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Biomass Stove with Low Carbon Monoxide Emission Fueled by Solid Fuel Coffee-Husk Biopellet

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Jember, Maret 2023

Cover Letter

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27 July 2022

Dear Sir/Madam

I am pleased to submit an original research article entitled "Biomass Stove With Low Carbon Monoxide Emission Fueled By Solid Fuel 2 Coffee Husk Pellet" for consideration for publication in SUSTAINABILITY.

We believe that this manuscript is appropriate for publication by *SUSTAINABILITY* because it shows that role of biomass pellets is important right now.

This manuscript has not been published and is not under consideration for publication elsewhere. We have no conflicts of interest to disclose.

Thank you for your consideration!

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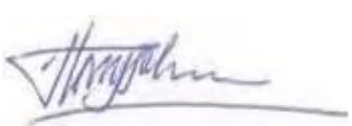

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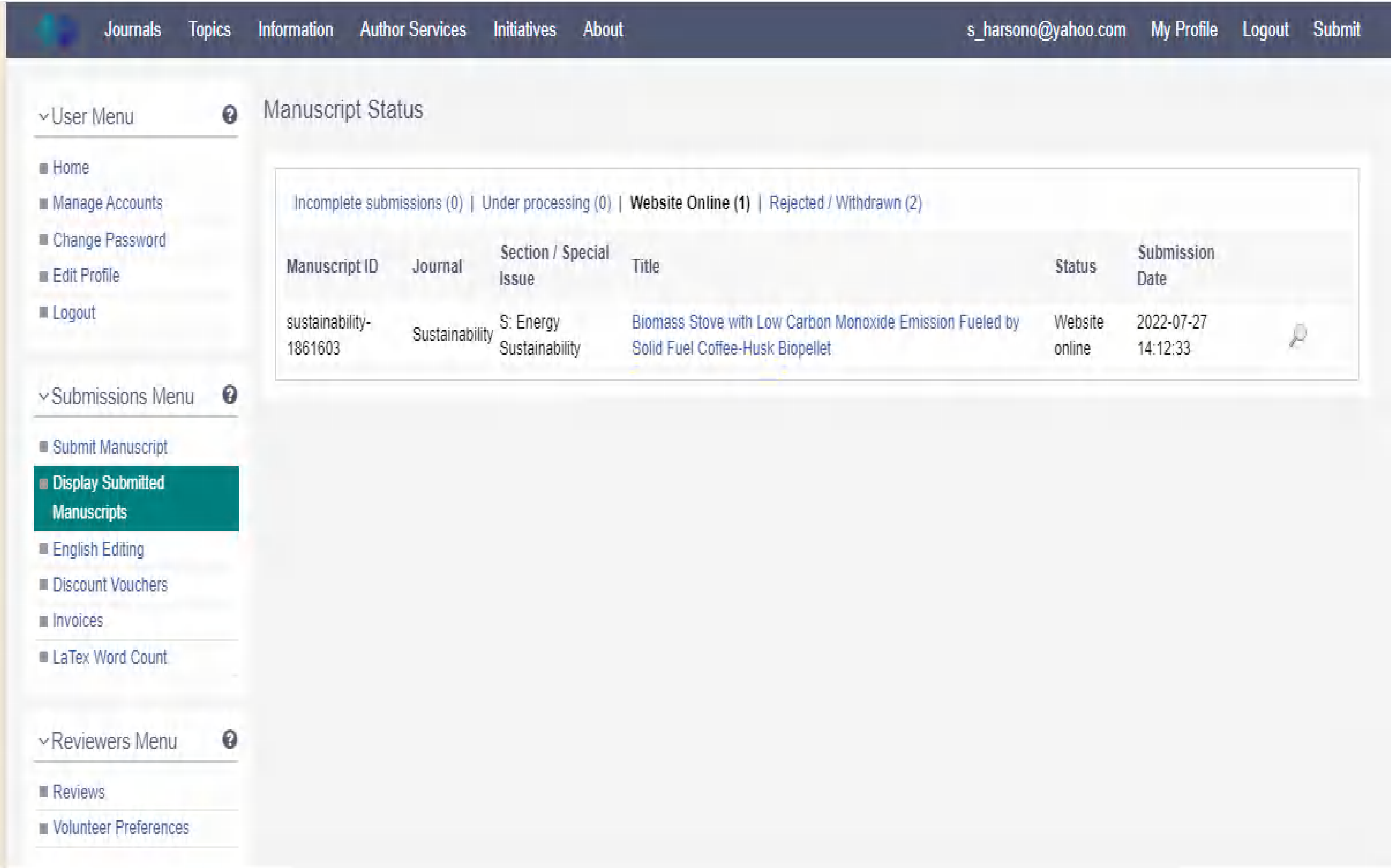

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Title	Biomass Stove with Low Carbon Monoxide Emission Fueled by Solid Fuel Coffee-Husk Biopellet
Authors	Soni Sisbudi Harsono * , Tasliman Tasliman Tasliman , Mukhammad Fauzi , Robertoes Koekoeh Koentjoro Wibowo , Edy Supriyanto
Section	Energy Sustainability
Abstract	In this study, coconut husk waste was used as the primary material to produced bio-pellet with a mixture of tapioca flour and molasses as a binder. The concentration of each binder used is 10, 15, and 20 %. The addition of tapioca flour and molasses at different concentrations increased the density, ash content, fixed carbon content, and reduced moisture content and volatile matter content. Bio-pellet with the best formulation was obtained by adding 10% tapioca flour with a density was 0.61 kg/cm3, ash content 3.03%, moisture content 8.03%, volatile matter content 81.79%, fixed carbon content 15.18%, calorific value 17.55 MJ/kg, water boiling time 0.169 hour, FCR 0.504 kg/hour, and thermal efficiency 33.15%. The design results are obtained distance from (diameter 26.5 cm, and height 37) stove to the outside of the furnace (amounting to 8 cm), which can minimize the furnace causing the heat generated from burning. The speed of the blower can be adjusted according to its users using a dimmer. The results obtained from the stove's performance are the average thermal efficiency of the furnace by 10.03% and the average CO gas emission of 3.25 ppm.

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Article

Biomass Stove with Low Carbon Monoxide Emission Fueled by Solid Fuel Coffee-~~-~~Husk ~~Bio-Pellet~~Biopellet

Soni Sisbudi Harsono [1,*], Tasliman [2], R. Koekoeh T. Wibowo [3] and Edy Suprianto [4]

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Abstract: In this study, coffee husk was used as the primary material to produce ~~bio-pellet~~biopellets, with a mixture of tapioca flour and molasses as a binder. The concentration of each binder used was~~is~~ 10, 15, and 20%. The addition of tapioca flour and molasses at different concentrations increased the ~~bio-pellet~~biopellet density, ash content, and fixed carbon content, and reduced moisture content, and volatile matter content. ~~bio with~~ T~~t~~he best formulation was obtained by adding 10% tapioca flour; it had a ~~with a bio-pellet~~biopellet density of ~~was~~ 610 kg/m^3, an ash content of 3.03%, a moisture content of 8.03%, a volatile matter content of 81.79%, ~~fixed carbon, a~~ fixed carbon content of 15.18%, a calorific value of 17.55 MJ/kg, a water-~~-~~boiling time of 10 min, a f~~F~~uel c~~C~~onsumption r~~R~~ate of 0.008 kg/min, and a thermal efficiency of 33.15%. The design results were ~~are~~ obtained using the distance from (diameter = 26.5 cm and height = 37 cm) the stove to the outside of the furnaces (this amount~~sing~~ to 8 cm, which can minimize the furnace, causing ~~the~~ heat to generate~~d~~ from burning). The speed of the blowers can be adjusted by ~~according to its~~ users using a dimmer. The results obtained from the stove's performance ~~are~~ showed the average thermal efficiency of the furnace, which was ~~by~~ 10.03% ~~and~~ with an average of 3.25 ppm.

