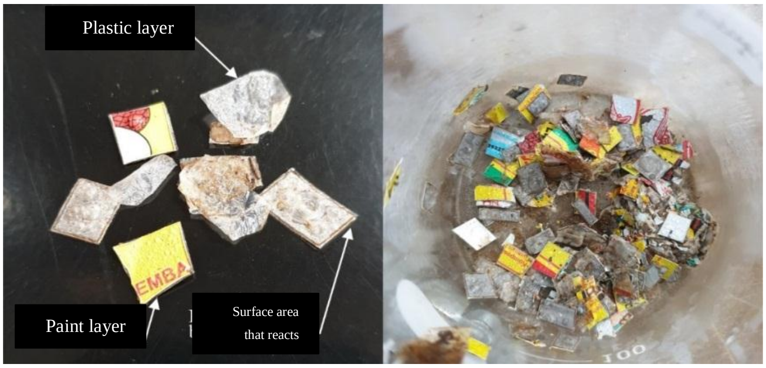


Fig. 9. Samples of used aluminum beverage cans that is not completely reacting

Table Hydrogen gas production results using used aluminum beverage cans

Tests	Initial Volume (L)	Final Volume (L)	Total Volume (L)
1	0	24	24
2	5	20	15
3	5	13	8

Fig. 9. shows that a layer of plastic and paint on both sides of the aluminum surface inhibits the reaction so that the rate of hydrogen gas production takes more than 12 hours and the final volume of hydrogen gas is still far from calculation because a lot of the remaining aluminum does not react until it runs out. Hydrogen gas in the first test is used to test gas stoves that have been modified so that it is known that the modified stove can be continued for the Water Boiling Test. Hydrogen gas in storage tubes is used until it is read on an indicator of 5 liters.

The second and third tests were also carried out by reacting 30 grams of used aluminum beverage cans and can be said to have the same problem, where the reaction occurred more than 12 hours so the reaction rate could not be measured due to time constraints. The final volume of hydrogen gas produced is presented in Table 1 with the assumption that in the first test the total volume is the volume read on the tube that is 19 liters and 5 liters of compressed gas is added. Hydrogen gas produced from the 2nd and 3rd tests is used for the water boiling test. The water boiling test must be in accordance with the volume of hydrogen gas available in the storage tube.

3.3. Aluminum foil testing results

Hydrogen reactor testing using aluminum foil is done only 1 time with the final result approaching the calculation. This test is planned to be able to produce 49 liters of hydrogen gas by reacting 36.54 grams of aluminum foil, 10 liters more than the calculation used to boil as much as 500 grams of water. Compared to testing using aluminum beverage cans, the rate of hydrogen gas production in this test is greater, so it can be noted the increase in the volume of gas produced every minute until the aluminum reacts. The measured volume before the reaction starts is 3 liters and the final volume recorded is 52 liters with a reaction time of 1 hour 25 minutes. An increase in the volume of hydrogen gas every minute can be seen in Fig. 10.

The rate of hydrogen gas production can be seen from the slope of the curve on the graph, where the steeper the slope of the curve displayed the greater the rate of hydrogen gas reaction, and vice versa. The high rate of hydrogen gas production is also accompanied by an increase in the reactor surface temperature measured by an infrared thermometer.

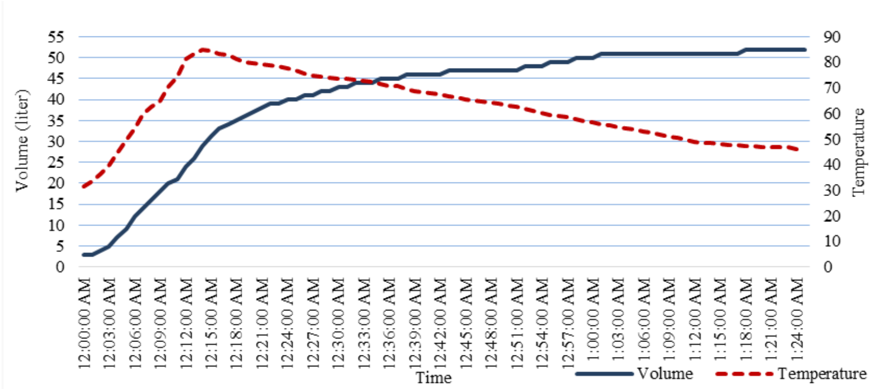


Fig. 10. Graph of hydrogen gas production and increase of reactor surface temperature when reaction using aluminum foil

