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Effect of airflow rate and honeycomb channels addition on the efficiency of bagasse-fuelled top-lit updraft (TLUD) gasification stove

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Abstract

The use of Liquefied Petroleum Gas (LPG) fuels has increased over time and has triggered the innovation of renewable fuels that do not affect the environment. This renewable fuel is biomass. Biomass is derived from organic materials of plants or animals that can be used as fuel. The conversion of biomass into thermal energy using gasification stoves can increase thermal efficiency up to twice that of conventional biomass combustion. Common stoves that use nowadays is Top-Lit Updraft (TLUD) gasifier that easy to optimize. This type of gasifier has a simple design and can be fuelled with any type of biomass with a water composition of less than 20%. Gasification stoves have so far been developed using various biomass fuels, one of which is bagasse waste. Bagasse is also easy to obtain in Indonesia because it has an abundant number of quantities. In addition to the fuel aspect, the ability of the gasification stove to produce good thermal efficiency depends on the stove design, such as stove type, stove dimensions, and combustion airflow rate. It is tested with the water boiling test method using variations of airflow rate of 2 m/s, 3.5 m/s, 5 m/s, and 6.5 m/s and honeycomb channels addition. As a result, it reached 30% thermal efficiency.

***Keywords**: airflow rate; bagasse; biomass; honeycomb; TLUD*

1. Introduction

A stove is a result of technological development that results in flame for specific purposes. The experiment on the need for energy for fuelling stoves has varied and it has been experimented for the needs of society. Generally, people use liquified petroleum gas (LPG) fuelled stoves because they have several advantages. They are efficient, practical in operating, and produce no residual fuel. The use of fossil fuels for appliances and transportation has increased over time. This has triggered the innovation of renewable fuels, such as biomass, that do not affect the environment. Biomass resulted from organic materials, commonly from plants and animals, that can be used as fuel (1). Energy from biomass can be obtained by direct burning, gasification, or pyrolysis to produce gas or liquid fuels (2). The conversion of biomass into thermal energy using gasification stoves can increase thermal efficiency up to twice that of conventional biomass burning (3). The utilization of biomass has developed through several methods, one of which is gasification.

Gasification is a process in which solid materials are converted into gas in a high-temperature reactor. The solid material contains carbon, such as biomass or coal and produces carbon monoxide (CO), hydrogen (H_2), and methane gas (CH_4) (4). Gasification includes a thermochemical process, that the raw material heated at high temperatures produces gases. These gases encounter chemical reactions that it forms synthesis gas. (5). Stoves that use the principle of gasification have several types including top-lit updraft (TLUD) gasifier, fixed bed downdraft gasifier, fluidized bed reactor, and entrained flow gasifier. A type of gasification stove that is not difficult to optimise is the TLUD gasifier. It has a simple design and can be operated with any type of biomass fuel, which the water content of biomass is less than 20% (2). TLUD can burn biomass even though its moisture content reaches 60%, but it burns with low burning temperatures (6). However, TLUD gasification reactors have the disadvantage of being unable to be operated continuously (7).

To date, gasification stoves have been developed by utilizing biomass fuels in the operation. One of the biomasses used in this kind of stove is bagasse. Bagasse is abundant in Indonesia. Therefore, it is not difficult to obtain (8). In a sugar factory, sugar production can result in 35% to 40% of bagasse from the milling process (9). The moisture content of biomass fuel can influence its quality. The higher of biomass moisture content, the lower its quality and as a result, it will be more difficult to burn (10). Therefore, previous research has proven that the reduction of moisture content to 40% using drying technology increases the calorific value of bagasse up to 2305 kcal (11). Aside from fuel, a gasification stove with efficient thermal depends on the stove characteristics such as the stove type, dimensions, and burning airflow rate of the stove (12). According to the previous research on fuel variations for gasification stoves, bagasse resulted in the lowest flame time, but it has the highest flame height and boiling time. The best efficiency gasification stove with bagasse fuel is 5.68% with the additional device of fan with 1.5 m/s speed (13). Another previous research also used sugarcane bagasse to obtain 6.14% efficiency (14). These results of the research have weaknesses in burning residue. Bagasse fuel cannot be burned completely in all parts. Therefore, the burning process of bagasse fuel still results in partly carbon and ash.