Keywords: coffee husk; tapioca flour; molasses; ~~bio-pellet~~biopellet; thermal efficiency; CO emission

Citation: Harsono, S.S.; Tasliman; Wibowo, K.T.; Suprianto, E. Biomass Stove with Low Carbon Monoxide Emission Fueled by Solid Fuel Coffee-Husk ~~Bio-Pellet~~Biopellet. *Sustainability* **2022**, *14*, x. https://doi.org/10.3390/xxxxx

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1. Introduction

Indonesia needs to find alternative fuels due to the reduced availability of fossil fuel sources~~,~~ caused by~~due to~~ the increasing consumption ~~growth~~ of the population [1,2]. One of the most commonly used briquette stove fuels is coal [3]. However, using coal as a fuel for briquette stoves ~~is~~ still produces bad ~~not good in~~ exhaust emissions due to ~~resulting from~~ the combustion process [3,4]. Research and studies conducted by Zhi et al. [4] in the laboratory ~~researchers~~ found that coal briquette stoves still produced very high carbon monoxide (CO) gas, with a multiple of 100 ppm, which~~that~~ can reach a magnitude of 7. ~~Bio-pellet~~Biopellet is a solid, biomass-based fuel in a tubular solid form, which has uniform size, shape, humidity, density, and energy content. Compared to briquettes, ~~bio-pellet~~biopellets ha~~ve~~s better density and size uniformity [5,6].

~~Bio-pellet~~Biopellet is a biomass that is converted and used as fuel using the densification technique [7]. The densification technique aims to increase the density of a~~the~~ material and facilitate storage and transportation [8]. Biomass conversion can increase the calorific value per unit volume, ~~be~~ size uniformity ~~in size,~~ ~~and~~ quality, and ease~~y~~ of~~to~~ storage or transportation. The main factors affecting the strength and durability of the

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pellets areis the material raw materials, moisture content, particle size, compression conditions, adhesive addition, tools densification tools, and the treatment after the production process [9]. The potential waste obtained from the coffee--processing stage is coffee skin, consisting of wet fruit skin, liquid waste containing mucus, and skin dry skin spindles, and dry shells [10]. Coffee skin is a byproduct that makes up between 50 and 60% percent of the harvest [11]. If When the harvest is 1000 kg of fresh--skinned coffee is harvested, then the coffee beans are would beamount to about 400–500 kg, and the rest would be is a by-product in the form of the coffee husk [10,11].

According to the Indonesia Coffee and Cocoa Research Institute [12], coffee bean production in Indonesia reaches 611,100 tons and produces 1,000,000 tons of coffee husk. Notably, 55% of Ccoffee skin includes plantation waste that has not been optimally utilized [13]. Skin Coffee skin contains a high calorific value, a water content of 75–80%, and quite a low sulfur content. The raw coffee rind contains high levels of water (2.25%),; 0.73% ash content,; 74.20% volatile 74.20%,; and 25.07% solid carbon [14]. Coffee fruit skin contains 10.78% crude protein and 33.13% crude fiber 33.13%. In addition, coffee fruit skin contains 24.67% lignin and 20.22% cellulose 20.22% [14,15]. Coffee solid waste, such as fruit peels, and shells, and cCoffee beans, have the potential to be processed into useful materials used as ingredients for renewable alternative renewable fuels. Solid coffee waste, such as peels and fruit peels and coffee beans, have the potential to be converted into useful feedstocks for renewable alternative renewable fuels [15]. Research on the economics of bio-pelletbiopellets made from coffee husks in Indonesia was conducted by Rusdianto et al. [16], who showeds that the bio-pelletbiopellet coffee sector satisfies the requirements for being financially viability viable in the Jember Regency of Indonesia by using the financial analysis techniques like such as sensitivity analysis, break-even point (BEP), payback ratio, net present value (NPV), internal rate return (IRR), and net benefit, and cost ratio (BC) ratio.

2. Materials and Methods

2.1. Tools and Materials

The tTools used in thise study included electric weldingwelders, cut pliers, drills, wrenches, screwdrivers, scales, thermometers, measuring glasses, gas analyzers, stationery, and cameras. The Wwood powder waste used wasis a type of zinc wood. Another material used wasis stainless steel, which was used as a stove-making material.

A stove is a combustion device that produces high heat [17,18]. The types of stoves 7that are commonly used by the public today are gas stoves and kerosene stoves [19]. Since the government established a policy toof switching the use of kerosene fuel to gas, there has been an increase in gas stoves, causing gas demand to increase.

Natural gas reserves, as with all fossil fuels, are decreasing in availability every year are decreasing in availability. Therefore, to help overcome the natural gas crisis, developing a stove with that uses alternative fuels derived from renewable energy sources, such as in bio-pelletbiopellets, has been developed.

During the combustion process, a sufficient air supply is necessary. The bio-pelletbiopellet fuel is placed in a perforated place to drain the primary air. In After supplying air during the combustion process, the installed air regulators to regulate air induction in the stove to regulate the output power of the furnace.

Based onAccording to previous research [10], existing bio-pelletbiopellet stoves produce a combustion quality that has not beenis not optimal, the air supply is still lacking, CO gas emissions still exceed the threshold, and the actual efficiency is still tiny. Therefore, it is necessary to review the performance of bio-pelletbiopellet stoves by maximizing the air supply and mass of the bio-pelletbiopellets so that maximum combustion quality, lowsmall CO gas emissions, and high thermal efficiency are obtainable. To find out the optimization, of the effect of the amount of air supply on the stove's performance and the efficiency of the furnace was analyzed based on air supply will be done to analyze the

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~~effect of the amount of air supply on the stove on the performance and efficiency of the furnace eternal~~.

2.2. Combustion Performance of~~on~~ ~~Bio Pellet~~Biopellet Stoves

Carbon m~~M~~onoxide ~~Emissions~~ (CO) emissions are obtainable ~~from~~ by burning biomass in stoves [20]. These emissions can cause air pollution within~~in~~ CO gas, sulfur, nitrogen oxides, and hydrocarbons [21]. In this study, the exhaust gas ~~that will be measurable~~ measured is the CO gas emission~~s~~ because the level of CO emissions ~~is much or at least will be a~~indicates the perfect or imperfect character of the combustion process. CO emissions come from the inadequate oxidation reactions of the hydrocarbons and carbons contained in the ~~biopellet~~biopellets.

Thermal efficiency compares the heat value produced~~received~~ by water and the heat ~~valuegiven~~value produced by ~~the bio pellet~~biopellets. In this study, calculations to determine the magnitude of ~~the most~~ efficiency are defined~~able~~ in the following equations~~s~~ [17]:

$$n_T = m_a \times c_a \times \Delta T + \Delta m_b \times L \quad (1)$$

Here,~~With~~ ma = water mass (kg), Δma = evaporated water mass (kg), L = latent heat of water = 2,268,000 (J/kg), ΔT = change in temperature (°C), Δmb = mass of fuel burned (kg), Ca = water type heat = 4186 (J/((°C.kg)), and LHV (low heating value) = enthalpy of ~~bio pellet~~biopellet (20,974,800 J/kg).

2.3. Operational Plan

In t~~T~~he first operational design of the stove, ~~is to insert~~ the ~~bio pellet~~biopellets were inserted through the top of the furnace (approximately 700–800 g), then ~~turn on~~ the ~~bio pellet~~biopellets were turned on using denatured alcohol ~~for~~ as the starter, and the button was pressed ~~the button~~ after the fire appeared~~s~~. The ~~It was then rotated the~~ dimmer was then rotated to set the blower speed. The ~~Put the~~ blower was set at a low rate first. The air produced by the blower ~~will~~ flowed through~~in~~ the holes of the furnace so that it could~~an~~ provide enough oxygen into the furnace.

The hole of ~~sourced from~~ the wind-turning pressure furnace was ~~to~~ tilted downwards so that the air column could rotate and blow toward~~s~~ the bottom. It caused~~s~~ the ~~fibre~~fiber to spin, and the air that blew~~ows~~ towards the bottom could~~an~~ hit the ~~bio pellet~~biopellet parts that were~~is~~ burning.

2.4. Functional Design

The functional design of the furnace and ~~bio pellet~~biopellet stove with rotational wind pressure can be seen in Figure 1 ~~include~~:

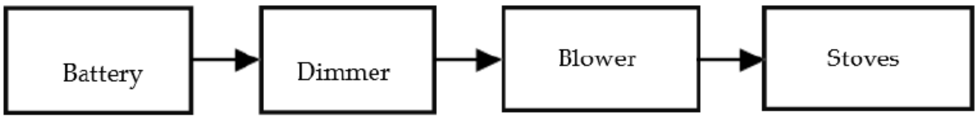

Figure 1. The functional design of the ~~bio pellet~~biopellet stove.

(1) The ~~B~~battery

It serves as a source of energy in the blower. The battery used is in the form of a dry battery, which~~ith~~ produces ~~the power produced by~~ 12 V of power;~~.~~

(2) The d~~D~~immer;~~,~~ this tool is worn to regulate the speed of the blower so that the furnace receives~~gets~~ the required intake of air.