The reaction between aluminum and NaOH solution causes an increase in the temperature of the NaOH solution in the reactor so that the reactor surface temperature also increases. This temperature increase indicates that the rate of hydrogen gas production runs up to the 14th minute with a temperature of 84.8 °C when the volume of gas produced was recorded 29 liters. The reactor surface temperature also decreases along with the decreasing rate of hydrogen gas production, it can be seen the volume curve on the sloping graphs as the reactor surface temperature curve decreases.

The higher hydrogen gas production rate affects the length of reaction required to react all aluminum material to produce hydrogen gas. The rate of production of hydrogen gas is also influenced by the molarity of NaOH solution where the higher the molarity of NaOH used, the reaction rate between aluminum and water to produce hydrogen gas increases[1], [10].

Ahmad (2010) [8] and Yavor et al. (2013) [19] showed that the surface area or size of aluminum affects the rate of hydrogen gas production where the surface area that reacts or the smaller the size of aluminum will increase the rate of hydrogen gas production. The smaller the size of aluminum used has a side effect that is the oxide layer on the surface of the aluminum is also getting bigger. Ahmad (2010) [8] in his research proved the side effect of the use of nano-sized aluminum powder that is the aluminum content that reacts with water about 60%, so that the total hydrogen gas produced also does not reach the theoretical calculation of the total mass of aluminum powder used.

3.4. Water boiling test result

Water boiling test is conducted to compare the power and efficiency of each stove with different fuels. The data needed to find the power produced by each stove is the rate of consumption of fuel used and the total time during testing, while the efficiency of the stove can be measured from the ratio between the energy absorbed by water with the total energy used in the stove to heat water.

Tests for hydrogen fuel stoves are carried out using hydrogen gas produced in the 2nd and 3rd tests using beverage cans and aluminum foil. Comparison of fuel used is portable LPG gas with a stove with SNI 7368: 2007 standard, the use of portable LPG cylinders is intended so that the mass of LPG gas used during testing can be known accurately by using digital scales with high accuracy so that it can know the total energy used. The results of this test can be seen in Table 2 and Table 3 below.

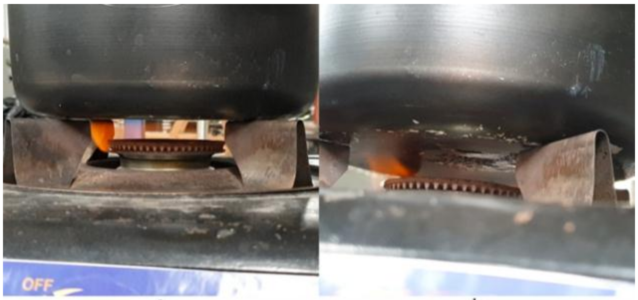
The flame produced by hydrogen gas in the burner is orange, it can not even be seen if in sufficient light conditions, the color of the flame produced is different from the flame of the LPG gas which is blue when it is completely burned. This is caused by several factors including the chemical nature of the type of gas or fuel used and the adequacy of oxygen in the combustion process that occurs. The process of burning hydrogen gas without emissions because the byproduct of combustion of hydrogen gas is water vapor, this is evidenced by the formation of water vapor at the bottom of the pan when testing the water boiling test. The color of the flame of hydrogen gas in the burner and water vapor from the combustion process of hydrogen gas can be seen in Fig. 11.

Table 2. Test result data using hydrogen gas fuel

No	Water Mass (g)	Δ T (℃)	Gas Used (l)	Time (s)	Steam Mass (g)	Discharge Gas (l/s)	Available Heat (kJ)	Absorbed Heat (kJ)	Stove Power (kW)	Efficiency (%)
1	500	35	15	142	7.5	0.10563	150.75	90.1475	1.06162	59.799
2	500	22	9	81	4.5	0.11111	90.45	56.1805	1.11667	62.112
3	500	67	46	453	73.5	0.10154	462.3	306.0535	1.02053	66.202

Table 3. Test result data using LPG gas fuel

No	Water Mass (g)	Δ T (℃)	Gas Used (l)	Time (s)	Steam Mass (g)	Discharge Gas (l/s)	Available Heat (kJ)	Absorbed Heat (kJ)	Stove Power (kW)	Efficiency (%)
1	500	71	7.9304	287	64.5	0.02763	367.01891	294.1085	1.27881	80.134
2	500	70	7.2711	283	53.5	0.02569	336.50650	267.1895	1.18907	79.401
3	500	71	7.8346	286	59	0.02739	362.58528	281.695	1.26778	77.690



a b

Fig. 11. Observation of hydrogen gas flames (a) color of hydrogen gas flame; (b) combustion water vapor.

