Performance Analysis of Mobile Vertical Burner Using Various Types of Biomass Pellets

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Abstract. The high availability of biomass waste in the agricultural sector as an energy source promises sustainable energy for drying agriculture product. The low efficiency of air heating of biomass burners due to their separate design from the heat exchanger. This study aims to analyse the effect of various types of biomass pellets on the performance of a mobile vertical burner according to the air heating system efficiency and carbon emission production. This experiment used biomass waste from tea plantations as raw material for the pellets. There are three variations of biomass pellets used in this study: black pellet (A), mixed pellet (B), and white pellet (C). An analysis for the efficiency of the air heating system is conducted at six different heating process levels. The analysis showed that the mobile vertical burner machine can provide up to 1,028 CFM with a temperature of 89.9°C. The highest air heating efficiency is achieved using black pellet [80.6%], followed by mixed pellet [75.2%], and white pellet [71.4%]. Carbon monoxide gas emission production from this machine ranges from 33,6-114,8 ppm. These results indicate that black pellets have the potential to improve air heating efficiency with low gas emission production.

1 Introduction

The global market for Indonesian tea commodities has been trending downward due to its comparatively lower competitiveness compared to Kenya, Sri Lanka, and India, although it remains higher than China [1]. This decline may be attributed to the lower quality of the product and types of tea that do not meet market needs [2]. Statistical data in January-December 2021, Indonesian tea exports were recorded at USD 377,965, a decrease of 7,2% compared to the same period the previous year, which was recorded at USD 522,988 [3]. However, the production and export volumes of Indonesian tea have been declining over the past three years. Indonesian tea exports from 2020 to 2022 decreased by 8.27%. Additionally, the production of dried tea leaves in Indonesia also fell by 11.06% [4]. This data indicates that the Indonesian tea industry needs to improve its product competitiveness through quality

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enhancement and production cost efficiency. One of the largest contributors to tea production costs is energy expenses, particularly in the drying process which requires thermal energy.

The air heating system in the drying process must be optimally designed. Overheating risks causing the tea to become over dried and spoiled, whereas insufficient heating prolongs the drying time. Therefore, managing the heat supply in drying equipment is crucial. Thermal energy contributes significantly to the cost of tea production. In the green tea processing at PT. Teh Hijau Cap Jago Tasikmalaya [5], the thermal energy used in each stage of green tea processing is as follows: withering (2,952.74 MJ/kg), first drying (2,927.82 MJ/kg), and second drying (1,503.79 MJ/kg). Another study by Suprianti [6] reported that energy used in the tea drying process accounts for approximately 84.36% or the equivalent of 7,940 kWh/kg of dried tea. Energy costs in the green tea production process at the Tea and Quinine Research Center (PPTK) Gambung in 2022 accounted for 59.55% of the total cost. One factor contributing to the high energy cost is the use of LPG gas as fuel, which tends to increase in price. LPG has advantages such as low exhaust gas emissions and high efficiency, and Indonesia has abundant natural gas supplies [7]. However, LPG has a higher price compared to other fuels like biomass. One solution is to convert the energy use through the utilization of biomass via palletization. CO_2 emissions from wood pellet fuel are about ten times lower than those from coal and oil, and eight times lower than those from gas [8]. This potential is supported by research from [9], which showed that biomass waste from tea plantations at PPTK Gambung can be used as raw material for producing wood pellets with a potential of 8,186 tons/year, sufficient to meet the fuel needs for green tea processing at the PPTK Gambung factory.

The production of wood pellets from tea plantation biomass waste has variable quality; thus, this study uses three variations of biomass pellets from different materials. Wood pellet burners are energy conversion devices that use wood pellet fuel with a combustion system inside the chamber. Using this burner has significantly reduces exhaust gas emissions and has an efficiency of up to 83% [10]. These devices are usually used as heating sources in the food processing industry such as boilers, rotary dryers, bed dryers, multilayer dryers, and kiln dryers. In industry, the performance of burners must be optimal. Common issues with burners include prolonged ignition processes, incomplete combustion, temperature control problems, and fuel feeding, leading to low thermal efficiency. Separating the burner from the heat exchanger can result in heat loss during energy transfer. Additionally, burner design significantly affects the efficiency of the air heating process. The mobile vertical burner has a design where the burner is integrated with the heat exchanger to provide hot air with a controllable temperature based on the fuel feed rate at high air flow rates. The mobile vertical burner features a tiered heat exchanger consisting of plate and tube types to enhance the air heating efficiency by increasing the contact area and time between the air and the heat exchanger.

