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THE EFFECT OF SECONDARY HOLE VARIATION ON THE PERFORMANCE OF CONCENTRIC CYLINDER TOP-LIT UP DRAFT GASIFIER (TLUD) STOVE

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Abstract: The Bagasse is one of the fuels that can be used as biomass fuel in micro-gasification because the fuel is abundant. Bagasse is a by-product of the sugar industry which can be used as a biomass fuel for micro-gasification in Indonesia because of its abundance. Gasification is a process of converting biomass fuel into syngas fuel that occurs in the gasifier. This research was conducted to determine the effect of secondary orifice variations on the TLUD Concentric Cylinder Type gasification stove on flame length, flame temperature, fuel efflux rate and thermal efficiency with secondary orifice variations; 30, 40, and 50. The test was carried out using the water boiling test method. The results showed that the stove with 50 secondary holes produced the highest flame temperature at T2 (the temperature at the top of the TLUD stove gasifier) of 653.3 °C, the best flame duration was 14.15 minute, the highest burning rate was 0.88 gr/s. The highest thermal efficiency value was achieved by a stove with a secondary 50 exhaust hole of 67%. Based on the tests, it shows that the variation of the furnace hole affects the flame temperature, flame duration, combustion rate and thermal efficiency.

Keywords : Gasification, TLUD, Stove, Biomass, Bagasse

1. INTRODUCTION

Indonesia is a country with the fourth largest population in the world. According to the Central Statistics Agency (BPS) in 2020 there will be 270 million people. Indonesia's population growth increased by 1.4% per year. Meanwhile, energy demand increases by around 2.8% per year. The more people there are, the more energy is needed. Liquified Petroleum Gas (LPG) is one of the most widely used energy today. Due to the increasing need for LPG, the government seeks to fulfil this need by importing LPG. According to Bappenas, the need for LPG has increased by approximately 5,07% every year since 2015. According to the Ministry of Energy and Mineral Resources, natural gas reserves in Indonesia in 2019 were 27,55 Trillion Square Cubic Feet (TSCF) and in 2020 it has decreased by 18,82 TSCF [1]. Based on these data, there is a need for alternative energy as an environmentally friendly fuel to replace fossil fuels. One alternative energy that can replace fossil fuels is biomass fuel. Biomass is organic material produced through the process of photosynthesis, both in the form of products and waste (Parinduri, 2020) [2]. One of the bio-mass is bagasse. According to the Ministry of

Agriculture, in 2021 the province of East Java will produce the most sugarcane with a total production of 1.132.963 tons [3].

Gasification is a thermo-chemical process that converts solid fuel into gas, where the amount of air required is less than the traditional combustion process. Gasification is a process that occurs in a device called a gasifier, where solid fuel such as biomass is introduced into the reactor to undergo partial combustion. This process involves a reaction between oxygen and solid fuel, but the combustion is not complete. Gasification aims to convert liquid or solid fuel into flammable gas using a reactor called a gasifier where the biomass fuel is converted into syngas which mainly contains carbon monoxide (CO), carbon dioxide (CO2), hydrogen (H2), water vapor (H2O) and methane (CH4) [4] [5].

The gas produced during gasification is called biogas, producer gas or syngas [6]. The gasification process consists of four stages that take place in the gasifier, namely drying, pyrolysis, partial combustion (oxidation), and reduction [7][8].

Micro gasification is the gasification of biomass in a small device such as a TLUD gasification furnace. If the air is well mixed with combustible gases, the biomass will burn cleaner. The Top Lit Up Draft (TLUD) stove was developed in the 1990s by Thomas B. Reed and Norwegian architect Paal Wendelbo. This stove is a stove that is used to make biochar and heated for cooking [9]. Research on TLUD gasification stoves conducted by Saputro (2017) [10]. Pambudi et al (2019) [11] shows that the greater the secondary airflow in the combustion chamber, the greater the temperature of the combustion flame, but if the secondary airflow in the combustion chamber is too large, the temperature the burning flame will decrease and the boiling time of water will be longer. TLUD stoves also have high thermal efficiency, research by Anggara et al (2019) [12], Sunarya, R., Zulfansyah, and S. Helianti (2012) [13], and Digdo et al (2022) [14] produces stoves TLUD with a thermal efficiency of 13.55%, 31.00% and 42.95% respectively and this thermal efficiency value can still be increased.

Increasing the thermal efficiency can be done by varying the geometry of the combustion chamber of the TLUD stove and the number of secondary airflow holes in the combustion chamber. This research was conducted to determine the effect of the combustion chamber of the Concentric Cylinder type TLUD stove and the variation of the number of secondary air flow holes in the combustion chamber on the flame duration, flame temperature, water boiling time and combustion rate. So that it can produce a higher thermal efficiency.