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(3) The b~~B~~lower:~~,~~ this tool serves to provide air intake to~~in~~ the stove so that it requires low speed.
(4) The b~~B~~lower is made sufficient so that the flame can be perfect and does not cause soot. ~~and~~
(5) The furnace is the part of the ~~bio pellet~~biopellet stove that ~~to~~ burns the ~~bio pellet~~bio-pellets to heat-resistant 139 materials. The stove can be removed from the furnace so that treatment on the stove is more accessible.

2.5. Structural Design

The structural design aims to regulate the design of an existing stove by paying attention to every part of the stove that can withstand the load it holds. The stove's design, size, and materials should be selected based on the available costs, the ease of obtaining materials, and the durability of the materials used.

This wind round pressure ~~bio pellet~~biopellet stove has a tube shape with a height of 32 cm and a diameter of 26 cm. During~~In~~ combustion, the tube has a diameter of 10.5 cm, ~~with~~ a height of 22.5 cm, and ~~has~~ air holes that ~~are~~ spiral and tilt~~ed~~ so that the air path obtained from the blower can make the wind rota~~te~~ry ~~on~~ in the tube. The goal is to simulate the air so that the soot that ~~will~~ comes out is ~~can be~~ lost and does not leave marks~~not make a rub~~ on the back of the cookware. The developmental design model of the biomass stove can be seen in Figures 2 and 3.

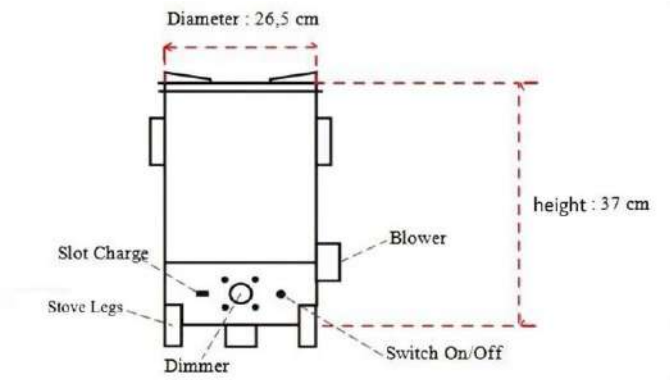

Figure 2. How the ~~B~~biomass stove appears from the front on the frame of the stove.

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Figure 3. The front of the ~~bio pellet~~biopellet stove ~~own~~ equipment.

On the stove's edge (Figure 2), there is a blower hole with a diameter of 7 cm, and the stove has~~'s~~ ~~legs~~ as many as three ~~seeds~~legs. ~~So~~Thus, ~~that~~ the furnace can still be balanced when used on the ground. The blower aims to increase the wind column that goes into the tube. The blower seeks to improve the wind column that goes into the box.

2.6. Stove Feasibility Testing

Stove testing was i~~I~~mplemented ~~stove testing~~ to find out if the quality and function of the stove always ~~to~~ worked well and efficiently. The data needed for the stove tests are~~is~~ the amount of ~~bio pellet~~biopellet (kg), the heat, the number of emissions produced, and the length of combustion time (minutes). ~~Testing~~ T~~t~~he feasibility of the stove was tested using~~is carried out with~~ the following steps.~~:~~

The d~~D~~etermination of stove parameters based on heat parameters and emission results is ~~to be~~ tested when making the stove. ~~So~~Thus, it is necessary~~eded~~ to ~~for the~~ assess~~ment of~~ the feasibility of the furnace. According to Santi and Said [22], the formula for determining the amount of heat required to raise the temperature of an object is as follows:

$$Q = m \times c \times \Delta T \quad (2)$$

Information:
Q = A lot of heat is needed~~.~~ (J);~~,~~
m = Mass of substances (kg);~~,~~
c = Heat type of substance (J/kg °C);~~,~~
ΔT = Temperature difference (°C).

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~~Implemented d~~Data analysis was implemented to find out the suitability of the research results found in the ~~conducted with~~ existing literature. The analysis conducted in this study was on the effect of blower speed on the cooking process, heat, and total emissions. Thi~~s~~e ~~retrieval~~ can ~~know~~ determine the suitability of the ~~analysis~~ analyzed results of the data and calculations carried out.

3. Results and Discussion

This section ~~may be~~is divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

3.1. Subsection

Based on the research results on the design of the dimension and shape of the stove and modifications to the furnace hole that can determine the best biomass stove, ~~based on~~ the number of holes in the combustion furnace and the size of the output hole (located at the top of the furnace) were determined. ~~The~~ A picture of the biomass stove can be seen in Figure 3.

3.2. Figures, Tables and Schemes

According to Nurhilal [23], thermal efficiency is the ratio between the calorific value used to heat water and ~~with~~ the heat generated by the ~~bio-pellet~~biopellets. The formula for determining the ~~amount of efficiency~~ thermal efficiency is as follows:

$$nT = \frac{ma \times ca \times \Delta T + \Delta ma \times L}{\Delta mk \times LHV} \times 100\% \quad (3)$$

Wind Round Pressure-Based Stove Frame

The w~~W~~ind round pressure-based stove frame is made of stainless steel. The use of stainless-steel material aims to make the biomass stove resistant to heat and ~~more~~ durable for a longer time. Wind round pressure-based biomass stoves have a diameter of 26.5 cm, with a height of 37 cm, and consist~~ing~~ of several parts. The top of the skeleton has a diameter of 26.5 cm, with a height of 26 cm. The upper skeleton serves as the~~a~~ tube where the furnace burns. There is a~~A~~ blower hole measuring 7.5 cm in diameter on the upper frame and a blower pipe length measuring 6.5 cm. The bottom of the skeleton has a diameter of 26.5 cm, with a height of 11 cm. The lower structure serves as a place for an electrical tube to supply~~place~~ power; it has ~~with~~ an area of 20 cm × 6 cm. Finally, th~~e~~ose biomass stoves can be quickly moved to another location.

On the upper skeletal side, there is a handle. Biomass stoves are equipped with handles so that users can move furnaces quickly and safely [23]. The bottom of the stove has a buffer leg due to the circular dimensions of the stove. ~~Another effort to keep us in~~If kept in an uneven place, then we use~~d~~ the three~~3~~ support feet ~~of support~~ with a height of 12 cm.

Combustion Furnace

The combustion furnace has a diameter of 10.5 cm and a height of 24 cm. In the combustion furnace, several holes have different functions. At the top of the stove, there is a small hole measuring 3 mm in diameter. There are nine~~9~~ small holes, ~~where~~ and each hole has a distance of 1 cm. The upper holes in the furnace are tilted and spiraling~~. Serves~~ so that the air passing at the top ~~can~~ causes the fire to spin inside the stove. At the bottom of the furnace, there is an air hole with a diameter of 5 mm. The excavations at the bottom of the stove provide air circulation from the bottom of the furnace. The fire remains positioned on the upper furnace lip during~~of the~~ combustion, even though the fuel is below. Each stove has a different number of bottom holes. There are ~~3~~ three variations of

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combustion tubes, namely, combustion tubes with lower holes amounting to 9 holes, 18 holes, and 27 holes.

This combustion furnace can accommodate 800 grams of ~~bio pellet~~biopellet. Each combustion furnace has a different amount of air intake due to variations in the number of ~~other~~ lower holes.

Blower

The b~~B~~lowers used in the ~~on~~ stoves ~~use~~ are the same as blowers used ~~as Used~~ in hair dryers. The ~~Selection of~~ blowers were selected based on the speed of the dynamo in ~~on~~ the hairdryers, which is enough, and the relatively small power needed on the doer ~~is also relatively small~~, which is 12 V. The manufacture of the blowers required 12- V dynamos, electric pipe clamps, and hairdryer -~~-~~blower propellers.

Electric pipe clamps ~~are~~ were used as blower frames to attach the dynamos in the middle to avoid heat propagation coming from the stove wall.

Dimmer

The use of a dimmer serves to increase and decrease the electrical voltage of the blower. The speed of the dynamo blower (in a rotating state) helps to regulate ~~how much~~the amount of air. The amount~~size~~ of the air entering the furnace affects the heat ~~to be~~ generated by the stove. To set a ~~sizeable~~ small blower speed, ~~then~~ a dimmer with a current of 12–24 V was~~is~~ required.

Stove Performance

The heat needed to increase the temperature of an object is affected by its mass, heat type, and the temperature difference. To find out the results of the heat test, ~~then use~~ the ~~boil ing~~boiling water process was used. ~~Much of the~~Usually, the water used for such testing is 1 L. The results of the heat test can be seen in Table 1. The development of the time spent burning can be seen in Table 2. The results of the highest temperature measurements produced in combustion can be seen in Table 3. The effects of the size of the vaporized mass of water can be seen in Table 4.