Therefore, the author developed research on TLUD gasification stove with honeycomb channel assembled between the stove wall and the blower. It is fuelled with bagasse. The installation of a honeycomb channel in this stove is aimed at obtaining a uniform fluid flow (15). Based on previous research using variations in airspeed, the highest efficiency is at 3.5 m/s, which is 17.55% (16). This research also used variations in the airflow rate of 2 m/s, 3.5 m/s, 5 m/s, and 6.5 m/s generated by the blower. It was aimed at supplying oxygen in the reactor (17). This study used these variations in TLUD gasification stove with installed honeycomb channel and fuelled with bagasse to obtain a high efficiency. It was tested using the water boiling test (WBT) method and the characteristics of fire produced. These characteristics include flame duration and combustion chamber temperature.

2. METHODS

The effect of airflow rate and installed honeycomb channels on the efficiency of bagasse-fuelled TLUD gasification stove was tested in the Laboratory of Energy Conversion, Jember University, Indonesia. Four variations of airflow rate by blower (2 m/s; 3.5 m/s; 5 m/s; 6.5 m/s) and honeycomb channels were selected, and the samples were subjected to elemental analysis.

2.1 Material

Bagasse is the fuel material in this research. It was dried under the sun and was cut in the same size of + 5 cm without pressing it into briquettes. The energy resulting from burning wood is only 3300 kcal/g, while biochar or briquettes can reach 5000 kcal/g (18). Therefore, 500 grams of bagasse was put into the gasifier tube.

2.2 Equipment

This research used a TLUD gasification stove for the experiment. It is made of iron with 3 mm thickness and was installed with honeycomb channels as shown in Figure 1. It was set in varying airflow rates. The dimensions of this stove are 40 cm in height and 35 cm in diameter. The reactor is cylindrical with dimensions of 30 cm in height and 25 cm in diameter.

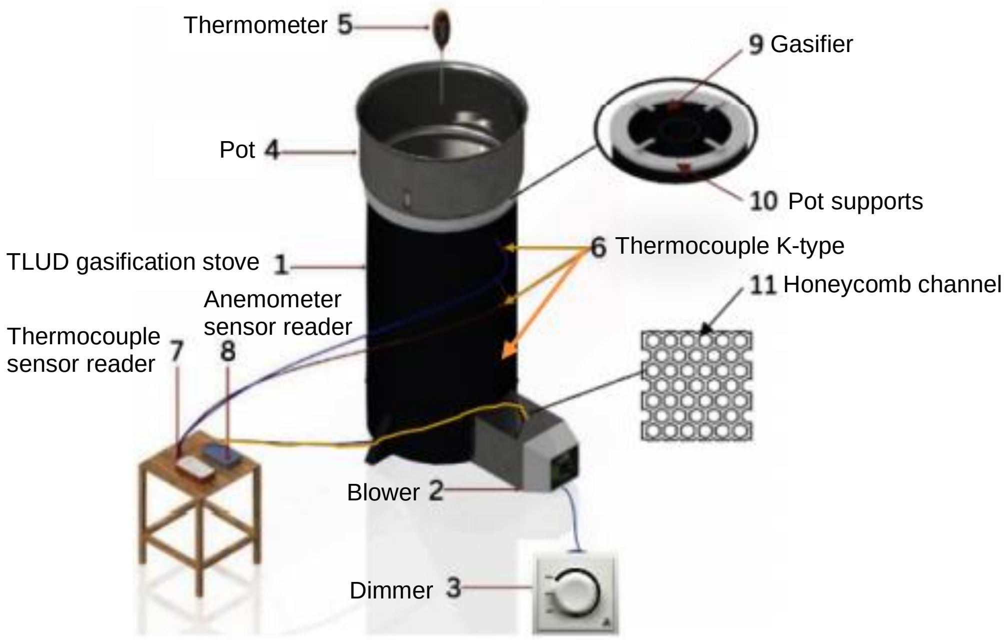

Figure 1. The stove installation

The first procedure of this research was filling the gasifier tube with 500 grams of bagasse and preparing 1 Liter of water in the pot. Secondly, the process of gasification was started by burning the surface of the bagasse on the gasifier using the lighter. Following this process, the blower was turned on. After the gasification process began, the temperature at the burner was measured using a thermocouple (19), while the time process was noted using a stopwatch. The steps were conducted repeatedly with a time of one minute until the fire completely stopped.