2. MATERIALS AND METHODS

This research method was by observing fire characteristics such as flame time, fire temperature, weight of char, weight of fuel, and by observing the time of boiling water and the increase in water temperature using the water boiling test (WBT) method. This type of research was research with experiments conducted at the Energy Conversion Laboratory at the University of Jember and data analysis by observing the resulting graphs. The following is a schematic of a TLUD gasification stove his section is related to methods used for conducting research. It is obligatory to cite the author of the applied method.

2.1 Materials

In this study used materials and equipment for the gasification process as follows:

a. Aluminum for making TLUD stoves

b. bagasse with a dryness level of 10%
c. type k thermocouple thermometer
d. thermoreader with 0.1 0 C degrees accuracy.
e. exhaust fans with a power of 25 watts
f. mass scales with 0.5 gram degrees accuracy
g. anemometer with 0.1 meter/second accuracy

2.2 TLUD Stove Design

The design of the TLUD gasification stove used is made of aluminum, 0.2 cm thick, 60 cm high and 26 cm in diameter. The reactor on the gasification stove has a diameter of 20 cm and a height of 35 cm and there is a pipe in the middle of the reactor with a diameter of 5 cm and a length of 35 cm. So that the TLUD gasification stove reactor is of the Concentric Cylinder type. The pipe has a hole as a way to enter the secondary hole which is located at the top of the pipe with a total of 30 holes arranged in 3 levels, each level has 10 holes. On the outside of the rector, there are 40 holes for primary air inlet located below the reactor, and 30 holes on the top of the reactor for secondary air inlet. At the bottom of the pipe there is a primary air inlet with the same conditions as the secondary. Each hole has a diameter equal to 0.3 cm. The scheme of this study is shown in Figure 1 and the design of the concentric cylinder type TLUD gasification stove combustion chamber is shown in Figure 2.

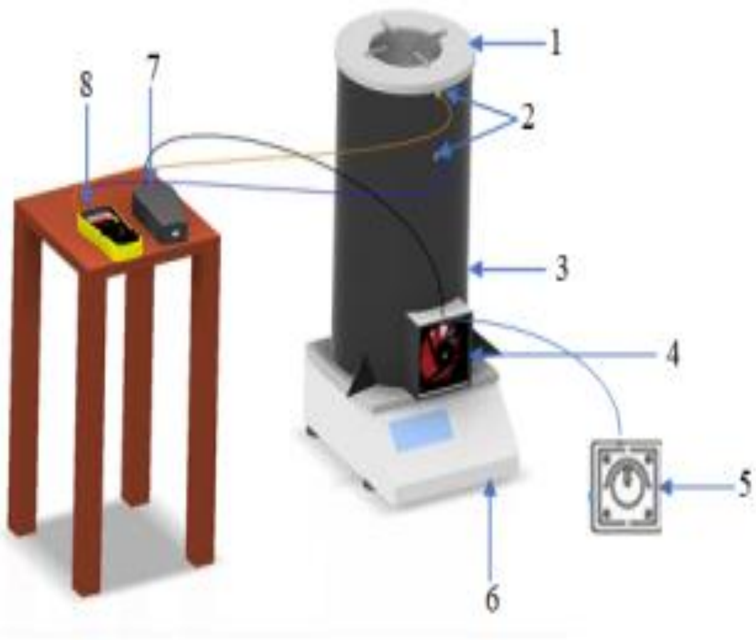

Fig. 1. Gasification stove components

Caption :

No	component name
1	close the stove
2	thermocouples
3	combustion chamber
4	fan
5	current regulator
6	mass balance
7	anemometer
8	thermoreader

