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PERFORMANCE STUDY OF WOOD CHIPS GASIFICATION STOVE

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ABSTRACT

This research aims at investigating the performance of a gasification stove with wood-chips as fuel and recognizing the factors affecting. The stove consisted of a reactor, a char chamber, and a burner. The fuel was fed into the reactor with a certain amount of primary air was flowed through the bottom part of the reactor, and then was ignited from the topside of the fuel. Meanwhile, combustion zone move down and left char that would be taken out after the process finished. Combustible gases resulted from reactions flowed to the burner where the secondary air enters through holes located at burner side combusted the combustible gases. Water boiling test was conducted to measure the efficiency. The highest performance achieve was still relatively low (7.3 %), so that model design improvement is required. The stove performance could be possibly influenced by the following parameters, namely: combustion zone propagation rate, fuel consumption rate, and specific gasification rate, which all of them were very interrelated and indicated temperature stability that was proportional to the efficiency achieved. These were shown by stable water temperature profile obtained from boiling process during gasification. The more stable the process the higher the efficiency.

Keywords: Keywords: design, gasification, performance, stove, wood chips

INTRODUCTION

In the developing countries, Liquefied Petroleum Gas (LPG) has been generally used for household especially due to its advantages, such as: the easiness in operation and control as well as the clean flame. However, the increase in world oil price caused the increase in LPG price (IEA, 2019). Looking at the price and the availability of this unrenewable energy source, the alternative energy-based technology development would be a serious challenge to overcome the problem. Biomass as one of renewable energy sources, including all organic materials coming from trees, shrubs and algae is very appropriate to be chosen as alternative fuel due to its abundance. On the other hand, the resources has not been utilized maximally and efficiently (Panwar, Kaushik and Kothari, 2011). Even, appropriate design of machines specifically designed for distinct characteristics of them needs to be developed (Sutar *et al.*, 2015). Moreover, the efficiency achieved was still unsatisfactory (Ayoub and Brunet, 1996; Panwar and Rathore, 2008), so that intensive gasification research, through biomass stove design in order to reach equal performance as the LPG usage would be urgently needed.

Experiment of cooking stove was conducted by Suvarnakuta (2006) that using rice husk as fuel and achieved efficiency of 21.86 %. It was concluded that it was environmentally friendly with low operating cost and equal quality as that of LPG stove (Suvarnakuta and Suwannakuta, 2006).

Practical method for designing fluidized bed gasifier for rice husk has been developed by Ramirez et al. (2007) in order to give energy added value of farming solid waste. Reaction chamber of gasifier with Diameter of 0.3 m and height of 3 m produced power of 70 kW (Ramírez, Martínez and Petro, 2007).

Nwakaire and Ugwuishiwu (2015) conducted research at cross-draft type gasification stove. The stove used rice husk briquette and gained average efficiency of 21.10% (Nwakaire and Ugwuishiwu, 2015).

Therefore, the research aimed at investigating the performance of wood chips fueled stove and its influencing factors. Previously, many research related to gasification stoves has actually been conducted, however this research field deserves continuous development to gain the best design and optimum performance as well as environmentally-friendly.

RESEARCH METHOD

Reactions taking place in the reactor are as the following (McKendry, 2002; Kumar, Jones and Hanna, 2009; Situmorang *et al.*, 2020):

Partial oxidation: $C + \frac{1}{2} O_2 \leftrightarrow CO$

$dH = -268$ MJ/kg mol

Complete oxidation: $C + O_2 \leftrightarrow CO_2$

$dH = -406$ MJ/kg mol

Water-gas reaction: $C + H_2O \leftrightarrow CO + H_2$

$dH = +118$ MJ/kg mol

Heat reaction from the above process indicates that the most released energy are derived from complete oxidation of carbon to be carbon monoxide. Meanwhile, partial oxidation of carbon to be carbon monoxide released about 65% energy for complete oxidation. Unlike combustion which produce only hot gases, carbon monoxide, hydrogen and steam can undergo further reaction during gasification as the following (McKendry, 2002; Kumar, Jones and Hanna, 2009; Situmorang *et al.*, 2020):

Water-gas shift reaction:

$CO + H_2O \leftrightarrow CO_2 + H_2$

dH = - 42 MJ/kg mol

Methane formation:

$CO + 3H_2 \leftrightarrow CH_4 + H_2O$

dH = - 88 MJ/kg mol

Gasification produces mixing gas of carbon monoxide, carbon dioxide, methane, hydrogen, and steam.

