JIEETech
Journal of Industrial, Energy and Environment Technology
e-ISSN : 3031-5700
Vol. 2, Issue 2 (2024) : 62-65

Performance Analysis of Biomass Stove Based on Air Velocity using Biomass Solid Fuel

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Article's Information

Received
24/10/2024

Revised
27/11/2024

Accepted
28/11/2024

ABSTRACT

Biomass stove technology is the most potential stove to be developed as a replacement for traditional stoves by blowing air from bottom to top to burn pyrolysis gas. The purpose of this research is to analyze the effect of airflow velocity on thermal efficiency, Specific Fuel Consumption (SFC), and flame duration produced by biomass stoves. The airflow velocity variatons of this research are 3 m/s, 4 m/s, 5 m/s, and 6 m/s using a biomass fuel mixture of rice husk – wood powder and rice husk – bamboo chips. From research that has been done, variations in airflow rate speed are very influential on thermal efficiency, SFC, and flame duration. Biomass stove has passes the thermal efficiency test because all the result of thermal efficiency meet the minimum value of 20% of SNI 7926 : 2013. Airflow velocity can improve thermal efficiency and minimize fuel usage during combustion. However, after reaching the optimal speed, an increase in higher airflow velocity can lead to a decrease in thermal efficiency and an increase in SFC. The flame duration will also be faster as the velocity of the supplied airflow increases.

Keywords: *Biomass Stove, Air Flow Velocity, Biomass.*

1. INTRODUCTION

The energy needs of the Indonesian people are currently highly dependent on fuel oil. Therefore, efforts are needed to find alternative fuels that are renewable, environmentally friendly, and economically valuable. Biomass energy is a type of renewable energy that is widely used as an alternative fuel because it is easy to find and does not require large costs. In addition, biomass is widely utilized due to its carbon content including cellulose, hemicellulose, lignin, ash content, moisture content to help the combustion process [1].

Biomass energy sources have the advantage of being a renewable energy source that can provide energy sources in a sustainable manner [2]. Energy needs at the household scale currently tend to use biomass fuels such as wood as a rational and cheap option. However, inefficient biomass combustion methods, especially using traditional stoves, are still widely used in many areas, especially rural areas. These traditional furnaces are often not equipped with adequate emission control systems, resulting in significant indoor air pollution. The impact of uncontrolled biomass burning is not only limited to energy efficiency losses, but also brings serious health risks to users.

Combustion of solid biomass is usually done through open fires and traditional stoves, which can produce large emissions of carbon monoxide (CO), fine particulate matter, and other pollutant gases. Poor combustion results in efficiencies of no more than 10% due to the large amount of energy lost during the combustion process [3].

The development of clean and sustainable energy is needed to reduce the dependence of rural communities on such combustion. One alternative technology that is effective, efficient, and environmentally friendly is the use of biomass stoves which aims to provide solutions related to the fulfillment of cheap, clean, healthy, safe, and environmentally friendly energy. Biomass stoves are the most potential type of stove to be developed because they have high energy efficiency and are able to minimize harmful gas emissions produced by the stove by burning the gas produced from biomass pyrolysis [4]. Biomass stove technology will significantly improve combustion and displacement efficiency. This increased efficiency also means less smoke pollution, which is harmful to health.

Many previous researchers have conducted research on biomass stoves. Previous research said that, primary air velocity affects the specific consumption of fuel, the higher the primary air velocity causes the specific consumption of fuel to be higher while the higher the secondary air velocity will cause the specific fuel to be lower [5]. Previous research also suggested improving the design of the biomass stove by adding a fan to the stove to speed up the combustion process [6]. Therefore, the purpose of this research is to analyze the effect of airflow velocity variations on thermal efficiency, Specific Fuel Consumption (SFC), and flame length on biomass stoves.

2. MATERIAL AND METHODS

2.1 Material

The research was conducted from March 2024 to June 2024 at the Chemical Engineering Laboratory, Energy Engineering Laboratory of Politeknik Negeri Sriwijaya and PT Geoservices Coal Laboratory Palembang. The tool used are a set of biomass stoves. Test equipment such as scales, stopwatches, thermometers, thermoguns, anemometers, and gas analyzers are confirmed to be ready for use. here is a picture of a set of biomass stoves with their components. The biomass stove can be seen in Figure 1.