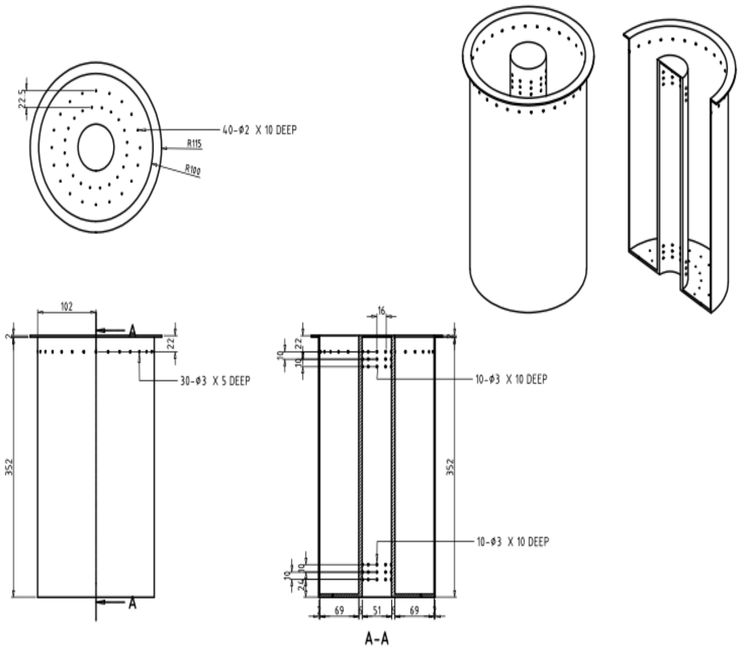

Fig. 2. Combustion chamber

2.3 Experimental Setup

This study used 500 grams of bagasse as fuel with three tests and the air supply came from a fan with a speed of 1 m/s. Tests to measure the temperature of the flame on a TLUD gasification stove are carried out with 3 (three) thermocouples. The first point (T1) Place a distance of 5.2 cm from the top of the stove, the second point (T2) is located 8 cm above the first point vertically and the third point (T3) is 14 cm from T2. Flame temperature measurements at the three points are carried out every 30 (thirty) seconds with 500 grams of fuel until the fire is extinguished.

Testing the measurement of the combustion rate is carried out by recording fuel weight data every 30 (thirty) seconds, the measurement starts at the beginning of combustion, namely the fire ignites until the end of combustion, namely the fire goes out. The fuel burning rate is the combustion rate required to burn the fuel, the formula used to calculate the fuel burning rate is as follows:

$$Burn\ rate\ = \frac{Mbb_a - Mbb_b}{t} \quad (1)$$

Where :
Mbb_a : Initial fuel mass (grams)
Mbb_b : Final fuel mass (grams)
t : Time (seconds)

Measurement of the amount of biochar produced to test the weight of the biochar produced in the combustion process is carried out by weighing the weight of the biochar which has been separated from the ashes at the end of the combustion process using a digital scale.

2.4 Characteristics

This study used the water boiling test method (WBT), WBT is a process of testing water evaporation to perform thermal efficiency analysis calculations [15]. Measurements were made to determine the amount of fuel and water used during the combustion process. During this process, observations were made of flame time, flame temperature, fuel rate, water boiling time, and biochar weight. Calculation of thermal efficiency according to the definition set by BSNI (2013) [16] and Saravanakumar, A (2007) [17] as follows:

$$\eta t = \frac{ma \times Cp \times \Delta T + \Delta mb \times L}{\Delta mk \times LHV} \times 100\% \quad (2)$$

Where :
ηt = Thermal efficiency (%)

ma = Mass of water (kg)

Cp = Specific heat of water (1 cal/kg °C)

ΔT = Temperature difference (°C)

Δmb = Evaporated mass of water (kg)

L = Heat of vaporization of water (2.268.000 J/kg)

Δmk = Mass of fuel that has been burned (kg)

LHV = Calorific value of fuel (1825 cal/gr)

3. Results And Discussion

3.1. Fire Temperature

a. Temperature of flame without boiling water

The figure of temperature flame without cooking water can be seen in Figure 3.