The primary plate-type heat exchanger is placed on the side of the combustion chamber, contribute to relatively stable and high temperatures because of contact time and area between the air and the heat exchanger are higher. Adding a tube-type heat exchanger on top of the combustion chamber aims to capture more heats from the flame, ensuring that heat from the combustion chamber is fully transferred to the [11]. The efficiency of wood pellet combustion in burners ranges between 66.8% and 85.5% [12]. These values can be improved through the development of a flexible burner design with good control mechanisms. Considerations of the size, geometry, and position of the air inlet in the combustion chamber provide control over airflow and combustion. The air flow rate affects the combustion rate, firing rate, fuel consumption, air heating system efficiency, and energy utilization percentage. This research has novelty in the aspects of analyzing the effect of different biomass pellet types on air heating efficiency and gas emission production.

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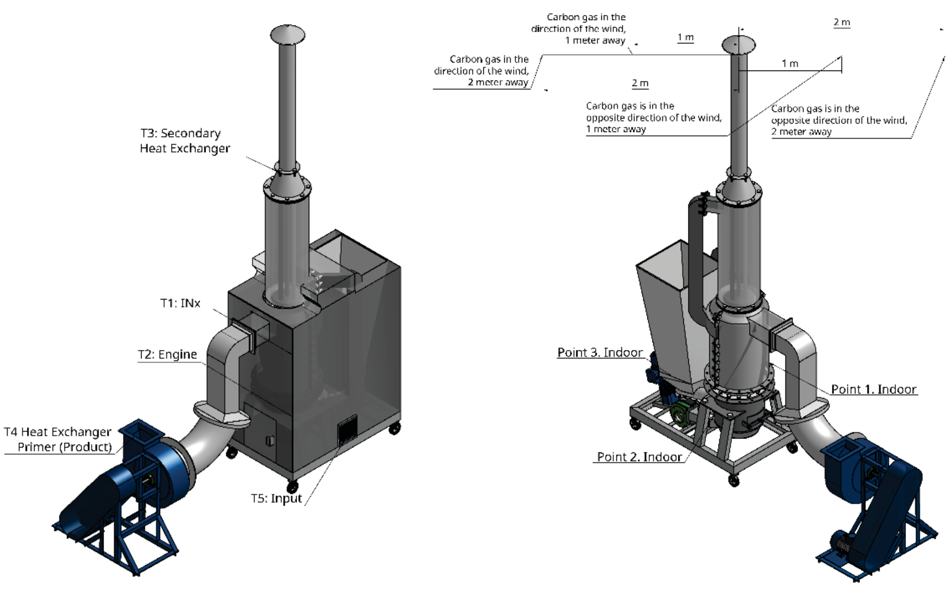
2 Materials and Methods

This research is a quantitative research that requires data analysis to obtain conclusions from the expected objectives. The design method and data collection were carried out after the observation variables were determined. From these independent variables, an experimental design was made with one parameter to be observed, namely type of biomass pellet. This research began with the preparation of raw materials, pellet production, operation of mobile vertical burners, measurement of temperature and gas emission levels, as well as analysis of the efficiency of the air heating system and the production of carbon monoxide gas emissions.

2.1 Sub-Materials and Methods

The main materials used in this research are biomass waste in the form of solid wood and wood charcoal. The wood used is biomass waste from the Tea and Cinchona Research Center in Gambung. Another main material used is wood charcoal obtained from the market. Meanwhile, the adhesive components, tapioca flour and charcoal, were obtained from the market. The main tools used in this research are the mobile vertical burner and pellet press machine. Measurement and testing equipment include the digital type k thermocouple, thermometer and rh data logger, anemometer, digital scale, measuring cup, stopwatch, and carbon monoxide meter. The calorific value testing of biomass pellets is conducted using the Parr 1341 calorimeter. Also, a hammer mill machine for material grinding purpose equipped with mesh sieve of 80. When the mobile vertical burner machine is operated, two measurements are conducted: temperature measurement and carbon emission measurement at several points as shown in Fig.1.



(a) (b)

Fig. 1. (a) Temperature measurement point of the machine ; (b) Carbon emission measurement point of the machine.

The working system of the mobile vertical burner is shown in Fig. 2. as follows: Pellets are burned and supplied by a screw conveyor integrated with a hopper at a 30° vertical angle. The flame from the biomass pellet combustion enters the primary heat exchanger (HE) chamber of the plate type, then proceeds to the secondary Heat Exchanger chamber of the tube type. Fresh air enters the secondary HE from the bottom, creating turbulence within the heat exchange pipes. The air exits from the top of the secondary HE and is recirculated back into the primary HE from the top, where it mixes and rises according to the direction of the heat exchange fins. Finally, the air is drawn out through the hot air outlet as the product air.