3. Result and Discussion

The results of the performance test on the TLUD gasification stove were obtained. The stove was installed with honeycomb channels and fuelled with bagasse during the testing process. There were five parameters used in this test to collect the data. These parameters include flame duration, burning chamber temperature, water boiling time, char mass, and thermal efficiency. This test was also conducted by boiling the water to 90°C.

3.1 Flame Duration

The measurement of flame duration for the flame test was conducted by observing the flame time from when the bagasse was fired up until it was completely burned out. The time was observed by using a stopwatch. This test was conducted by comparing the airflow rates with the use of honeycomb channels and without it. After testing, the flame duration in the two variables decreased as the airflow rate increased. Figure 2 shows that the longest flame at an airflow rate of 2 m/s, which is 12 minutes 2 seconds on the use of honeycomb channels and 10 minutes 20 seconds without the use of honeycomb channels. This is because the higher the airflow velocity given, the shorter the flame length.

The greater the air flow rate, the greater the transfer of energy through heat in the process of operating a biomass stove so that the length of the flame is shorter (20). The longest flame is obtained with the use of a honeycomb channel, which is 12 minutes 2 seconds because the air produced by the blower flows more directionally than without a honeycomb channel. The use of honeycomb makes the air uniform and stable (15).

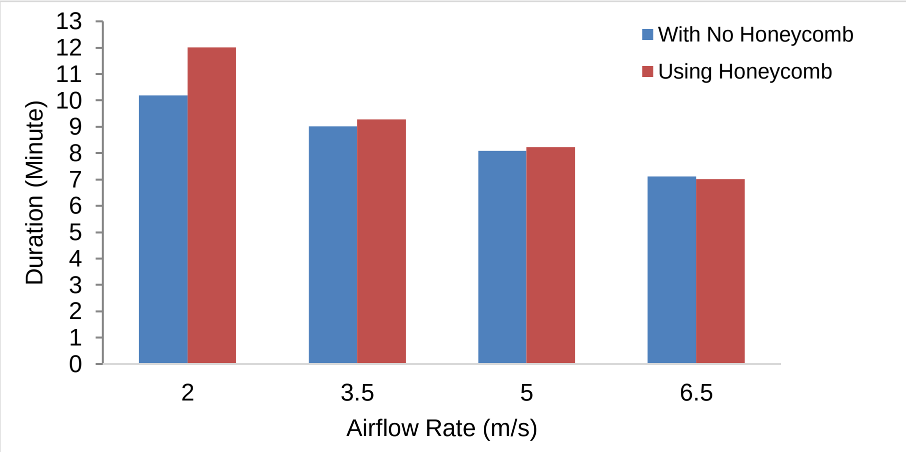

Figure 2. The results of flame duration test

3.2 Burning Chamber Temperature

This test was conducted using a thermocouple read by a datalogger at three points (T1, T2, and T3) as shown in Figure 3. T1 is 8 cm away at each point vertically. The data is the result of the initial ignition of the fire until the fire is completely extinguished with an interval of one minute.

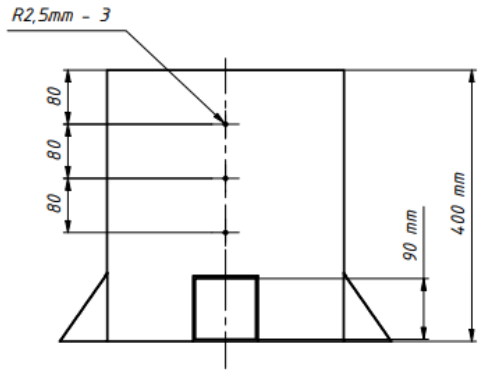

Figure 3. Combustion chamber temperature test points (T1, T2, and T3)

3.2.1 Burning chamber Temperature without Honeycomb Channels

The result of temperature test for burning chamber without honeycomb channel is presented in Figure 4.