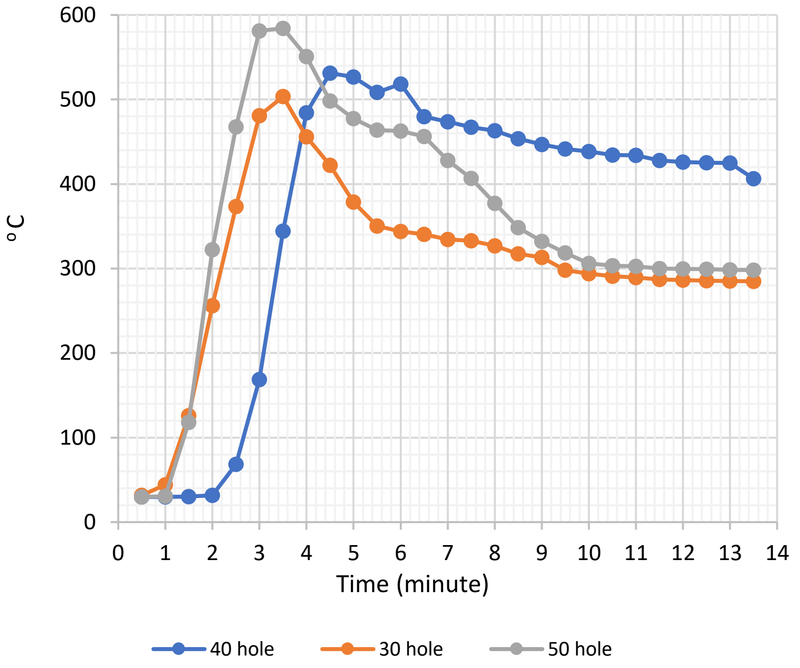

Fig. 3. The temperature of flame without boiling water

Figure 3 shows a graph of the temperature of flame at thermocouples (T2) without boiling water. Variation of secondary holes 30 holes with the highest temperature 503,50 °C. in the variation of 40 holes the highest temperature is 531,27°C and when the variation is 50 holes the highest temperature is 584,33°C. The effect of the amount of secondary air flow on the burner on the combustion flame temperature is very significant. The amount of secondary air flow through the 50 holes is more than the number of secondary air flows through the 40 holes and 30 holes. So that the more the number of secondary air flows, the more fuel will be burned, so that the higher the temperature of the resulting combustion fire [10]. As shown in the flame temperature graph line in Figure 3. When the stove is turned on, the temperature increases until it reaches the highest point and then decreases. This happens because at the beginning of combustion, the fire begins to spread throughout the fuel so that the flame temperature increases, and after reaching the highest peak flame temperature, the graph line becomes smaller because the fuel is almost completely burned so the flame gets smaller and the flame temperature begins to fall. The phenomenon in this research is as produced by research conducted by Saputro (2017) [10].