Table 1. Heat c~~C~~alculation results.

No	Type of Furnace	Heat (Joule)			
		Replication 1	Replication 2	Replication 3	Average
1	Hole 9	294,954	306,030	307,261	302,748
2	Hole 18	315,465	314,235	307,671	312,457
3	Hole 27	322,439	318,747	320,388	320,525

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Table 2. The measurement of the time it took~~akes~~ to cook.

No	Type of Furnace	Time (Minutes)			
		Replication 1	Replication 2	Replication 3	Average
1	Hole 9	4.27	5.2	4.45	4.64
2	Hole 18	3.13	4.3	3.54	3.66
3	Hole 27	3.25	3.43	3.57	3.42

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Table 3. The result of the highest temperature resulting from combustion.

No	Type of Furnace	Highest Temperature (°C)			
		Replication 1	Replication 2	Replication 3	Average
1	Hole 9	328.00	361.10	336.40	341.83
2	Hole 18	335.80	387.70	368.70	364.07
3	Hole 27	346.00	399.40	370.60	372.00

Table 4. The result of calculating the mass of evaporated water.

. No	Type of Furnace	Mass of Water Vapor (kg)			
		Replication 1	Replication 2	Replication 3	Average
1	Hole 9	0.035	0.034	0.045	0.038
2	Hole 18	0.054	0.05	0.051	0.052
3	Hole 27	0.055	0.06	0.069	0.061

Based on the table data above, we know that each repetition of calculations obtained an average furnace heat of ~~with hole 9 holes of~~ 30.28 kJ with 9 holes, an average furnace heat of 31.25 kJ with ~~hole~~ 18 holes ~~of 31.25 kJ~~, and a moderate furnace heat of 32.05 kJ with ~~hole~~ 27 holes ~~of 32.05 kJ~~. This~~It~~ proves that the difference in oxygen intake due to the difference in holes in the furnace can affect the small amount of heat produced during combustion. The higher the heat value created by the stove, the higher the temperature produced, and the higher the temperature made when burning causes~~ing~~ the cooking time to be faster~~. But~~. However, excessively high air intake in the furnace can also~~,~~ cause combustion fires in~~on~~ unstable stoves.

Thermal Efficiency Test Results

The thermal efficiency of biomass stoves is obtainable by comparing the heat used to cook water with the heat produced from the ~~bio-pellet~~biopellets. Each ~~bio-pellet~~biopellet furnace has a diffe-rent thermal efficiency calculation. Knowing the thermal efficiency analysis requires the results of latent heat calculations, ~~the results of bio-pellet~~biopellet mass calculations, and ~~the results of heat~~ calculations for the heat produced by the fuel. Based on the data, ~~namely~~ the average thermal ~~the~~ efficiency of stoves with ~~holes~~ 9 holes was ~~by~~ 10.85%, the average thermal efficiency of stoves with 18 ~~holes 18 by~~holes –was 9.82%, and the average thermal efficiency of stoves with ~~holes~~ 27 holes ~~by~~ was 9.42%. It can be concluded that furnaces with ~~holes~~ as many as 27 holes have the lowest thermal efficiency. The ~~more~~ increased air intake in the stove~~, it~~ causes a ~~the~~ faster ~~the~~ combustion rate, so the mass of fuel needed to cook the water, which was 0.27 kg, ~~is~~ was also ~~more and more~~increased~~, which is 0.27 kg~~.

After completing the test, the data obtained the average thermal efficiency of the furnace with ~~hole~~ 9 holes ~~by~~ (10.85%), ~~the average thermal efficiency of~~ the stove with ~~hole~~ 18 holes ~~of~~ (9.82%), and ~~the average thermal efficiency of~~ the furnace with ~~hole~~ 27 holes ~~by~~ (9.42%). The fuel needed to cook 1 L of water in each furnace was~~is~~ also different. Furnaces with ~~holes~~ 9 holes required 0.199 kg of ~~bio-pellet~~biopellet, those with ~~holes~~ 18 holes required 0.248 kg ~~bio-pellet~~ of biopellet, and furnaces with ~~holes~~ 27 holes required 0.273 kg of ~~bio-pellet~~biopellet. Furnaces with ~~holes of~~ 27 holes ha~~ve~~d the lowest efficiency. ~~It~~ This is due ~~—~~ to the increased mass of ~~bio-pellet~~biopellet used to cook compared to the~~more than~~ other furnaces. Based on the results of statistical tests, the value F calculates less than the F table. Th~~en it~~is means that Ho is accepted. It shows no real difference between the number of holes in the furnace and the thermal 296 efficiency. Each stove has different thermal efficiency results, but the 297 difference ~~is not 297~~ is not accurate.

Wind Round Pressure-Based Stove Emission Test Results

When burning stoves with biomass fuel, sometimes ~~still occur~~ imperfect combustion still occurs, and imperfect combustion produces CO. With t~~T~~he higher ~~the~~ level of CO made by the furnace, the explosion created becomes imperfect [24]. Based on the data in the table above, furnaces with ~~holes~~ 9 holes ~~have~~ had emissions of 3 ppm, furnaces with ~~holes~~ 18 holes ~~have~~ had an emission result of 2 ppm, and stoves with ~~holes~~ 27 holes ~~have~~ had emissions of 1.5 ppm. The data above show~~s~~ that the furnaces ~~with holes with~~ with the highest oxygen intake ~~have~~ had the lowest CO levels. ~~In~~ F~~f~~urnaces with ~~holes~~ 27 holes also ~~have~~ had the highest combustion temperature;~~,~~ they ~~it~~ can also ~~cause~~ have low~~-~~CO gas produc~~ed~~tioned when burning. According to Inayati [23], biomass furnaces passed the CO gas test if CO gas emissions did not exceed 67,000 ppm. The data above show~~s~~ that all the furnaces ~~have~~ me~~e~~et the standard because the CO gas produced ~~is~~was below 67,000 ppm;~~,~~ ~~which~~ furnaces with ~~holes of~~ 27 holes ha~~ve~~d the most negligible average ~~result of~~ CO gas, which ~~is~~was 1.5 ppm, so ~~that~~ its use is more efficient.

According to Nurhilal [24], imperfect combustion often produces carbon monoxide (CO) in the combustion process. Each furnace with a different number of holes has different CO gas emission results. After conducting emissions tests, the average CO emissions in the 9-hole furnace was ~~hole 9 of~~ 3 ppm, CO emissions in the 18-hole furnace ~~hole 18~~ amounted to 2 ppm, and CO emissions in the 27-hole furnace ~~hole 27~~ amounted to 1.5 ppm. From the data above, the higher the oxygen intake 317 given, the smaller the CO gas produced when burning. The temperature at combustion 318 also ~~affects~~ affected the CO gas produced. The higher the combustion temperature, the smaller the emission gas produced. F~~rom the~~or testing ~~of~~ emission gases of ~~above all~~ furnaces, by the standards provided by the National Standardization Agency [25], the emission gas ~~is~~ was low, at 67,000 ppm~~. But~~. However, the ~~a~~ stove with ~~hole~~ 27 holes produce~~s~~d the most negligible exhaust emission gas, so its use ~~is~~ was more efficient. In the results of statistical tests, the value of F calculate~~s~~d ~~isa~~was smaller than the T~~t~~able F, which means H0 ~~is~~ was accepted. The results showed no noticeable difference between the number of holes in the furnace and the emissions produced. Each stove ~~has~~ had different emissions results, but the difference ~~is~~ was not accurate.

Best Biomass Stove ~~Stoves~~

Based on the various tests above, the biomass stove ~~stoves~~ with the best results and efficiency can be ~~known~~determined. The best biomass stove is a furnace with ~~a hole of~~ 27 holes.

Based on Figure 4 above, this furnace has the highest average heat of 320,524 kJ and ~~has~~ the lowest emission~~s~~ yield of 1.5 ppm~~. But~~. However, th~~is~~e biomass furnace has the lowest ~~amount of~~ thermal efficiency, ~~which is~~at 9.42%. The stove with ~~hole~~ 27 holes has the highest combustion result, so ~~that~~ the fuel needed is also increased ~~more and more~~. This can happen because the ~~more~~ increased holes in the furnace~~heat, the~~ lower the efficiency, which can lead to the occurrence of fuel wastage~~.~~ (342). ~~So~~Thus, in this case, the ~~hole~~ 27-hole furnace produces the highest heat but most wasteful combustion;~~,~~ therefore, ~~so~~ the~~it is~~ 343 ~~necessary for~~ 18-hole furnace~~18~~ is ~~as~~ the most moderate ~~hole~~ because the efficiency is lower, but the heat is higher than the 9-hole ~~9~~.