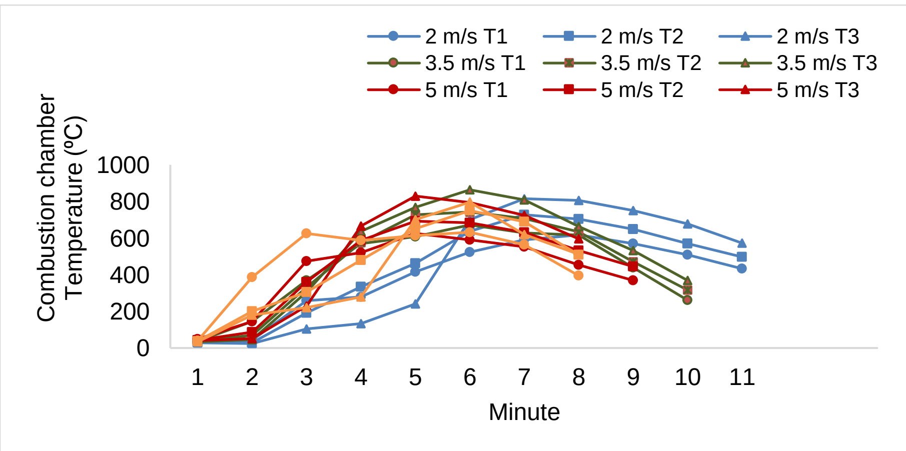

Figure 4. Combustion chamber temperature without honeycomb channels test results

Figure 4 shows a comparison graph of combustion chamber temperatures (T1, T2, and T3) without using honeycomb at airflow rate of 2 m/s; 3.5 m/s; 5 m/s; and 6.5 m/s. From Figure 4, it is known that the longest effective flame is using an airflow rate of 2 m/s for 10 minutes 32 seconds. The highest combustion chamber temperature is at T3 airflow rate 3.5 m/s of 863.7^{0}C in the 6th minute. Comparison of test data displayed on the graph shows that the temperature produced without *honeycomb* variation is irregular because the air is not well distributed in the reactor. This is in accordance with the statement that the presence of turbulence causes the research results to be less accurate (19).

3.2.2 Combustion chamber Temperature Using Honeycomb Channels

Combustion chamber temperature testing using honeycomb is conducted to improve the results of variations without honeycomb in order to obtain good results. The results of this test are shown in Figure 5 below.

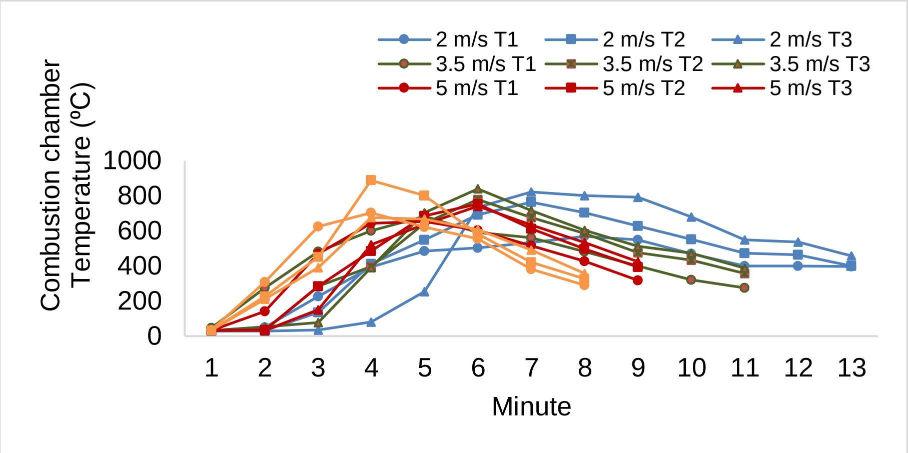

Figure 5. Graph of combustion chamber temperature using honeycomb channels test results

Figure 5 above shows the longest effective flame is obtained at an airflow rate of 2 m/s which is for 12 minutes 2 seconds. The highest combustion chamber temperature of the reactor is using an airflow rate of 6.5 m/s, at T2 and 4th minute is 887.6^{0}C. From the test results obtained in the test, it shows that the greater the airflow rate, the greater the combustion chamber temperature in the reactor. The addition of airflow rate to the reactor will reach the highest flame temperature more quickly due to increased air *supply*. The higher the air speed, the amount of oxygen used for combustion in the oxidation area also increases (20).