b. Temperature of flame by boiling water

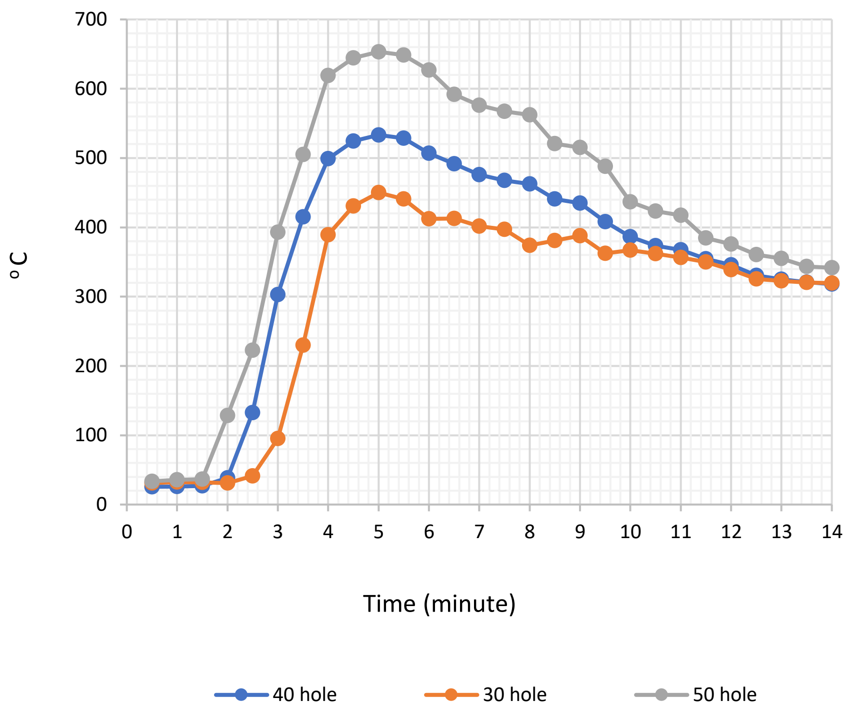

Fig. 4. The temperature of flame by boiling water

Figure 4 shows a graph of the flame temperature increase at T2 with water cooking treatment. At hole 30 the highest temperature was recorded at 450.00 °C, at hole 40 the highest temperature was 533°C, and at hole 50 the highest temperature was 653.3°C. As in the experiment without boiling water, the TLUD stove with a variation of the number of secondary holes of 50, produced the highest temperature value, so that it can be said that the effect of the number of secondary air flow holes on the burner on the temperature of the combustion flame is very significant. The more secondary air flow on the burner, the higher the resulting combustion flame temperature [10]. In addition to the amount of secondary airflow, the amount of primary airflow that enters the combustion chamber is also proportional to the flame that comes out of the stove (Tryner et al., 2016)[18]. Most gasifier stoves, such as TLUDs, rely on secondary air to burn the gas produced in the pyrolysis zone. Too little secondary air keeps the pyrolysis gas from burning. Too much secondary air cools the pyrolysis gas, results in an unstable flame and lowers efficiency [19]. So for, a TLUD stove design, the combination of the number of holes on the secondary and primary air ducts must be considered in order to produce optimal efficiency values. This study produced a higher temperature (653.3°C) higher than that produced by Prayogi (2022) [20] which produced a highest temperature of 593.98°C. This is due to differences in the number of secondary holes, air supply and moisture content contained in the bagasse used. The moisture content of the material, the level of density of the material, the number of holes and the air supply can affect the combustion process in the LTUD stove combustion chamber so that it affects the resulting fire temperature value. However, this fire temperature value is lower than the results of the research by Digdo Listyadi Setyawan et al (2022) [14] where the LTUD gasification stove with a 15 cm chimney has a fire temperature value of 750 ^{o}C. This happens because the chimney will lower its pressure, so that air will flow into the stove through the primary air inlet and secondary air inlet [21]. A chimney with a higher height can also cause a higher pressure difference, for that it is expected that the air flow rate will be higher. However, the higher the chimney, the lower the viscosity [22].

3.2 The Duration of The Flame

The flame length test was measured from the start up time of the fire ignition until the fire died. This test uses a stopwatch to determine the length of time the flame is produced from the fuel combustion process. The data from the test results for the long flame time can be seen in Figure 5. Figure 5 shows that in the test without cooking water, the time needed for the fire to ignite faster occurs in hole 50 for 14,15 minutes, in the test with boiling water the fastest flame is produced by hole 50 for 15,61 minutes.

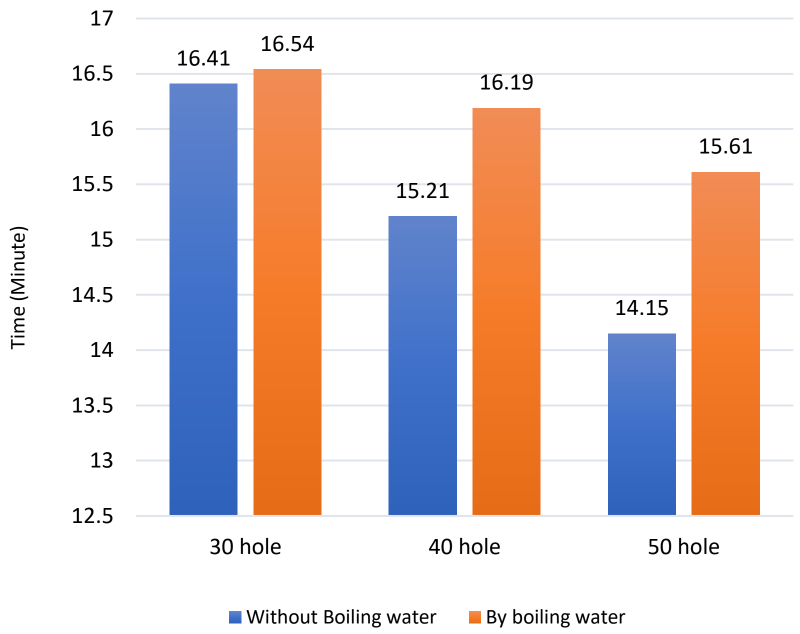

Figure 5. The duration of the flame

In the test by boiling water, the time it takes for the fire to burn is longer, this is due to the airflow coming from the primary hole through the combustion chamber and reacts with the fuel so that it produces a hot flame which cannot escape from the combustion chamber directly into the environment because the flow blocked by a pan filled with water, causing the air mixed with the heat of the fire to return to the burner which reduces the flow of air into the combustion chamber. The flow of air entering the combustion chamber affects the length of the flame, where the more air that enters the combustion chamber, the more air reacts with the biomass in the combustion process [23].