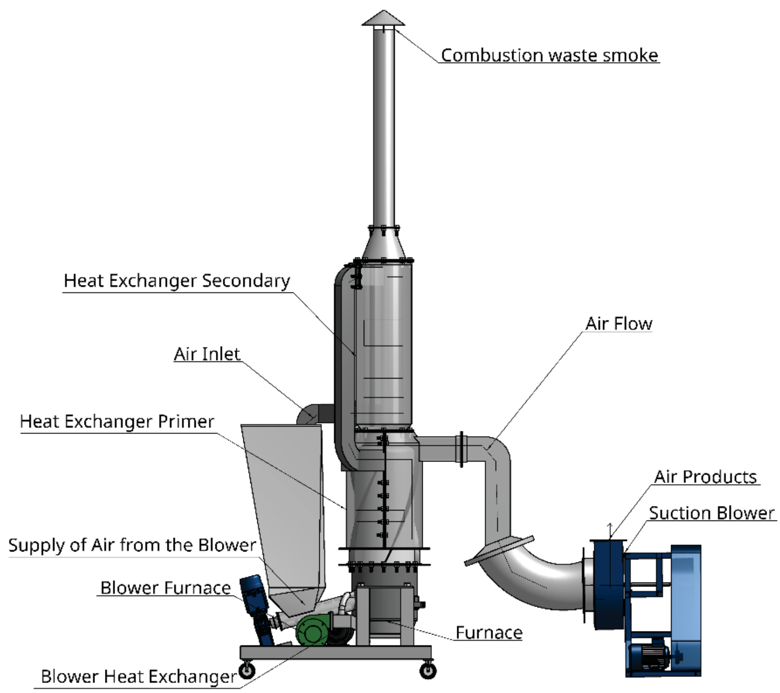


Fig. 2. Design of mobile vertical burner air heating system.

2.2 Experimental Design

2.2.1 Biomass Pellet Variations

In this study, three types of biomass variations were used to determine the performance of the machine. The experiments were conducted with three replications for each biomass pellet variation. Data analysis was performed using Microsoft Excel software to obtain the efficiency values of the air heating system and carbon emissions, as well as One-way ANOVA by using SPSS statistical application v27 to analyze the significance of each fuel type on the test parameters. Preliminary research is conducted before the main research, which is the density measurement on each biomass pellet variation. This density test is used to determine the inherent setting time for each fuel and is used in the performance test of the mobile vertical burner. The design of the experiment can be seen in Table 1 as follows.

Table 1. Experimental design

Fuel	Setting Time
Black Pellet (A)	(2/36)
Mixed Pellet (B)	(2/50)
White Pellet (C)	(2/47)

2.2.2 Analysis Methods

a. Analysis of the efficiency of the air heating system

The efficiency of the air heating system is a measure of the performance effectiveness of the mobile vertical burner machine in heating air relative to the fuel used. Furthermore, the efficiency of the air heating system is the ratio between the energy supplied by the heater and the energy supplied for combustion, in this case, biomass pellets. In the study by Carlon et al. [12], the equations used to calculate the efficiency of air heating can be found in Equations 1, 2, and 3.

1. Air Heating Energy ($Q_{Heat\ Exchanger}$)

The formula for the primary and secondary heat exchanger can be seen in Eq. 1.

$$Q_{Heat\ Exchanger} = \dot{m} \times C_p \times \Delta T \times t \quad (1)$$

Description:

$Q_{Heat\ Exchanger}$ (kJ) = Energy used in the heat exchanger
$\dot{m}$ (kg/s) = Mass flow rate of air in the heat exchanger
C_p (kJ/kg°K) = The specific heat of air
ΔT (°C) = Temperature difference
t (s) = Heating time

2. Fuel Energy (Q_{Fuel})

The formula for energy combustion by fuel can be seen in Eq. 2.

$$Q_{Fuel} = m \times \text{Calorific value (kJ/kg)} \quad (2)$$

Description:

Q_{Fuel} (kJ) = Combustion energy of the fuel
m (kg) = Total weight of the fuel per unit time
Calorific Value (kJ/kg) = Fuel calorific value (High Heating Value)

3. Efficiency of Air Heating System by Engine ($\eta_{Heat\ exchanger}$)

The formula for air heating efficiency can be seen in Eq. 3.

$$\eta_{Heat\ Exchanger} = \frac{Q\ Heat\ exchanger\ (kJ)}{Q\ Fuel\ (kJ)} \times 100\% \quad (3)$$

Description:

$\eta_{Heat\ exchanger}$ = Efficiency of the heat exchanger
$Q_{Heat\ exchanger}$ (kJ) = Energy used in the heat exchanger
Q_{Fuel} (kJ) = Energy of the fuel

b. Analysis of carbon monoxide emissions from mobile vertical burner

Carbon monoxide is one of the incomplete combustion gases that can pollute the air and affect human health. In this study, carbon monoxide measurements are divided into two types: indoor and chimney. In indoor measurements, measurements are taken at three points: the first point around the combustion chamber, the second point on the pipe from the primary heat exchanger to the suction blower, and the third point at the back of the device Meanwhile, chimney measurements are taken at four measurement points: the first and second points, which are measurements in the direction of the wind at distances of 1 meter and 2 meters from the chimney, and the third and fourth points, which are measurements against the wind direction at distances of 1 meter and 2 meters from the chimney. Measurement using a carbon monoxide meter for 90 minutes with a 30-minute interval, divided into 4 stages as shown in Table 2 as follows.

Table 2. Measurement of carbon monoxide gas emissions from mobile vertical burner.

Carbon Monoxide Value (ppm)							
Time	Indoor			Chimney			
				Unidirectional		Opposite Direction	
				1 meter	2 meter	1 meter	2 meter
	Measurement Point						
	1	2	3	4	5	6	7
0							
30							
60							
90							

3. Results and Discussion

This study aims to explore the characteristics of biomass pellets used as fuel for engines, as well as identify the optimal settings of the machine to achieve the highest air heating efficiency with the lowest carbon monoxide emission production. The characteristics of the fuel analyzed include density, calorific value, and combustion rate. This analysis is carried out because these factors directly affect combustion performance and energy efficiency. In addition, this research also focuses on reducing exhaust emissions, with the aim of producing environmentally friendly results from this biomass harvesting process. Thus, these efforts not only have the potential to improve the efficiency of using biomass fuel in engines, but also reduce negative impacts on the environment.

3.1 The characteristics of fuel

The composition determines the physical and chemical characteristics of pellets. Important indicators such as calorific value and density need to be carefully analyzed, and in this study, they are used as the basic parameters to differentiate the use of various fuels in air heating efficiency. Calorific value refers to the amount of energy produced when fuel is completely burned. Density, on the other hand, reflects the mass of fuel contained in a specific volume. Both of these indicators play a crucial role in determining engine efficiency.

3.1.1 Density

Density (ρ) is the ratio of mass to volume of a material, including the empty spaces between material particles [13]. Based on Fig. 3 and Table 3, black pellets have the lowest density value, while mixed pellets have the highest density value It can be observed that the composition of pellet materials affects the density value, with an inverse relationship to particle size. When particle size is small, the inter-particle pores also decrease. This can cause the material volume to decrease. As the material volume decreases, the density value increases. Charcoal powder particles are smaller compared to wood powder particles, which is why mixed pellets can have a high density due to the charcoal powder coating the wood powder particles.

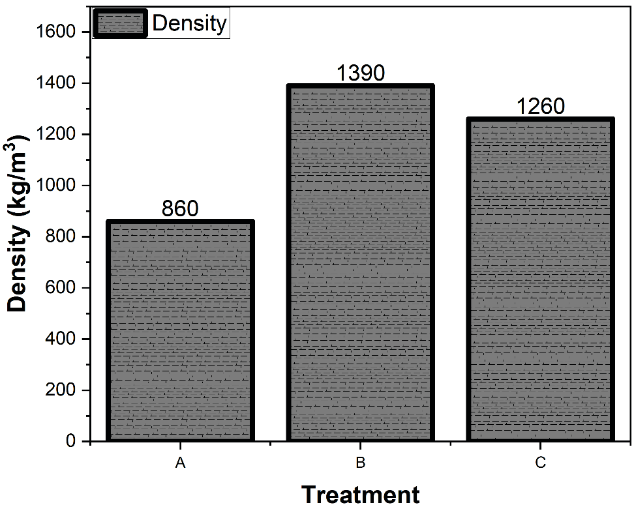


Fig. 3. The influence of raw materials on biomass pellet density.
Description: A: Black Pellet 4,9 kg/ f 55; B: Mixed Pellet 5 kg/ f 55; C: White Pellet 5,2 kg/ f 55.

Density analysis was also conducted through manual calculations. The results of the analysis can be seen in Table 3.

Table 3. Calculation of density values for fuel variations.