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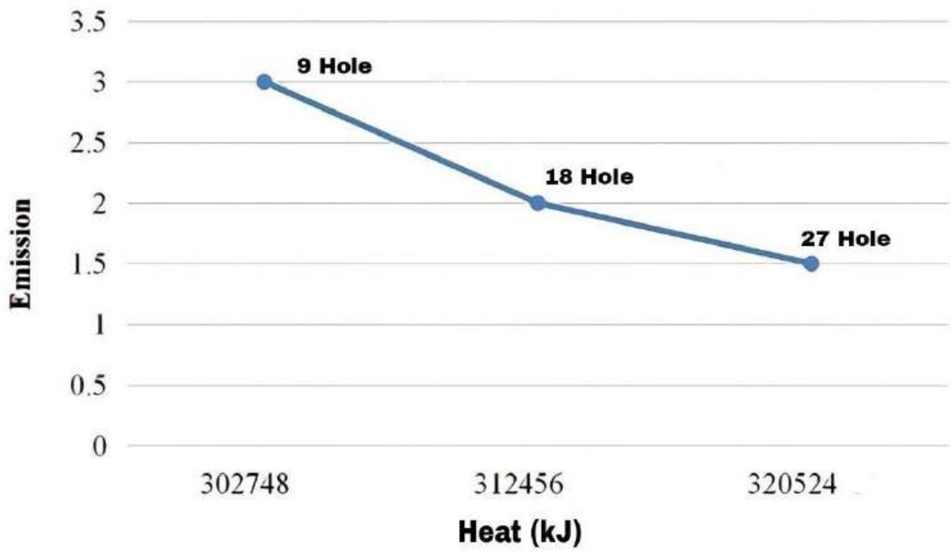

Figure 4. The efficiency of use of stoves.

4. Conclusions

Based on the results obtained by ~~of~~ this research, ~~obtained~~ the conclusion is that wind-based ~~bio-pellet~~biopellet stoves can minimize briquette combustion emissions; the more holes in the furnace, the more significant the heat produced~~,~~ and the lower the thermal efficiency, which~~and~~ minimizes the emission gas produced. The f~~F~~urnace with ~~9~~ nine holes had~~s~~ a heat of 302,748 kJ, ~~the~~ a thermal the efficiency of 10.85%, and a CO gas emissions~~s~~ of 3 ppm. The f~~F~~urnace with 18 holes produced~~s~~ a~~the~~ heat of 312,456.99 kJ,~~;~~ a thermal efficiency of 9.82%, and a~~;~~ CO emissions~~s~~ of 2 ppm. The ~~A~~ furnace with 27 holes had~~ve~~ a heat of 320,524 kJ, a~~;~~ thermal efficiency of 9.42%,~~;~~ and a CO emissions~~s~~ of 1.5 ppm. The best biomass stove is ~~in a~~the furnace with 27 holes. This~~ese~~ stove furnaces~~s~~ has~~ve~~ the highest heat and the lowest CO exhaust emissions but has~~ve~~ the lowest thermal efficiency.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: title; Table S1: title; Video S1: title.

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Abstract In this study, coffee husk was used as the primary material to produce biopellets, with a mixture of tapioca flour and molasses as a binder. The concentration of each binder used was 10, 15, and 20%. The addition of tapioca flour and molasses at different concentrations increased the biopellets density, ash content, and fixed carbon content, and reduced moisture content and volatile matter content. The best formulation was obtained by adding 10% tapioca flour; it had a biopellet density of 610 kg/m^3, an ash content of 3.03%, a moisture content of 8.03%, a volatile matter content of 81.79%, a fixed carbon content of 15.18%, a calorifi value of 17.55 MJ/kg, a water-boiling time of 10 min, a fuel consumption rate of 0.008 kg/min, and a therma efficiency of 33.15%. The design results were obtained using the distance from (diameter = 26.5 cm and height = 37 cm) the stove to the outside of the furnaces (this amounts to 8 cm, which can minimize the

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height = 37 cm) the stove to the outside of the furnaces (this amounts to 8 cm, which can minimize the furnace, causing heat to generate from burning). The speed of the blowers can be adjusted by users using a dimmer. The results obtained from the stove's performance showed the average thermal efficiency of the furnace, which with an average of 3.25 ppm.

Keywords coffee husk; tapioca flour; molasses; biopellet; thermal efficiency; CO emission

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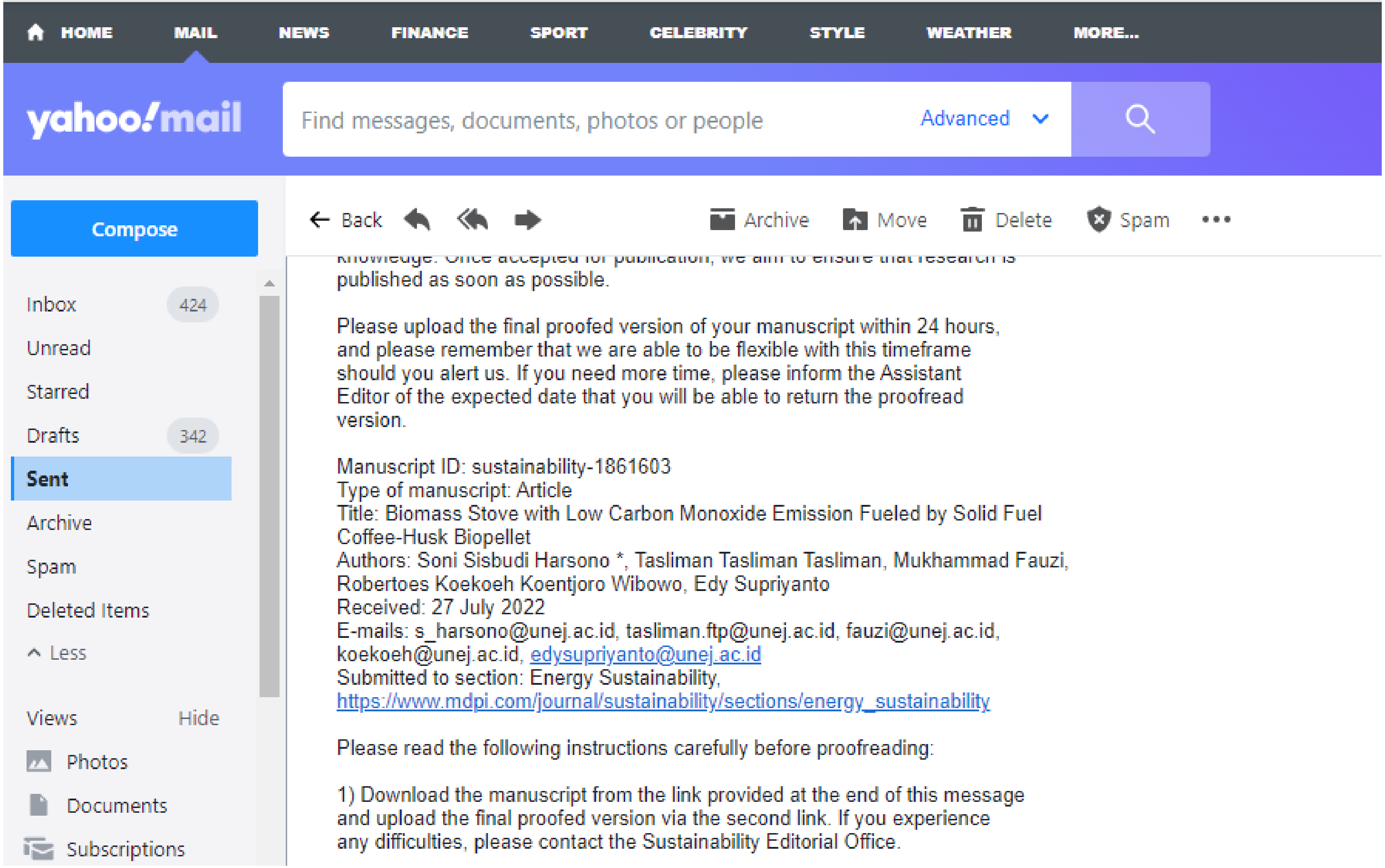