3.3 Fuel Burn Rate

a. Fuel burning rate without boiling water

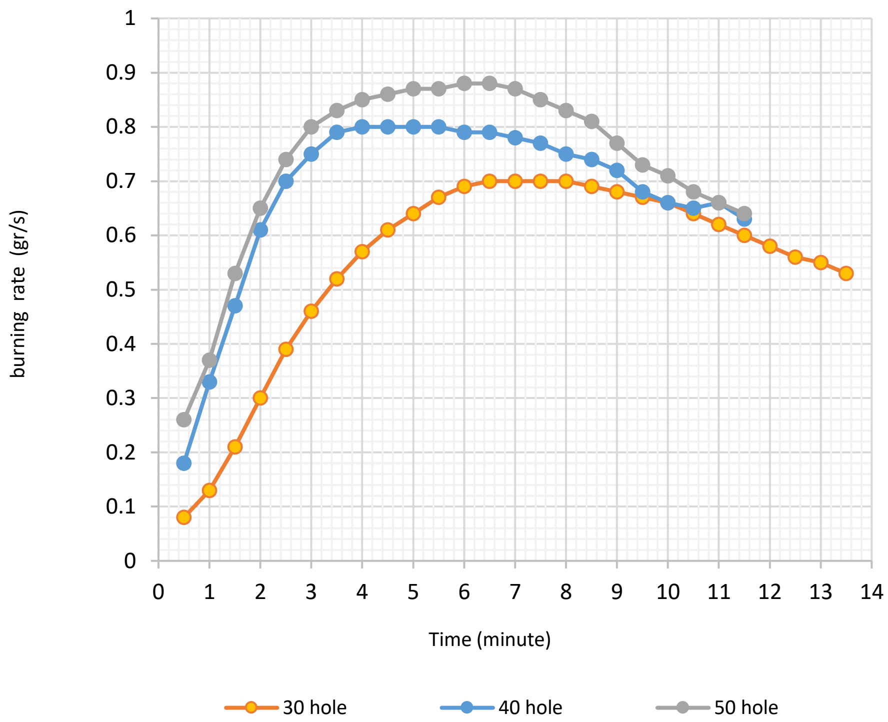

Figure 6. Burning rate without boiling water

In Figure 6 it can be seen that the highest combustion rate occurs in the number of secondary holes 50 of 0,88 gr/s, the smallest combustion rate value is found in the number of secondary holes 30 with a combustion rate of 0,77 gr/s. The more the number of secondary holes that are used, the more air flow will enter the combustion chamber so that the reaction of fuel combustion with air becomes faster [4]. This is in accordance with the results of this study, which show that the highest combustion rate value occurs in the number of secondary holes 50.

b. Burn rate by boiling water

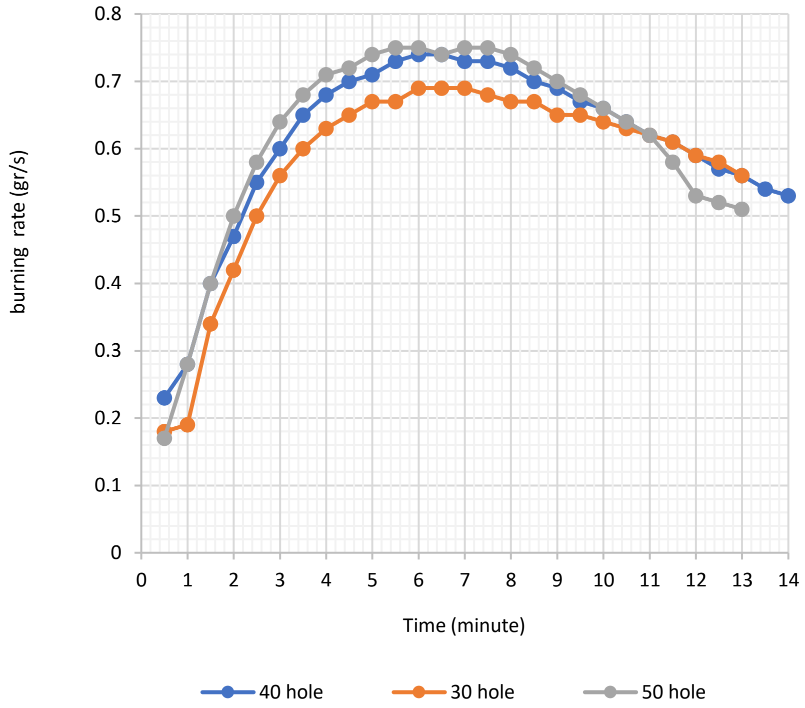

Fig. 7. Burning rate by boiling water

In Figure 7, the graph above explains that the secondary hole variation 50 has the highest combustion rate value with a rate of 0.75 gr/s, and the secondary hole variation 40 has a fuel efflux rate value with a value of 0.74 gr/s, and at hole variation 30 value of combustion rate has the smallest value with a value of 0.69 gr/s. This also shows that the amount of secondary air flow into the combustion chamber is affected by the number of holes. The more holes that are used, the more air flow that enters the combustion chamber so that combustion becomes faster, as a result the fuel runs out faster, conversely if a little air enters the combustion chamber, the combustion becomes slower and the fuel runs out less quickly (Pambudi , 2019) [11]. This study also shows that the highest combustion rate value is found in the number of secondary hole variations of 50.