Sampel Code	kg/m^3	g/cm^3
Black Pellet (A)	860	0.86
Mixed Pellet (B)	1390	1.39
White Pellet (C)	1260	1.26

Based on Table 3 and Fig. 3, all types of fuel variations used are in accordance with the density values in SNI 8021-2014. Pelletization is proven to significantly increase the density of materials, thereby improving fuel production efficiency, ease of distribution, and easy storage. Differences in density values across fuel variations can be caused by the raw materials and adhesive compositions used. The adhesive content used must be appropriate, too much will produce excessive water vapor production when the pelletization process takes place and make the resulting pellets mushy and wet texture. If there are too few, it will cause the pellets to break easily. Calorific value is one of the determining parameters for pellet quality; the higher the calorific value, the better the quality of the pellet This value can be measured using a calorimeter The principle of bomb calorimeter measurement is based on the amount of heat measured in calories and produced when the sample is completely oxidized in the calorimeter bomb (referred to as the total energy of the pellet) [14]. The calorific value is greatly influenced by the ash content and moisture content, so pellet quality must meet the specifications according to the Indonesian National Standard for Biofuel Pellets [14].

3.1.2 Calorific value

The calorific value is one of the determining parameters for pellet quality; the higher the calorific value, the better the quality of the pellet. This value can be measured using a calorimeter. The principle of bomb calorimeter measurement is based on the amount of heat measured in calories and produced when the sample is completely oxidized in the calorimeter bomb (referred to as the total energy of the pellet [14]. The calorific value is greatly influenced by the ash content and moisture content, so pellet quality must meet the specifications according to the Indonesian National Standard for Biofuel Pellets [14].

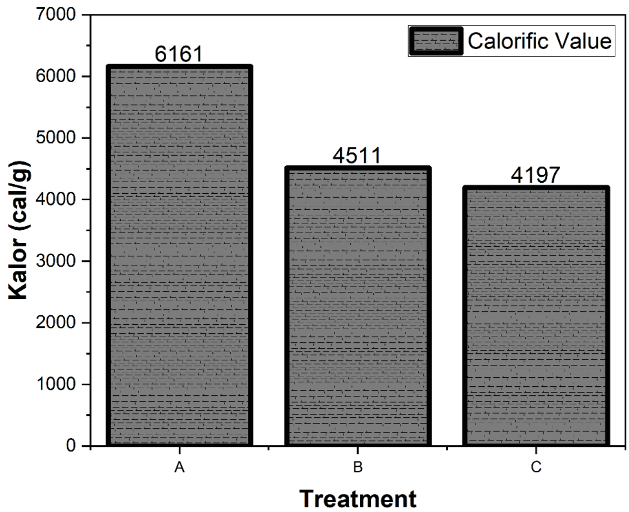


Fig. 4. The influence of raw materials on the calorific value of biomass pellets.

The calorific value analysis is also conducted through manual calculations. The analysis results can be seen in Table 4.

Table 4. Results of calorific value calculations for various fuels.

Sample Code	t (°C)	b (°C)	m (g)	W	Calorific Value (cal/g)	Specific Heat (KJ/kg)
A	2.526	19.32	1.0071	2.464	6.161	25.814,59
B	1.872	18.63	1.0182	2.464	4.511	18.904,7
C	1.73	19.55	1.0109	2.464	4.197	17.587,18

Based on the test results, the calorific values indicate that all fuel variations meet the calorific value standards in SNI 8021-2014, with a value of ≥ 4,000 cal/g. To achieve a high calorific value, it is necessary to undergo a carbonization process to increase the carbon content and reduce the volatile substance content in the material. The higher the carbon content, the higher the resulting calorific value [15]. In Fig. 4, it can be observed that the percentage of charcoal as a constituent material significantly affects the generated calorific value. The addition of binder reduces heat because binder has thermoplastic properties, is difficult to burn, and carries a lot of water, so the heat generated is first used to evaporate the water in the pellets [16]. One of the contents that affects the calorific value produced is bonded carbon, the higher the bonded carbon content, the higher the calorific value [16]. Ash content also contributes to this response variable. Ash is an inorganic material left after the combustion of biomass and includes calcium, magnesium, phosphorus, and other substances [16].

3.1.3 The combustion rate

The combustion rate refers to the speed at which the fuel burns, meaning that the higher the combustion rate value, the faster the fuel will be consumed [17]. Generally, a high moisture content will decrease the calorific value and combustion rate. The combustion speed of fuel is influenced by the carbon content present in the fuel; low carbon content causes the fuel to burn for a longer time. Based on Table 5, it can be observed that the highest combustion rate is found in mixed pellet fuel variations, as higher density values correspond to higher combustion rates. Consequently, the number of particles burned per unit volume increases.