3.3 Water Boiling Time

This test was conducted using the Water Boiling Test method using a stopwatch which is measured from the initial startup time until the water temperature reaches 90˚C. According to the research that has been done, the variation of the honeycomb channel gets a faster time than without honeycomb with a time range of 1 minute 56 seconds to 3 minutes 24 seconds, while the fastest time obtained without honeycomb is only 2 minutes 57 seconds which can be seen in Figure 6 below.

The best results obtained were 1 minute 56 seconds at an airflow rate of 6.5 m/s using honeycomb. This is because the higher the air supply in the reactor, the higher the combustion temperature so that the water boiling time is faster. The heat transfer rate shows the ability of the stove to increase the temperature and evaporate the water boiled during the stove test time. The higher the speed of the air flow given, the greater the transfer of energy through heat in the process of operating the stove so that the time to boil water is faster (2).

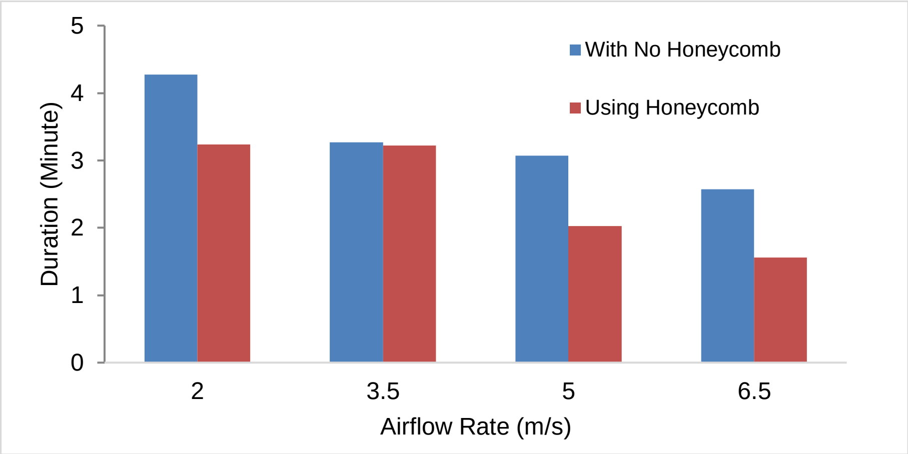

Figure 6. The results of water boiling time

In addition, the use of honeycomb also affects airflow through reducing turbulence so that the air supply in the reactor is getting better. Less turbulence will produce good airflow (15).

3.4 Char Mass

Testing the mass of char from burning TLUD stove fuel was conducted using a digital scale.

The highest char mass in the TLUD stove fuel combustion test with honeycomb channels through mass measurement using a digital scale in Figure 7 was obtained 12.6 grams with an airflow rate of 2 m/s and the smallest 9.5 grams with an airflow rate of 6.5 m/s. Meanwhile, without the use of honeycomb channels, the mass of char tends to be less, which is 9.2 grams at 6.5 m/s to 11.6 grams at 2 m/s. The data shows that the higher the airflow rate, the smaller the mass of char produced. Due to the small fuel consumption and the operating time of the stove which does not require a long time so that the char produced is less (20). The use of honeycomb which stabilizes the air affects the longer flame time so that more char is produced.