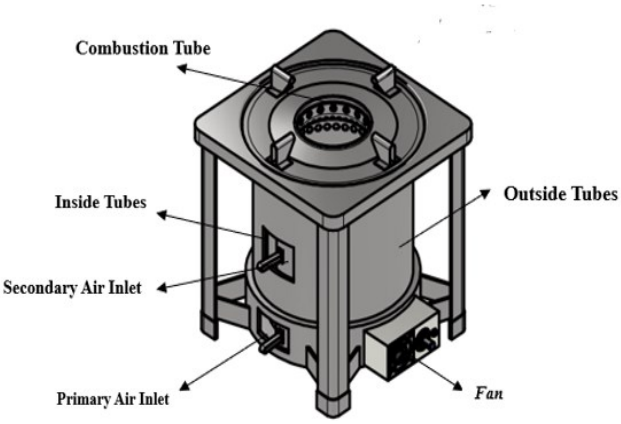

Figure 1. Biomass Stove

2.2 Methods

This research involves several research variables consisting of fixed variables and independent variables. The fixed variables in the research are fuel mass of 1 kg, fuel size of 2 - 5 cm, and primary and secondary air hole valves open perfectly. While the independent variable in the research is the supply air flow velocity of 3 m/s, 4 m/s, 5 m/s, and 6 m/s. The fuels used are rice husk biopellets, teak wood powder biopellets, and betung bamboo chips.

The research procedure was carried out in several stages, starting with the preparation of fuel to be taken as an analysis sample. Fuel samples will be subjected to proximate analysis (ASTM-D7582-10) at the Chemical Engineering Laboratory of Sriwijaya State Polytechnic and ultimate analysis (ASTM-D5373-16) method at PT Geoservices Coal Laboratory Palembang.

The next stage of the biomass stove performance test with the Water Boiling Test (WBT) method begins with mixing the rice husk bioleptics - sawdust biopellets and rice husk biopellets - bamboo chips that will be tested with a mass ratio of 50 : 50 as much as 1 kg and then put it into the furnace. A total of 2 liters of water was prepared and its initial temperature was measured. After the primary and secondary air valves were opened, the biopellet mixture was burned with methylated spirits and a lighter. The airflow speed was adjusted as required, and the stopwatch was activated when the flame was burning evenly. A pot of water was placed on the stove, and the time taken for the water to boil was recorded. The final water mass and fuel used were measured, and the flame duration and flame temperature were measured three times. This procedure was repeated for air velocity variations of 3 m/s to 6 m/s.

3. RESULTS AND DISCUSSIONS

Based on the results of experiments on biomass stoves, observation data in the form of Water Boiling Test (WBT) test results are obtained to be used as calculation and discussion data. The calculation data can be seen in table 1.

Table 1. Observation Data of Combustion Process on Biomass Stove

Air flow Velocity (m/s)	Biomass Fuels (kg)	Initial Water Mass (kg)	Mass of Evaporated Water (kg)	ΔT Initial and Final Water Temperature (°C)	Mass of Materials Used (kg)	Boiling Time (sec)	Duration of Flame (sec)
3	Rice Husk : Teak Wood Powder	2,0	0,16	70	0,24	433	3390
4		2,0	0,15	72	0,21	385	2761
5		2,0	0,18	69	0,19	380	2740
6		2,0	0,13	71	0,20	338	2365
3	Rice Husk : Bamboo Chips	2,0	0,15	71,6	0,25	510,6	3220
4		2,0	0,19	72,2	0,20	423	2471
5		2,0	0,15	71,7	0,23	316,8	2444
6		2,0	0,14	72,7	0,26	335,4	2399

3.1 Effect of Airflow Velocity on Specific Fuel Consumption (SFC)

Specific Fuel Consumption (SFC) is an indicator of the effectiveness of a combustion system that is calculated by dividing the amount of fuel burned by the duration of combustion.

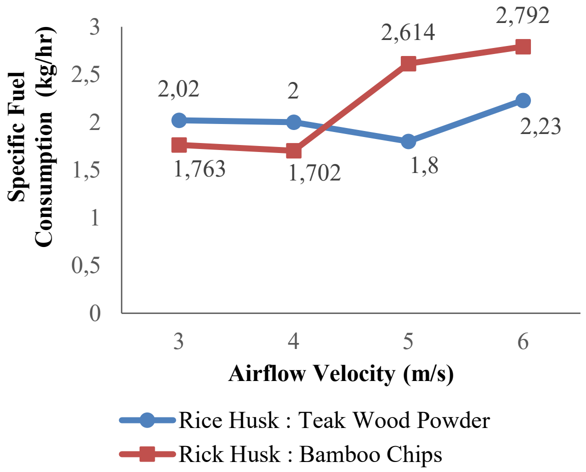

Figure 2. Effect of Airflow Velocity on Specific Fuel Consumption (SFC)

In the figure 2, it is involved that there is a decrease and increase in each fuel and airflow speed. When the air velocity is increased appropriately, the combustion process becomes more efficient as The thermal efficiency produced by the stove tends to increase with increasing incoming air flow rate, because increasing the combustion air flow rate will increase the thermal efficiency of the stove [7].

When the air velocity is increased appropriately, the combustion process becomes more efficient as sufficient oxygen is available to burn the fuel completely. This results in an improvement in SFC, where the biomass fuel burns more efficiently to produce the required energy. Conversely, if the air velocity is too low, combustion is incomplete and reduces the SFC because not all the fuel is burned completely.

Air velocity variations affect the fuel consumption rate where the higher the air flow velocity, the fuel consumption value tends to increase [8]. Therefore, proper airflow velocity regulation is key to maximizing the SFC of biomass stoves, maintaining energy efficiency, and reducing unburned emissions.