Table 5. The calculation results of combustion rate for different fuels

Sample Code	Calorific Value (Cal/g)	ΔT (°C)	Density (kg/m³)	Time (Minute)	Biomass Combustion Rate (g/s)
A	6161	2,524	860	12	0.00134
B	4511	1,826	1390	12	**0.00229**
C	4197	1,724	1260	12	0.00202

3.1.4 Air Heating Profile

The design of the mobile vertical burner consists of an integrated stove with a heat exchanger. One of the performance parameters for this equipment is the machine's ability to heat the air, which can be demonstrated through the temperature difference between the input air (ambient air) and the output air temperature. The heat transfer process in this machine is supported by a specially designed heat exchanger. The vertical stove design allows cold air to move smoothly upwards, enabling even heat distribution. In this experiment, the air velocity used for all fuel variations remains the same, aiming to obtain accurate and consistent results without adjustments for each fuel variation. The observed temperature changes during the 90-minute period from the start of the combustion process are shown in Fig. 5.

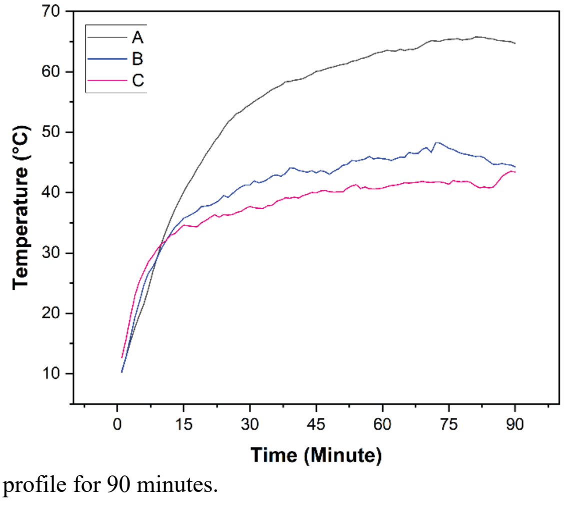


Fig. 5. Air heating profile for 90 minutes.

Based on Fig. 5 the highest rate of temperature difference between output and input is observed in. Treatment A with the lowest fuel consumption of 6 kg/hour. The lowest rate of temperature difference is shown in Treatment C with the highest fuel consumption of 6,9 kg/hour. The rate of temperature increase is not solely determined by the amount of fuel entering the combustion chamber; the calorific value of the fuel also significantly affects the generated air temperature increase. Based on the obtained results, Fuel A has the highest calorific value compared to the other two fuel variations. This can happen because higher calorific values produce more energy per unit mass than fuels with lower calorific values. This is consistent because the calorific value of each fuel is directly proportional to the rate of temperature increase.

The operational temperature stability of this engine is an important consideration, as it ensures consistent and efficient performance. In the initial stage of biomass pellet combustion, heat from the combustion chamber is used to raise the temperature in the primary and secondary heat exchangers. Under stable operational temperature conditions, the temperature in the heat exchangers tends to remain relatively constant with controlled and predictable fluctuations. Significant temperature changes can occur due to external factors affecting operational conditions, such as energy input and heating load changes. The time division is based on preliminary research where the highest temperature increase occurs in the first hour of operation and stabilizes in the following 30 minutes.

3.2 Optimal Engine Settings

This process involves a series of tests that include adjusting the timing and fuel air ratio. Proper timing ensures that the engine reaches stable and maximum operational conditions. Appropriate fuel air ratio settings prevent fuel wastage and reduce emissions. High efficiency in the air heating system can optimize energy usage CO gas emission testing ensures that the environmental impact of engine activity remains minimal. Considering all these aspects, optimal engine settings can serve as the foundation for the maximum performance of a sustainable mobile vertical burner.

3.2.1 Time Setting Testing

Setting time refers to the time it takes for the screw conveyor to start a fuel supply operation (life time) and stop from that operation (down time) using the unit of seconds (s). Setting time can help in optimizing the operation of the screw conveyor and ensuring that the fuel supply is in accordance with the needs of the combustion chamber. The setting time of each fuel is different due to the different density values of each other. The results obtained during the density test are used in the calculation of the screw conveyor process and the mass calculation. Based on the tests carried out, there is a difference between the calculated and tested fuel consumption amount has a difference of (A) : 0.348 kg/hour; (B) : 0.448 kg/hour; (C) : 0.638 kg/h. This can be caused by the fuel density value, as higher density values result in a faster combustion rate due to a greater number of burned particles per unit volume. Consequently, fuel consumption will increase.

3.2.2 Fuel Air Rate Testing

The wind speed in the suction air setup is a crucial component in this engine, as it directly impacts heating efficiency and air distribution in the targeted system. The measurement results for the blower air setup in this engine are presented in Table 6.

Table 6. Calibration of the air intake setup for primary air supply.