3.5. Stove power and efficiency analysis

The power of the stove produced depends on the heating value of the fuel used, the greater the heating value of the fuel used, the greater the stove power. The power of the stove on the gas stove is also influenced by the rate of fuel consumption so that in this study the power generated is regulated based on the flow of gas used by opening the tap at certain openings in the hope that the gas flow rate used will be uniform in each repetition. Power of the stove with hydrogen fuel from each repetition is in the range of 1.02 - 1.11 kW, this value is smaller than the power generated by the stove using LPG gas fuel which is in the range of 1.18 - 1.27 kW. Comparison of the power generated from the two stoves in each repetition can be seen in Fig. 12.

The power generated by the stove also affects the rate of increase in water temperature when water boiling test. The higher the power produced by the stove, the rate of increase in water temperature is also greater because the energy absorbed by the water in the pan is also getting bigger every second. The effect of power on the rate of increase in water temperature is proven in Tables 2 and 3 where the total time needed to boil water up to 100 °C is less when using a stove with LPG fuel gas than hydrogen gas. It is important to note that the total time recorded in Tables 2 and 3 do not represent a temperature increase of up to 100 ℃, because the water boiling test is still being carried out even though the water temperature has shown 100 ℃ so that the evaporated water data obtained in the test.

In a previous study, testing hydrogen gas as a fuel in burners with a diameter variation of 2 mm; 3 mm; 4 mm, and produces power that is directly proportional to the diameter of the burner. The diameter of the burner affects the rate of fuel consumption so that the greater the diameter of the burner used, the greater the power generated.

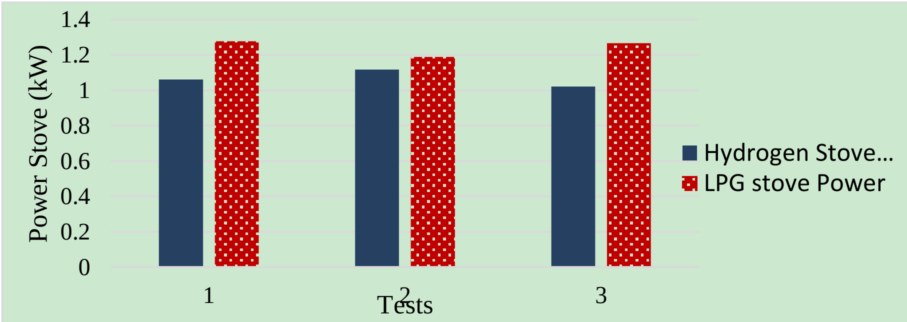


Fig. 12. The comparison of stove power with hydrogen and LPG fuels.

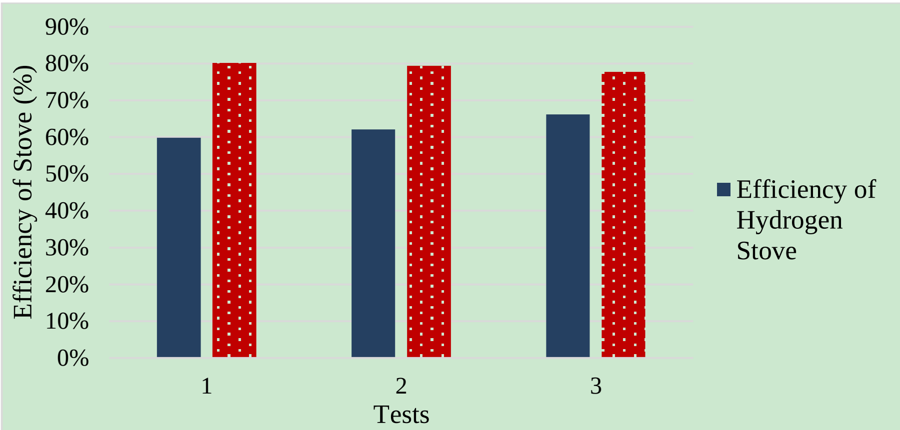


Fig. 13. The comparison of stove efficiency with hydrogen and LPG fuels.