3.4 Biochar Weight

The char weight test was measured by the amount of bio charcoal (biochar) resulting from burning fuel on the TLUD stove using a digital scale. The results of the boiling water test data that have been obtained from the bagasse fuel experiment can be seen in Figure 8.

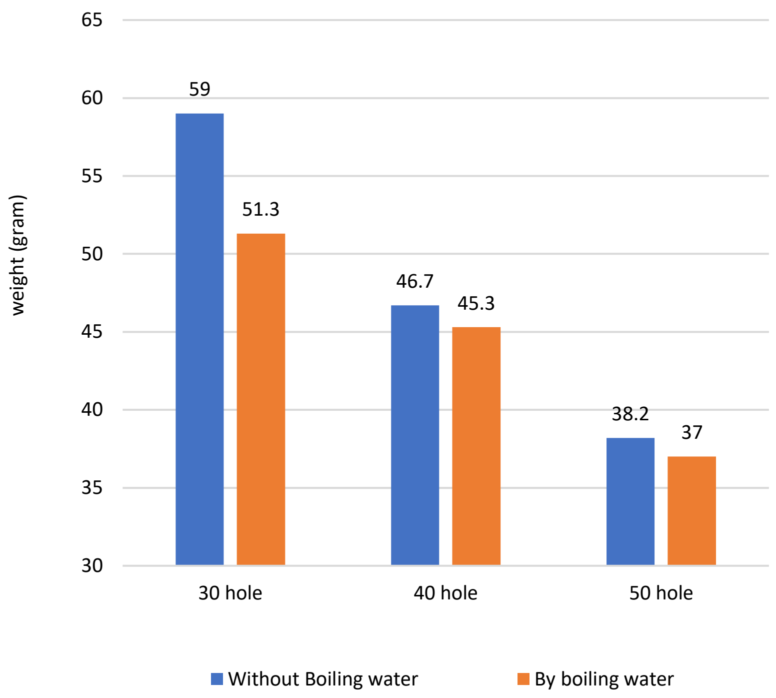

Fig. 8. Biochar weight

In Figure 8. Shows that the 50 holes variation produces a lighter weight of char than the other two variations. This is due to the number of 50 holes burning occurs faster than the other variations in the number of holes, so that the biochar produced is less, the faster combustion, the less biochar produced [24]. The overall variation in the number of secondary exhaust holes on TLUD stoves yielded biochar which amounted to less than 60% by weight of the total fuel for natural furnaces, this is comparable to the percentage in at least one other study using micro-gasification furnaces in East Africa (Whitman et al. (2011) [25] and Ioan Pavel et al (2019) [26]. This stove was not developed to produce biochar [27].

3.5 Water Boiling Time

Testing with the water boiler test method to obtain data on the increase in water temperature and the length of time the water boils. Testing the length of time the water boils is measured from the start up time of the fire ignition until the fire goes out. This test uses a stopwatch to determine the time for water at a temperature of 97°C from the combustion process on the TLUD stove, or testing the time for boiling water can be seen in Figure 9.