3.2 Effect or Airflow Velocity on Thermal Efficiency

In the research that has been done, it is obtained that the thermal efficiency of the biomass stove is more than 20% so that based on SNI 7926: 2013 the biomass stove is declared feasible for use [9].

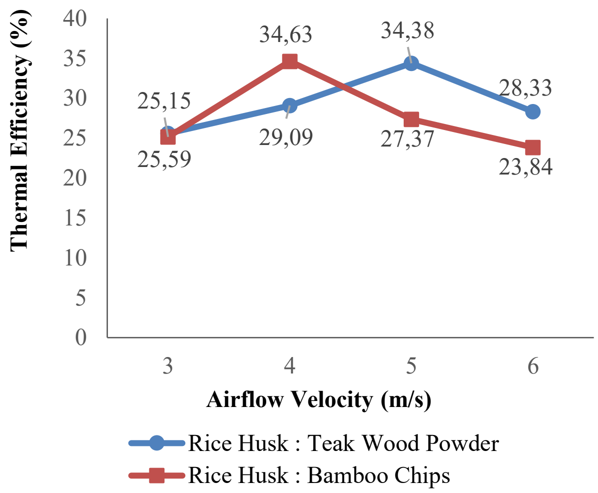

Figure 3. Effect of Airflow Velocity on Thermal Efficiency

Based on the graph above, the mixture of sadi husk and bamboo chips has a higher thermal efficiency at an airflow velocity of 4 m/s, but this efficiency decreases faster when higher airflow velocities are set. The mixture of rice husk and teak sawdust shows a more steady increase in thermal efficiency at an airflow velocity of 5 m/s, before eventually decreasing. This graph shows that the thermal efficiency of both types of fuel blends is affected by the airflow velocity.

The decreasing thermal efficiency for both biomass blends indicates that there is an optimum limit in airflow velocity to achieve maximum thermal efficiency. Non optimal air regulation can reduce thermal efficiency because there is no good control of the combustion process.

The higher the airflow velocity, the higher the efficiency. However, excessive airflow will also affect efficiency because excess air is not used for combustion but can reduce the calorific value of combustion products to increase the temperature of the excessive air [10].

3.3 Effect or Airflow Velocity on Flame Duration

Measurement of the duration of the flame produced by burning fuel using a stopwatch tool. The duration of the flame is calculated when the fuel in the combustion tube runs out and the fire is extinguished. The graph shows that increasing the airflow velocity has a significant impact on the flame length. The longest flame is found at the highest airflow velocity and the fastest flame is found at the lowest airflow velocity.

It can be seen in the figure 4. that with increasing airflow velocity, the flame length of both fuel mixtures tends to decrease. Rice Husk and Teak Wood Chips biomass blends generally have a slightly longer flame time than Teak Wood Chips and Bamboo Chips blends at lower airflow velocities. However, at higher airflow velocities, the difference in flame length between these two mixtures becomes insignificant. The duration of the flame decreases as the supplied airflow velocity increases.

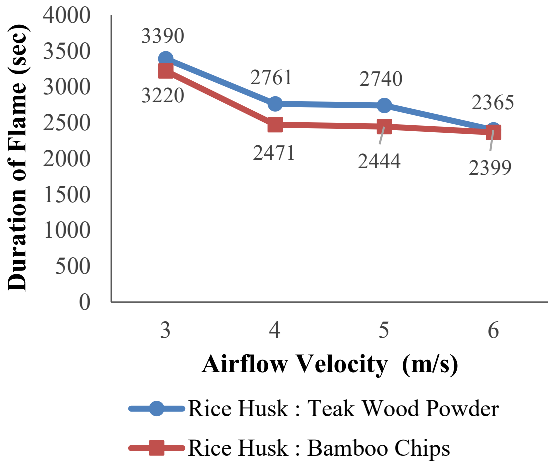

Figure 4. Effect of Airflow Velocity on Flame Duration

The duration of the flame decreases because the higher the airflow velocity, the less total time it takes to burn the fuel. The greater the air flow rate, the faster the combustion process and the faster the biomass will be consumed [7]. The higher airflow velocity causes the fuel to burn faster, resulting in a shorter flame duration.

4. CONCLUSIONS

Airflow velocity greatly affects thermal efficiency, Specific Fuel Consumption (SFC), and duration of flame. In this study, the biomass stove has passed the thermal efficiency test because all efficiency results meet the minimum value of 20% from SNI 7926: 2013. Airflow velocity can increase efficiency and minimize fuel usage during combustion. However, after reaching the optimum speed, a further increase in airflow velocity can lead to a decrease in thermal efficiency and a rise in SFC indicating that there is an optimum limit for airflow velocity in achieving maximum thermal efficiency and low SFC. The flame length decreases as the supplied airflow velocity increases because the higher the supplied air, the less total time it takes to burn the fuel.

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