The efficiency of the stove is the ratio of the energy released by the stove to the energy absorbed by the water in the pan during the test. The results of the comparison of the efficiency of hydrogen-fueled stoves with LPG fuels can be seen in Fig. 13.

Based on Fig. 13 it can be seen that the efficiency produced by LPG-fueled stoves is higher than that of hydrogen gas-fueled stoves. This can be influenced by the type of fuel used, the combustion process, the type of burner, and the state of the environment during testing. The combustion process on each stove is different, where the low-pressure hydrogen fuel stove is carried out without the process of mixing the fuel so that the combustion occurs outside the burner while the stove with LPG gas fuel uses the process of mixing fuel with air before burning outside the burner.

The type of burner used also affects the efficiency of the stove, whereas Sudarno and Fadelan (2015) [17] previously tested the efficiency of the stove by using the embers and without embers on the burner and comparing the efficiency produced by the stove. The use of 1 layer of embers in the burner can increase efficiency by 8.31% compared to the burner without using the embers, this is because the use of the embers can distribute the flame temperature evenly on the pan surface. Tests conducted in this study use two different stoves with different shapes and burner holes where the hydrogen-fueled stove has 4 points with 3 small holes at each point in the middle of the burner, while the LPG stove used has burner with 8 holes in the center which is located in a circle, so that the possibility of flame distribution on LPG stoves is greater than that of hydrogen stoves which results in greater efficiency on LPG stoves compared to hydrogen gas stoves.

4. Conclusion

The design of hydrogen reactor based on water decomposition by aluminum with a semi-continuous flow system has components consisting of reactors, reservoirs, inlets, bublers and gas storage tubes that are manually regulated through faucets in each component. Hydrogen reactor testing using the water boiling test method by reacting 30 grams of used aluminum beverage cans can produce a final volume of hydrogen gas is 19 liters (a total of 24 liters if added to compressed gas) after more than 12 hours of reaction. The test results are very different from the results of calculations that get 40 liters of hydrogen gas because the test material used has a plastic layer on the inside and a layer of paint on the outside surface so that the surface area of aluminum that reacts is very small which affects the reaction results. Testing a hydrogen reactor using aluminum foil can produce 49 liters of hydrogen gas by reacting 36.54 grams of aluminum foil. The rate of hydrogen gas production in testing using aluminum foil is greater than using used aluminum beverage cans. The high rate of hydrogen gas production is also accompanied by an increase in reactor surface temperatures. The reaction between aluminum and NaOH solution results in an increase in the temperature of the NaOH solution in the reactor so that the reactor surface temperature also increases. This temperature increase indicates that the rate of hydrogen gas production runs up to the 14th minute with a temperature of 84.8 °C when the volume of gas produced was recorded 29 liters. The rate of production of hydrogen gas is also influenced by the molarity of NaOH solution where the higher the molarity of NaOH used, the reaction rate between aluminum and water to produce hydrogen gas increases. The surface area or size of aluminum also affects the rate of hydrogen gas production, the smaller the size of aluminum or the surface area of aluminum will increase the rate of hydrogen gas production. The flame from the combustion process of hydrogen gas is orange, with a byproduct of the reaction in the form of water vapor. The combustion process of hydrogen gas is without emissions because the byproduct of combustion of hydrogen gas is water vapor. Hydrogen-fueled gas stoves produce power when testing ranging from 1.02 - 1.11 kW with a maximum efficiency of 66.02%, while stoves with LPG fuel gas produce power when testing ranging from 1.18 - 1.27 kW with efficiency a maximum of 80.13%.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

R.E.R. conducted the research, analized the data and co-wrote the paper and revised the paper; C,D analyzed the data; Y.H. conducted the research and analized the data; M.R.A. conducted the research, analized the data and wrote the paper.

Acknowledgements

The authors express our sincere thanks to the Renewable Energy Engineering Laboratorium, *Politeknik Negeri Jember* for the facility supports during the research.

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