Motor Frequency (Hz)	Blower wind speed (m/s)				Average (m/s)	Average (CFM)
	Point 1	Point 2	Point 3	Point 4		
55	20.35	17.15	16.45	20.725	18.67	1028.55

Air velocity calculation focuses on the volume of air moving through the duct. Cubic Feet per Minute (CFM) is the result of all system variables, including motor frequency. This means that CFM reflects the current operational conditions, allowing us to disregard other details in air velocity calculations. This machine can produce a CFM value of 1.028 with a blower wind speed of 18,67 m/s. The value generated by the suction blower on this machine can still be increased or decreased through the control mechanism provided on the motor frequency.

3.2.3 Air Heating System Efficiency

Combustion efficiency measures how effectively a system converts the chemical energy of fuel into heat or mechanical energy. Combustion efficiency is calculated as the ratio of the energy actually released during the combustion process to the energy contained in the fuel. High combustion efficiency indicates more efficient fuel use and results in less waste and carbon emissions. In this study, the amount of energy produced by biomass pellets serves as the denominator for the amount of energy needed by the machine to heat the air. The average air heating efficiency values are shown in Fig. 6 and 7.

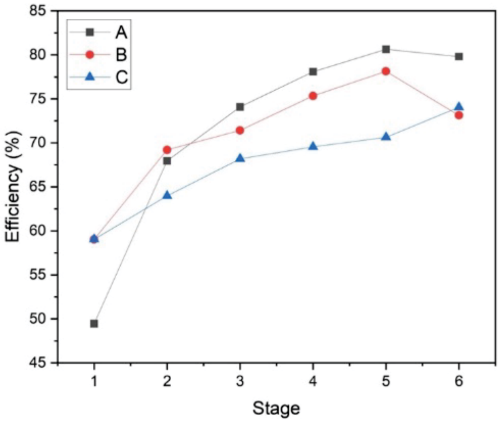


Fig. 6. Efficiency profile of air heating in all stages.

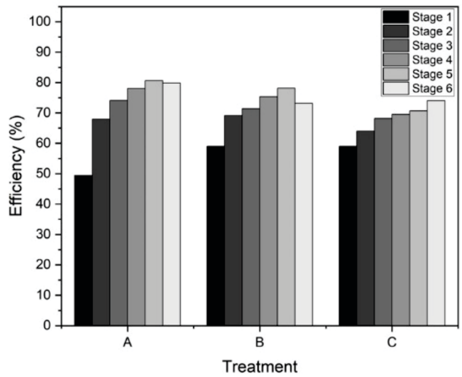


Fig.7. Air Heating Efficiency of Each Fuel at Each Stage.

The data processing was carried out similarly to the air heating profile. The highest air heating system efficiency at the 90_{th} minute during the heat exchange process in biomass pellet combustion was found in Treatment A at 79.81%, followed by Treatment C at 74.04%, and Treatment B at 73.13%. Factors contributing to the reduced efficiency in Treatment B include the quick completion time, which resulted in a temperature drop before the testing time was completed. To evaluate the performance of each fuel, one can use the overall air heating efficiency profile. Additionally, this can be attributed to the characteristics of the constituent materials, such as calorific value, density, and fuel combustion rate. Charcoal, having a high and pure carbon content, can store and release more heat energy during combustion. The combustion rate of charcoal tends to be slow and stable compared to wood combustion due to the high pure carbon content. This provides more time for the heat to be absorbed by the surrounding environment, enhancing overall heating efficiency.

The efficiency values at stages 1 and stage 6 for various fuels differ. At the 15_{th} minute, the lowest efficiency was observed in Treatment A at 49.46%, and the highest in Treatment B at 59.04%. This could be because the charcoal combustion in Treatment A involves a propagation reaction, resulting in efficient, slow, and stable combustion. At the 90_{th} minute, the efficiency changes, with the highest efficiency found in Treatment A. This indicates that charcoal can retain heat better and maintain stable combustion over longer period. The efficiency values of the three fuels were further analyzed using the compare means data analysis in one-way ANOVA with SPSS, as shown in Table 7, to understand the differences among the groups and identify significantly different groups. The three fuels are grouped into only two categories, marked with the letters 'a' and 'b'. This means that Fuel A significantly differs from Fuels B and C, but there is no significant difference between Fuels B and C. The ANOVA results indicate a statistically significant difference between the groups, as the p-value is 0.015. Since this value is below the threshold of 0.05, we can conclude that the variation in efficiency among the groups is not due to random chance, with at least one group differing significantly from the others.

Table 7. Results of Duncan's Multiple Range Test (DMRT) Using SPSS Statistic v27.