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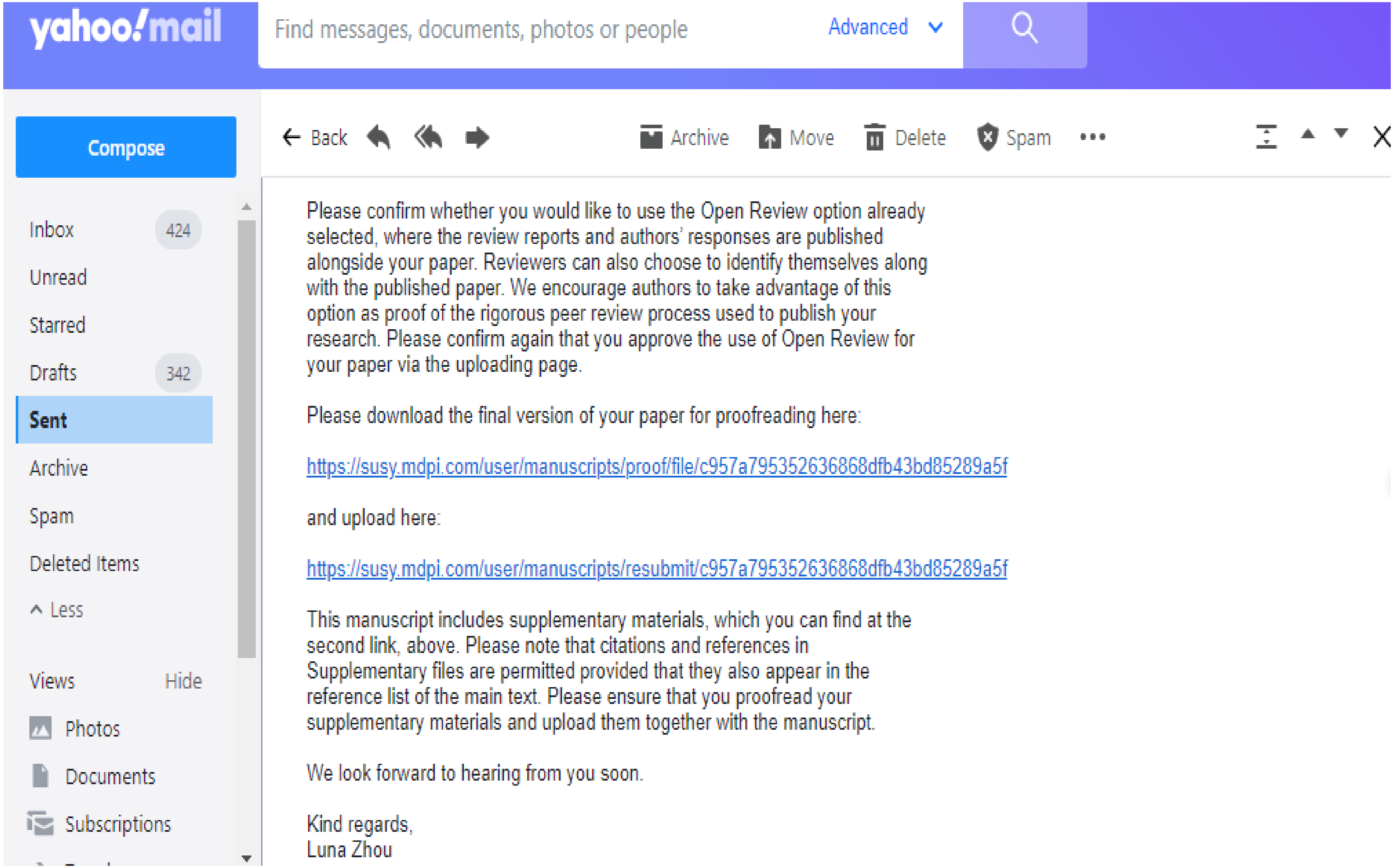

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Article

Biomass Stove with Low Carbon Monoxide Emission Fueled by Solid Fuel Coffee-Husk Biopellet

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Abstract: In this study, coffee husk was used as the primary material to produce biopellets, with a mixture of tapioca flour and molasses as a binder. The concentration of each binder used was 10, 15, and 20%. The addition of tapioca flour and molasses at different concentrations increased the biopellets density, ash content, and fixed carbon content, and reduced moisture content and volatile matter content. The best formulation was obtained by adding 10% tapioca flour; it had a biopellet density of 610 kg/m^3, an ash content of 3.03%, a moisture content of 8.03%, a volatile matter content of 81.79%, a fixed carbon content of 15.18%, a calorific value of 17.55 MJ/kg, a water-boiling time of 10 min, a fuel consumption rate of 0.008 kg/min, and a thermal efficiency of 33.15%. The design results were obtained using the distance from (diameter = 26.5 cm and height = 37 cm) the stove to the outside of the furnaces (this amounts to 8 cm, which can minimize the furnace, causing heat to generate from burning). The speed of the blowers can be adjusted by users using a dimmer. The results obtained from the stove's performance showed the average thermal efficiency of the furnace, which with an average of 3.25 ppm.

Keywords: coffee husk; tapioca flour; molasses; biopellet; thermal efficiency; CO emission

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1. Introduction

Indonesia needs to find alternative fuels due to the reduced availability of fossil fuel sources caused by the increasing consumption of the population [1,2]. One of the most commonly used briquette stove fuels is coal [3]. However, using coal as a fuel for briquette stoves still produces bad exhaust emissions due to the combustion process [3,4]. Research and studies conducted by Zhi et al. [4] in the laboratory found that coal briquette stoves still produced very high carbon monoxide (CO) gas, with a multiple of 100 ppm, which can reach a magnitude of 7. Biopellet is a solid, biomass-based fuel in a tubular solid form, which has uniform size, shape, humidity, density, and energy content. Compared to briquettes, biopellets have better density and size uniformity [5,6].

Biopellet is a biomass that is converted and used as fuel using the densification technique [7]. The densification technique aims to increase the density of a material and facilitate storage and transportation [8]. Biomass conversion can increase the calorific value per unit volume, size uniformity, quality, and ease of storage or transportation. The main factors affecting the strength and durability of the pellets are the raw materials, moisture content, particle size, compression conditions, adhesive addition, densification tools, and the treatment after the production process [9]. The potential waste obtained from the coffee-processing stage is coffee skin, consisting of wet fruit skin, liquid waste containing mucus, dry skin spindles, and dry shells [10]. Coffee skin is a by-product that makes up between 50 and 60% of the harvest [11]. If 1000 kg of fresh skinned coffee is harvested, then the coffee beans would amount to about 400–500 kg, and the rest would be a by-product in the form of the coffee husk [10,11].

According to Widyotomo [12], coffee bean production in Indonesia reaches 611,100 tons and produces 1,000,000 tons of coffee husk. It is known, 55% of coffee skin is plantation waste [13]. Coffee skin contains a high calorific value, a water content of 75–80%, and quite a low sulfur content. The raw coffee rind contains high levels of water (2.2%), 0.73% ash, 74.20% volatile, and 25.07% solid carbon [14]. Coffee fruit skin contains 10.78% crude protein and 33.13% crude fiber. In addition, coffee fruit skin contains 24.67% lignin and 20.22% cellulose [14,15]. Coffee solid waste, such as fruit peels, shells, and coffee beans, have the potential to be processed into useful materials used as ingredients for alternative renewable fuels. Solid coffee waste, such as fruit peels and coffee beans, have the potential to be converted into useful feedstock for alternative renewable fuels [15]. Research on the economics of biopellets made from coffee husks in Indonesia was conducted by Rusdianto et al. [16] who showed that the biopellet coffee sector satisfies the requirements for financial viability in the Jember Regency of Indonesia by using financial analysis techniques such as sensitivity analysis, break-even point (BEP), payback ratio, net present value (NPV), internal rate return (IRR), net benefit, and cost ratio (BC) ratio.

2. Materials and Methods

2.1. Tools and Materials

The tools used in this study included electric welders, cut pliers, drills, wrenches, screwdrivers, scales, thermometers, measuring glasses, gas analyzers, stationery, and cameras. The wood powder waste used was a type of zinc wood. Another material used was stainless steel, which was used as a stove-making material.

A stove is a combustion device that produces high heat [17,18]. The types of stoves that are commonly used by the public today are gas stoves and kerosene stoves [19]. Since the government established a policy to switch the use of kerosene fuel to gas, there has been an increase in gas stoves, causing gas demand to increase. Natural gas reserves, as with all fossil fuels, are decreasing in availability every year. Therefore, a stove with biopellet fuel was developed to prevent a conventional fuel crisis.

During the combustion process, a sufficient air supply is necessary. The biopellet fuel is placed in a perforated place to drain the primary air. After supplying air during the combustion process, the installed air regulators regulate air induction in the stove to regulate the output power of the furnace.