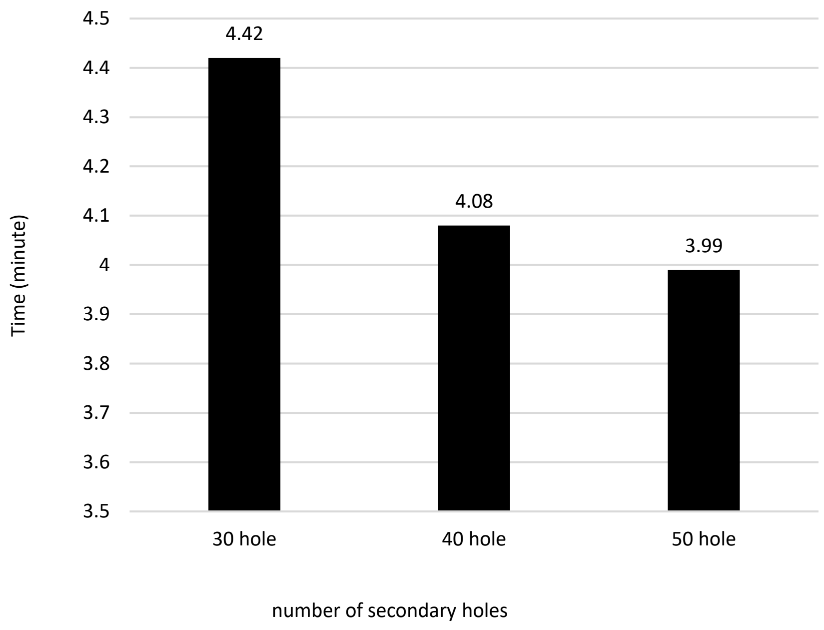

Fig. 9. Time It Takes To Reach 90°C

Based on Figure 9, the fastest time needed to reach a temperature of 97 °C is found in hole 50, because in hole 50 the incoming air flow is the most compared to the two variations of the hole so that variations in the amount of secondary affect the rate of heat transfer, the fire temperature becomes higher so the time to boil water. The heat transfer rate in the TLUD gasification stove testing process can indicate the ability of the stove to increase the temperature and increase the temperature of the water being boiled during the period of time the stove is operating. Because the fuel mass is the same for each variation of air hole, the sensible heat in each gasifier is the same as the temperature difference during the operating time [12]. So, it can be said that the more holes the burner has, the faster the water boils [28].

3.6 Thermal efficiency

Thermal efficiency is a measure of the extent to which biomass energy can be converted by a stove into thermal energy which is manifested in the form of a flame. It describes the ratio of the heat produced by the fuel to the heat received by the water to increase the temperature and evaporate the water. The results of the calculation of the thermal efficiency of the TLUD gasification stove in this study are shown in Figure 10.

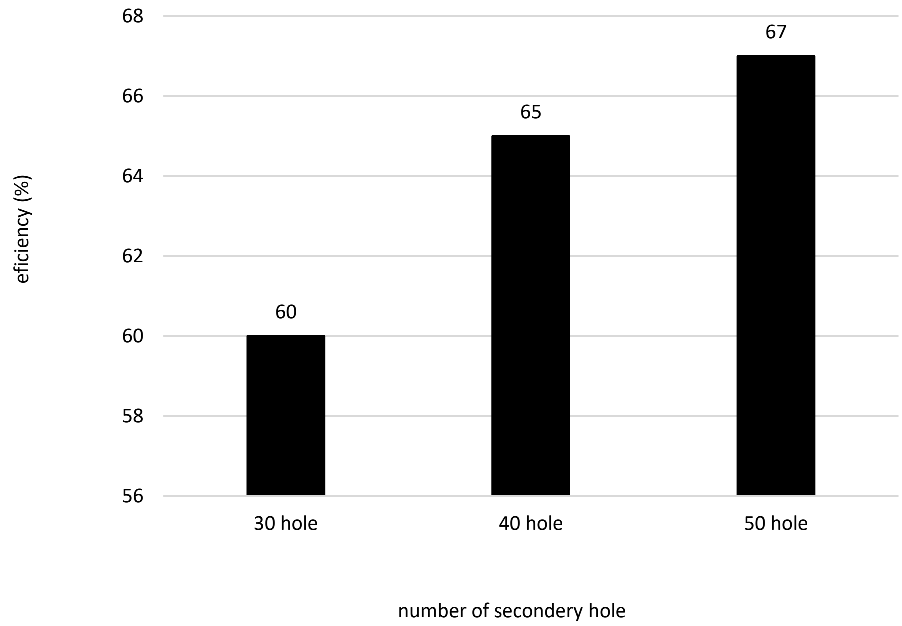

Figure 10. Thermal efficiency of a TLUD stove with variations in the number of secondary holes

The results shown in Figure 10, indicate that the highest thermal efficiency is produced at hole 50 which is equal to 67%, This is presumed to be because of the energy invested into the mass of the reactor body during ignition, which is a systematic loss, as are the non-combustible gases produced early, when considered as a fraction of the total gas volume produced [29]. The thermal efficiency value is influenced by the heat rate value, the higher the heat rate value, the higher the efficiency [21]. The thermal efficiency obtained (67%) was higher than that reported Anggara et al (2019) 13.55% [12], Sunarya, R., Zulfansyah, and S. Helianti (2012) 31.00 % [13], Digdo et al (2022) 42.95 % [14], Patrick Wamalwa 36.00% [30], and Riaz Ahmad et al (2019) [29].

4. CONCLUSION

Based on the research and data analysis that has been done, the following conclusions are obtained:

1 . Variation in the number of secondary holes in the combustion chamber on a concentric cylinder type TLUD stove affects the value of thermal efficiency, fuel rate, flame duration and flame temperature.

3. In this study, the thermal efficiency value of the concentric cylinder type TLUD stove with forced air flow was higher than the value of the concentric cylinder type natural airflow TLUD stove and the non-concentric cylinder TLUD stove.

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