Sample Code	Efficiency
A	80.6^{b}
B	75.2^{a}
C	71.4^{a}

The fin is one of the crucial parts of this machine, designed to optimize air heating. Finned surfaces are used to enhance the heat transfer rate due to the increased surface area for heat exchange. Conductive heat in an object must be dissipated to the environment through convection. The convection process requires fluid flow to collide with the fins, thereby increasing the air temperature. The heat exchanger material must have high thermal conductivity to minimize the temperature difference between the main surface and the extended surface. This machine uses stainless steel 316 (SS316) due to its advantages, such as strength and corrosion resistance at extreme temperatures, making it suitable for high and low-temperature applications, as well as high mechanical strength with good ductility. The thermal conductivity value of this material ranges from 16.3 W/m.K at 100°C to 21.5 W/m.K at 500°C.

3.2.4 CO Gas Emissions of Mobile Vertical Burner

The combustion of wood pellets in the burner produces not only heat but also pollutants in the form of smoke. The smoke from this combustion contains various gas components, one of which is carbon monoxide (CO). This gas poses health risks because CO binds to hemoglobin (Hb) 240 times more strongly than oxygen (O_2). If the CO levels in the blood (HbCO) are high, symptoms such as dizziness (HbCO 10%), nausea and shortness of breath (HbCO 20%), visual and concentration impairments (HbCO 30%), unconsciousness, coma (HbCO 40-50%), and potentially death can occur. Long-term exposure can lead to neurological disorders, brain infarction, heart infarction, and infant death [18]. The pollutant data was measured in parts per million (ppm) 10^{-6}. Based on the data collection, the data points inside the room (casing) showed no pollutants across all fuel variations and throughout the testing intervals. CO gas emissions from this machine are illustrated in Fig. 8.

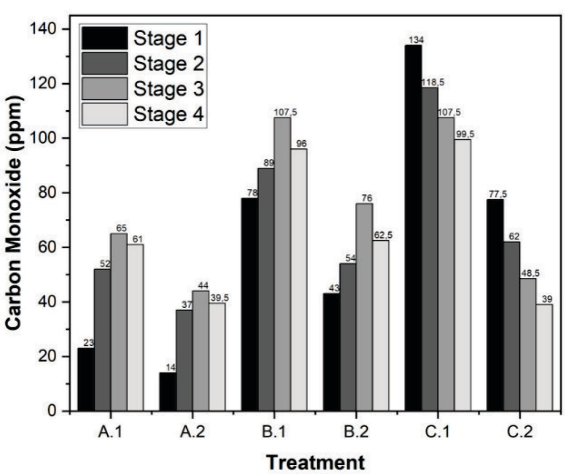


Fig.8. CO Gas Emissions of Mobile Vertical Burner.

Description : A.1: Black Pellet emissions at 1 meter; A.2: Black Pellet emissions at 2 meters; B.1: Mixed Pellet emissions at 1 meter; B.2: Mixed Pellet emissions at 2 meters; C.1: White Pellet emissions at 1 meter; C.2: White Pellet emissions at 2 meters.

Based on Fig. 8, the amount of carbon monoxide gas produced by the vertical-type wood pellet burner was measured at four points from the chimney. The highest emission value was observed in Treatment C.1 at stage 1, with 134 ppm, while the lowest emission value was observed in Treatment A.2 at stage 1, with 14 ppm. The results indicate that the combustion behavior of each fuel type exhibits varying trends. In Treatments A.1 and A.2, emission values remained stable across the last three stages. A similar pattern was observed in Treatments B.1 and B.2, with significant differences between stage 3 and stages 2 and 4. In Treatments C.1 and C.2, emission values showed a decreasing trend, with the highest values at stage 1. This could be attributed to the composition of the pellets, which are made from 100% wood dust, a material with a lower reactivity compared to charcoal dust. Consequently, the initial combustion process in the chamber produced more by products (smoke). In another study by Darma [19] using a pulverized burner with temperature variations at testing points of 800°C, 900°C, and 1000°C, the resulting emissions were 989 Mg/m^3, 931 Mg/m^3, and 746 Mg/m^3, respectively. It was found that higher temperatures resulted in lower emissions. These results align with the findings of this study, where charcoal dust pellets produced fewer emissions due to their higher calorific value compared to wood dust. Thus, during the combustion process, more heat energy is produced relative to the by-product (smoke).

4 Conclusion

This study aims to test the research hypothesis regarding the performance analysis of the mobile vertical burner machine. The results are as follows:

1. The highest air heating profile of the machine can be achieved using black pellets (65,76 °C), followed by mixed pellets (48,26 °C), and white pellets (43,53 °C). The machine can provide up to 1.028 CFM with temperatures reaching 89,9 °C.
2. The highest air heating efficiency at the final stage can be achieved using black pellets (80,6%), mixed pellets (75,2%), and white pellets (71,4%). The CO gas emission from this machine ranges from 33,6 to 114,8 ppm.

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