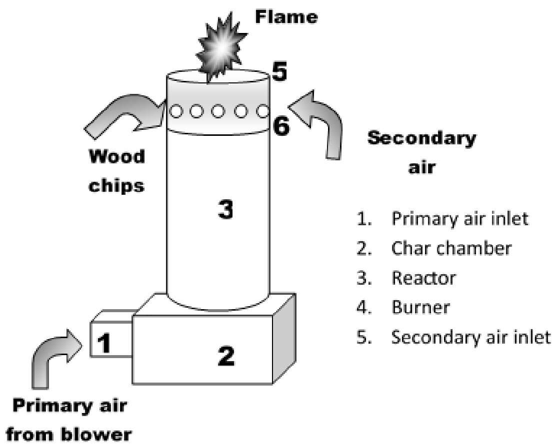

Figure 1. Schematic of Gasification Stove

The stove consisted of a reactor (diameter of 13 cm, height of 60 cm), a char chamber, and a burner. The wood chips as fuel was burned inside the reactor in a batch mode. The 0.9 kg of fuel was fed into the reactor with a certain amount of primary air was flowed by a blower through the bottom part of the reactor at speed of 1.0 m/s, and then was ignited from the topside of the fuel with aid of pieces of paper. Meanwhile, combustion zone move down and left char that would be taken out after the process finished. Combustible gases resulted from reactions flowed to the burner where the secondary air enters through holes located at burner side combusted the combustible gases.

Water boiling test was conducted to measure the efficiency by using the following equation (Belonio, 2005):

$$\eta_{th} = \frac{m_w . C_p . (T_b - T_i) + m_{evp} . L}{m_f . E_f} . 100\% \quad (1)$$

Where,

η_{th} = thermal efficiency

m_w = mass of water in the pot (kg)

m_{evp} = mass of water evaporated (kg)

C_p = specific heat of water (kJ.kg^{-1}.°C)

T_b = boiling temperature of water (°C)

T_i = initial temperature of water (°C)

E_f = calorific value of fuel (kJ.kg^{-1})

L = laten heat of evaporation (kJ.kg^{-1})

m_f = mass of fuel burnt (kg)

The water boiling test conducted, included pot, water, fuel (wood chips), weighing balance, thermometer, stopwatch, measuring cylinder, and lighter.

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RESULTS AND DISCUSSION

Based on the research conducted, several parameters were calculated to represent the stove performance, including: combustion zone rate, fuel consumption rate, specific gasification rate, water temperature profile, thermal efficiency and power output.

Combustion zone rate (CZR) is the time required for the combustion zone to move down the reactor. CZR is the ratio of length of the reactor (m) to the operating time (hour).

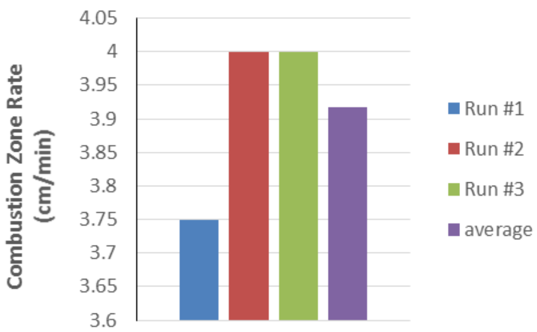

Figure 2. Combustion Zone Rate

As shown by Figure 2, the burning layer of the wood chips, or combustion zone, moved down the reactor at a rate of 3.75, 4.0, 4.0 cm/min for run #1, run #2, run #3, respectively. So, the average of the combustion zona rate was 3.92 cm/min. The difference in the combustion zone rate can be caused by the not-homogenous fuel particle size that build different particles configuration and pores size among particles so it will influence the ability of primary air in penetrating fuel column (Breault, 2010). This effected the propagations of fuel combustion zone rate.

Fuel consumption rate (FCR) is the amount of fuel used (kg) in operating the stove divided by the operating time (hour). As depicted by Figure 3, the amount of the wood chips used in operating the stove per hour were 3.37, 3.6, 3.6 kg/hour for run #1, run #2, run #3, respectively. So, the average of the fuel consumption rate was 3.53 kg/hour. Considering relatively different size of fuel particles, consequently fuel consumption rate as shown by Figure 3, is proportional to combustion zone rate which is shown by Figure 2.