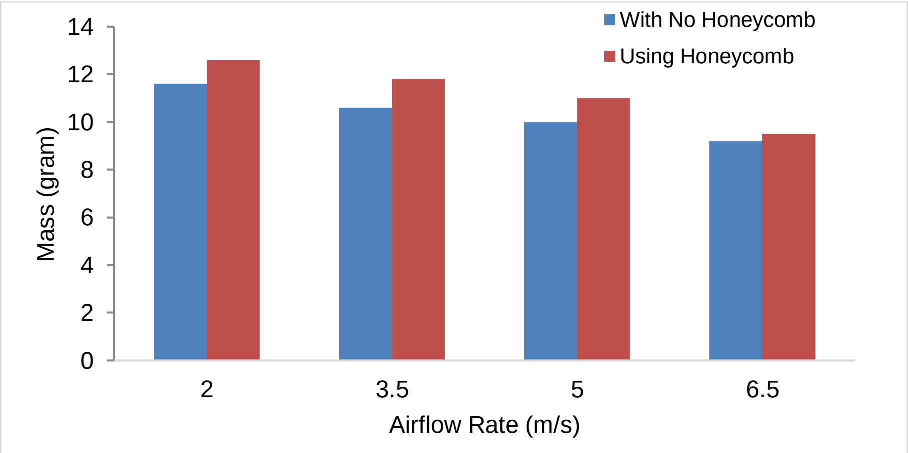

Figure 7. The results of char mass test

3.5 Thermal Efficiency

TLUD stove efficiency or thermal efficiency is the ratio of the heat produced by bagasse fuel to the heat received by water to raise its temperature and then evaporate it (20). A calculation of the thermal efficiency of the TLUD gasification stove using equation 1 below and the result shows in Figure 8.

$$\eta = \frac{(m_a.C_p.\Delta T)+(\Delta m_a L)}{\Delta m_k.LHV} \times 100\% \quad (1)$$

Where η is thermal efficiency, m_a is mass of water, Cp is specific heat of water, ΔT is change in temperature, Δm_a is mass of evaporated water, L is heat of evaporation of water, Δm_k is mass of fuel that has been burned, and LHV is calorific value of bagasse.

Figure 8 shows the comparison of efficiency in each variation with each airflow rate. The efficiency of the stove is influenced by the heat rate which is aligned with the time to boil water. Without the use of honeycomb, the lowest efficiency was obtained at an airflow rate of 2 m/s by 5.1% and the highest was 25.1% at an airflow rate of 6.5%. The honeycomb variation produced the highest efficiency among all experiments, which was 30% at an airflow rate of 6.5 m/s.

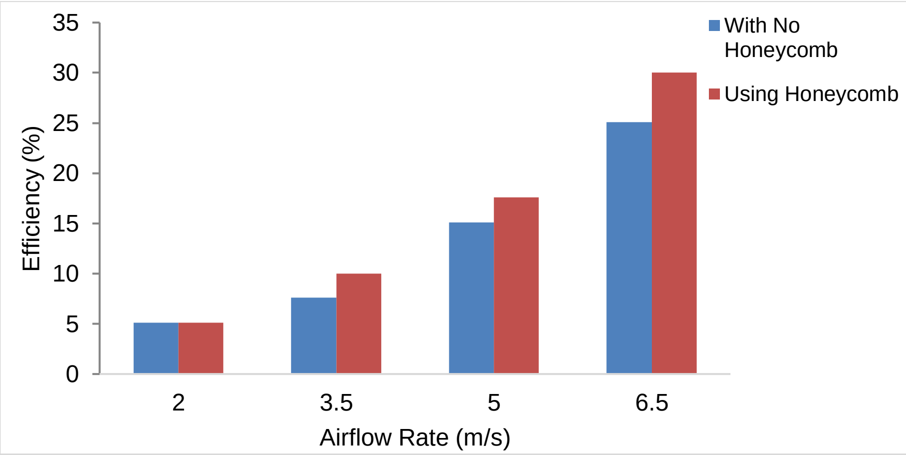

Figure 8. The result of efficiency test

The air flow passing through the *honeycomb* channel will distribute uniform air in the reactor so that the performance of the stove will increase and produce better *thermal* efficiency. This is also influenced by the greater the airflow rate, the greater the air *supply* and heat rate. high and the efficiency of the stove is getting better. The higher the heat rate, the higher the efficiency (20).

4. CONCLUSION

The use of *honeycomb* channels gets the longest flame, which is 12 minutes 2 seconds at 2 m/s and at an airflow rate of 6.5 m/s obtains the highest temperature of 887.6^{0}C, the boiling time of water is only 1 minute 56 seconds, the mass of *char is* 9.2 grams, and the efficiency reaches 30%. The higher air flow rate, the higher the combustion chamber temperature so that the flame duration is shorter; *The honeycomb* channels make the air more stable, resulting in higher efficiency.

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