According to previous research [20], existing biopellet stoves produce a combustion quality that is not optimal, the air supply is still lacking, CO gas emissions still exceed the threshold, and the actual efficiency is still tiny. Therefore, it is necessary to review the performance of biopellet stoves by maximizing the air supply and mass of the biopellets so that maximum combustion quality, low CO gas emissions, and high thermal efficiency are obtainable. The volume of air in the performance of the biomass stove and combustion efficiency are analyzed to obtain optimal production.

2.2. Combustion Performance of Biopellet Stoves

Carbon monoxide (CO) emissions are obtainable by burning biomass in stoves [20]. These emissions can cause air pollution with CO gas, sulfur, nitrogen oxides, and hydrocarbons [21]. In this study, exhaust gases are also measured as co-exhaust gas levels because emission levels show the perfection or imperfection of the combustion process. The insufficient oxidation processes of the hydrocarbons and carbons included in the biopellets result in CO emissions.

Thermal efficiency compares the heat value produced by water and the heat value produced by biopellets. In this study, calculations to determine the magnitude of efficiency are defined in the following equations [17]:

$$n_T = m_a \times c_a \times \Delta T + \Delta m_b \times \mathrm{L} \quad (1)$$

Here, m_a = water mass (kg), Δm_a = evaporated water mass (kg), L = latent heat of water = 2,268,000 (J/kg), ΔT = change in temperature (°C), Δm_b = mass of fuel burned (kg), c_a = water type heat = 4186 (J/kg), and LHV (low heating value) = enthalpy of biopellet (20,974 kJ/kg).

2.3. Operational Plan

In the first operational design of the stove, the biopellets were inserted through the top of the furnace (approximately 700–800 g), then the biopellets were turned on using denatured alcohol as the starter, and the button was pressed after the fire appeared. The dimmer was then rotated to set the blower speed. The blower was set at a low rate first. The air produced by the blower flowed through the holes of the furnace so that it could provide enough oxygen into the furnace.

The hole of the wind-turning pressure furnace was tilted downwards so that the air column could rotate and blow toward the bottom. It caused the fiber to spin, and the air that blew toward the bottom could hit the biopellet parts that were burning.

2.4. Functional Design

The functional design of the furnace and biopellet stove with rotational wind pressure can be seen in Figure 1:

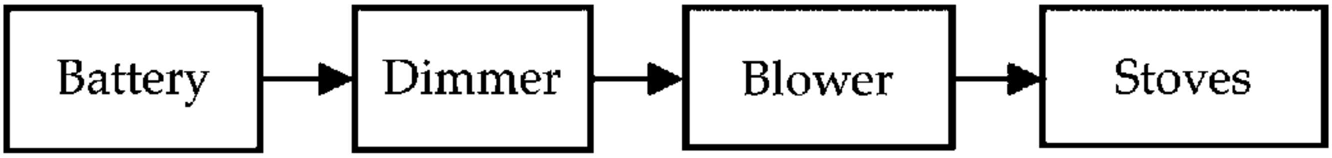

Figure 1. The functional design of the biopellet stove.

(1) The battery: serves as a source of energy in the blower. The battery used is in the form of a dry battery, which produces 12 V.
(2) The dimmer: this tool is worn to regulate the speed of the blower so that the furnace receives the required intake of air.
(3) The blower: this tool serves to provide air intake to the stove so that it requires low speed.
(4) The blower is made sufficient so that the flame can be perfect and does not cause soot.
(5) The furnace is the part of the biopellet stove that burns the biopellets to heat- resistant materials. The stove can be removed from the furnace so that treatment on the stove is more accessible.

2.5. Structural Design

The structural design aims to regulate the design of an existing stove by paying attention to every part of the stove that can withstand the load it holds. The stove's design, size, and materials should be selected based on the available costs, the ease of obtaining materials, and the durability of the materials used.

This wind-round pressure biopellet stove has a tube shape with a height of 37 cm and a diameter of 26.5 cm. During combustion, the tube has a diameter of 10.5 cm, a height of 26.5 cm, and air holes that spiral and tilt so that the air path obtained from the blower can make the wind rotate in the tube. The goal is to simulate the air so that the soot that comes out is lost and does not leave marks on the back of the cookware. The developmental design model of the biomass stove can be seen in Figures 2 and 3.

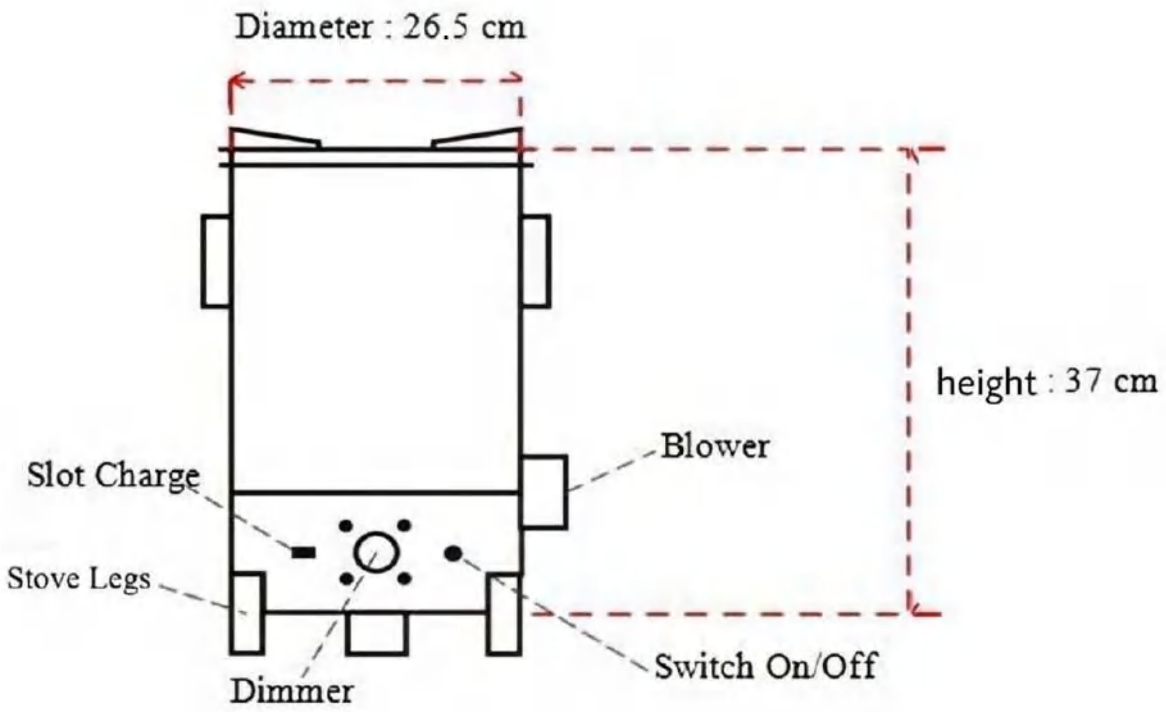

Figure 2. Position of the front biomass stove.

Figure 3. The front of the biopellet stove equipment.

At the end of the stove (Figure 2), there is a vent with a diameter of 7 cm, and this stove has three supports. Thus, the furnace can still be balanced when used on the ground. The blower aims to increase the wind column that goes into the tube. The blower seeks to improve the wind column that goes into the box.

2.6. Stove Feasibility Testing

Stove testing was implemented to find out if the quality and function of the stove always worked well and efficiently. The data needed for the stove tests are the amount of biopellet (kg), the heat, the number of emissions produced, and the length of combustion time (minutes). The feasibility of the stove was tested using the following steps.

The determination of stove parameters based on heat parameters and emission results is tested when making the stove. Thus, it is necessary to assess the feasibility of the furnace. According to Santi et al. [22], the following is a formula for calculating how much heat is needed to raise an object's temperature:

$$Q = m \times c \times \Delta T \quad (2)$$

Information:

Q = A lot of heat is needed (J);
m = Mass of substances (kg);
c = Heat type of substance (J/kg °C);
ΔT = Temperature difference (°C).

Data analysis was implemented to find out the suitability of the research results found in the existing literature. The analysis conducted in this study was on the effect of blower speed on the cooking process, heat, and total emissions. This can determine the suitability of the analyzed results of the data and calculations carried out.

3. Results and Discussion

Based on the research results on the design of the dimension and shape of the stove and modifications to the furnace hole that can determine the best biomass stove, the number of holes in the combustion furnace and the size of the output hole located at the top of the furnace were determined. Figure 3 shows an image of the biomass stove.