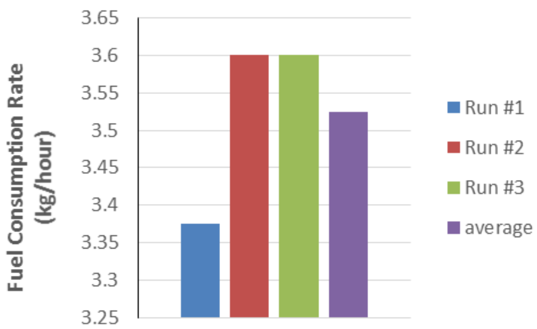

Figure 3. Fuel Consumption Rate

Specific gasification rate (SGR) is the amount of fuel used (kg) per unit time (hour) per unit area (m^2) of the reactor. Specific gasification rate as shown by Figure 4, is proportional to only fuel consumption rate which is shown by Figure 3. Figure 4 presents the specific gasification rate of the wood chips as 254.4, 271.36, 271.36 kg/m^2.hour for run #1, run #2, run #3, respectively. So, the average of the specific gasification rate was 265.71 kg/m^2.hour.

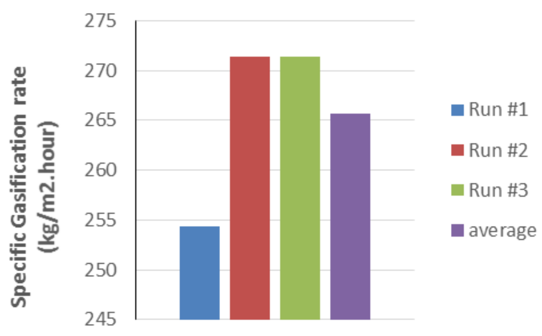

Figure 4. Specific Gasification Rate

It can be seen from Figure 5, that boiling time were 7.92, 7.62, and 7.55 minute for run #1, run #2, and run #3, respectively. So, the average boiling time was 7.69 minute. This time needed were almost similar with previous research conducted at around 7 minute for rice husk stove (PR *et al.*, 2017).

Figure 5 also illustrates that the operating time were 16, 15, and 15 minute for run #1, run #2, and run #3, respectively. So, the average operating time was 15.33 minute. As shown by Figure 5, water temperature profile reflected the stable gasification of wood chips.

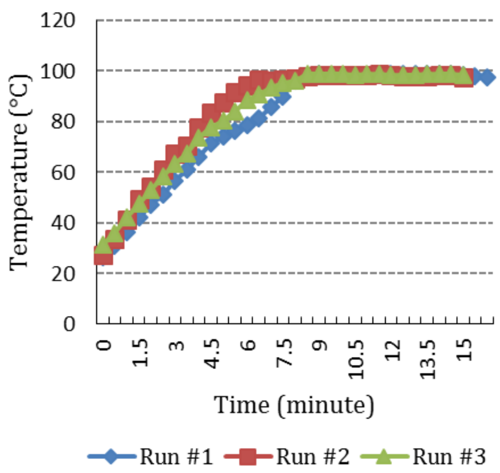

Figure 5. Water Temperature Profile

Thermal efficiency has a close relationship with water temperature profile. It is the ratio of heat consumed to the heat supplied (Nwakaire and Ugwuishiwu, 2015). Thermal efficiency values obtained in this experiment as presented in Figure 6 were 7.13, 7.34, and 7.22 % for run #1, run #2, run #3, respectively. So, the average of thermal efficiency obtained was 7.23 %.

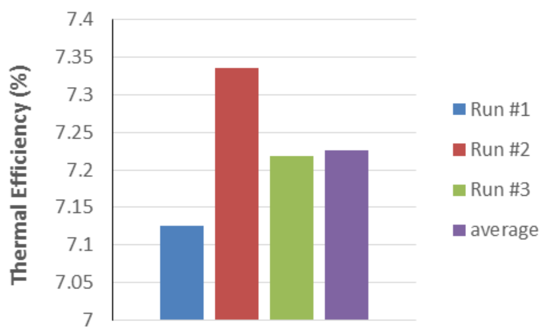

Figure 6. Thermal Efficiency

This lower efficiency was similar with the Patsari stove at high-power phase cold start. (Berrueta, Edwards and Masera, 2008).

The stove gained the average output power of 1.09 kW which was similar with the previous research conducted at wood gasification stove as 1.18 kW for force draft camping stove, 1.02 kW for double volume (pine), 1.11 kW for double volume (black wattle), (Kornelius *et al.*, 2013). Design improvements need to be continuously done to gain the best stove performance.

CONCLUSION

Based on the experiments, it can be concluded:

1. Stove performance with wood chips as fuel reach highest efficiency as 7.3 %. This low efficiency requires stove design improvements.
2. Factors affecting the stove performance comprised combustion zone rate, fuel consumption rate, and specific gasification rate are all interrelated and indicate the stable boiling temperature which linearly proportional to the efficiency.

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