According to Nurhilal [23], thermal efficiency is the ratio between the calorific value used to heat water and the heat generated by the biopellets. The following equation may be used to calculate thermal efficiency:

$$n_T = \frac{m_{\mathrm{a}} \times c_{\mathrm{a}} \times \Delta T + \Delta m_{\mathrm{a}} \times \mathrm{L}}{\Delta m_{\mathrm{k}} \times \mathrm{LHV}} \times 100\% \quad (3)$$

3.1. Wind Round Pressure-Based Stove Frame

The wind-round pressure-based stove frame is made of stainless steel. The use of stainless-steel material aims to make the biomass stove resistant to heat and durable for a longer time. Wind round pressure-based biomass stoves have a diameter of 26.5 cm, with a height of 37 cm, and consist of several parts. The top of the skeleton has a diameter of 26.5 cm, with a height of 26 cm. The upper skeleton serves as the tube where the furnace burns. There is a blower hole measuring 7.5 cm in diameter on the upper frame and a blower pipe length measuring 6.5 cm. The bottom of the skeleton has a diameter of 26.5 cm, with a height of 11 cm. The lower structure serves as a place for an electrical tube to supply power; it has an area of 20 cm × 6 cm. Finally, these biomass stoves can be quickly moved to another location.

On the upper skeletal side, there is a handle. Biomass stoves are equipped with handles so that users can move furnaces quickly and safely [23]. The bottom of the stove has a buffer leg due to the circular dimensions of the stove. If the place of the stove mat is not there, we can use three supporting legs with a height of 12 cm.

3.2. Combustion Furnace

The combustion furnace has a diameter of 10.5 cm and a height of 24 cm. In the combustion furnace, several holes have different functions. At the top of the stove, there is a small hole measuring 3 mm in diameter. There are nine small holes, and each hole has a distance of 1 cm. The upper holes in the furnace are tilted and spiraling so that the air passing at the top causes the fire to spin inside the stove. At the bottom of the furnace, there is an air hole with a diameter of 5 mm. The excavations at the bottom of the stove provide air circulation from the bottom of the furnace. The fire remains positioned on the upper furnace lip during combustion, even though the fuel is below. Each stove has a different number of bottom holes. There are three variations of combustion tubes, namely, combustion tubes with lower holes amounting to 9-holes, 18-holes, and 27-holes. This combustion furnace can accommodate 800 g of biopellet. Each combustion furnace has a different amount of air intake due to variations in the number of lower holes.

3.3. Blower

The blowers used in the stoves are the same as blowers used in hair dryers. The blowers were selected based on the speed of the dynamo in the hairdryers, which is enough, and the relatively small power needed on the doer, which is 12 V. The manufacture of the blowers required 12 V dynamos, electric pipe clamps, and hairdryer-blower propellers. Electric pipe clamps were used as blower frames to attach the dynamos in the middle to avoid heat propagation coming from the stove wall.

3.4. Dimmer

The use of a dimmer serves to increase and decrease the electrical voltage of the blower. The speed of the dynamo blower (in a rotating state) helps to regulate the amount of air. The amount of air entering the furnace affects the heat generated by the stove. To set a small blower speed, a dimmer with a current of 12–24 V was required.

3.5. Stove Performance

The heat needed to increase the temperature of an object is affected by its mass, heat type, and temperature difference. To find out the results of the heat test, the boiling water process was used. Usually, the water used for such testing is 1 L. Table 1 shows the results of the heat resistance test. Table 2 shows the change in burning time. Table 3 shows the results of maximum temperature measurements during combustion. The effects of the size of the vaporized mass of water can be seen in Table 4.

Table 1. Heat calculation results.

No	Heat (Joule)				
	Type of Furnace	**Replication 1**	**Replication 2**	**Replication 3**	**Average**
1	9-holes	294.954	306.030	307.261	302.748
2	18-holes	315.465	314.235	307.671	312.457
3	27-holes	322.439	318.747	320.388	320.525

Table 2. The measurement of the time it took to cook.

No	Time (min)				
	Type of Furnace	**Replication 1**	**Replication 2**	**Replication 3**	**Average**
1	9-holes	4.27	5.2	4.45	4.64
2	18-holes	3.13	4.3	3.54	3.66
3	27-holes	3.25	3.43	3.57	3.42

Table 3. The result of the highest temperature resulting from combustion.

No	Highest Temperature (°C)				
	Type of Furnace	Replication 1	Replication 2	Replication 3	Average
1	9-holes	328.00	361.10	336.40	341.83
2	18-holes	335.80	387.70	368.70	364.07
3	27-holes	346.00	399.40	370.60	372.00

Table 4. The result of calculating the mass of evaporated water.

No	Type of Furnace	Mass of Water Vapor (kg)			
		Replication 1	Replication 2	Replication 3	Average
1	9-holes	0.035	0.034	0.045	0.038
2	18-holes	0.054	0.05	0.051	0.052
3	27-holes	0.055	0.06	0.069	0.061

Based on the table data above, we know that each repetition of calculations obtained an average furnace heat of 30.28 kJ with 9-holes, an average furnace heat of 31.25 kJ with 18-holes, and a moderate furnace heat of 32.05 kJ with 27-holes. This proves that the difference in oxygen intake due to the difference in holes in the furnace can affect the small amount of heat produced during combustion. The higher the heat value created by the stove, the higher the temperature produced, and the higher the temperature made when burning causes the cooking time to be faster. However, excessively high air intake in the furnace can also cause combustion fires in unstable stoves.

3.6. Thermal Efficiency Test Results

The thermal efficiency of biomass stoves is obtainable by comparing the heat used to cook water with the heat produced from the biopellets. Each biopellet furnace has a different thermal efficiency calculation. Knowing the thermal efficiency analysis requires the results of latent heat calculations, biopellet mass calculations, and calculations for the heat produced by the fuel. Based on the data, the average thermal efficiency of stoves with 9-holes was 10.85%, the average thermal efficiency of stoves with 18-holes was 9.82%, and the average thermal efficiency of stoves with 27-holes was 9.42%. It can be concluded that furnaces with as many as 27-holes have the lowest thermal efficiency. The increased air intake in the stove causes a faster combustion rate, so the mass of fuel needed to cook the water, which was 0.27 kg, was also increased.

After completing the test, the data obtained the average thermal efficiency of the furnace with 9-holes (10.85%), the stove with 18-holes (9.82%), and the furnace with 27-holes (9.42%). The fuel needed to cook 1 L of water in each furnace was also different. Furnaces with 9-holes required 0.199 kg of biopellet, those with 18-holes required 0.248 kg of biopellet, and furnaces with 27-holes required 0.273 kg of biopellet. Furnaces with 27-holes had the lowest efficiency. This is due to the increased mass of biopellet used to cook compared to the other furnaces. Based on the results of statistical tests, the value F calculates less than the F table. This means that Ho is accepted. It shows no real difference between the number of holes in the furnace and the thermal efficiency. Each stove has different thermal efficiency results.

3.7. Wind Round Pressure-Based Stove Emission Test Results

When burning stoves with biomass fuel, imperfect combustion still occurs, and imperfect combustion produces CO. With the higher level of CO made by the furnace, the explosion created becomes imperfect. According to Nurhilal [23], imperfect combustion often produces carbon monoxide (CO) in the combustion process. Each furnace with a different number of holes has different CO gas emission results. After conducting emissions tests, the average CO emissions in the 9-hole furnace was 3 ppm, CO emissions in the 18-hole furnace amounted to 2 ppm, and CO emissions in the 27-hole furnace amounted to 1.5 ppm. From the data above, the higher the oxygen intake given, the smaller the CO gas produced when burning. The temperature at combustion also affected the CO gas produced. The higher the combustion temperature, the smaller the emission gas produced.

Based on the data in Table 1 above, furnaces with 9-holes had emissions of 3 ppm, furnaces with 18-holes had an emission result of 2 ppm, and stoves with 27-holes had emissions of 1.5 ppm. The data above show that the furnaces with the highest oxygen intake had the lowest CO levels. Furnaces with 27-holes also had the highest combustion temperature; they can also have low CO gas production when burning. According to Supramono dan Inayati [24], biomass furnaces passed the CO gas test if CO gas emissions did not exceed 67,000 ppm. The data above show that all the furnaces meet the standard because the CO gas produced was below 67,000 ppm; furnaces with 27-holes had the most negligible average CO gas, which was 1.5 ppm, so its use is more efficient.

For testing emission gases of furnaces, by the standards provided by the National Standardization Agency [25], the emission gas was low, at 67,000 ppm. However, the stove with 27-holes produced the most negligible exhaust emission gas, so its use was more efficient. Each stove had different emissions results, but the difference was not accurate.

3.8. Best Biomass Stove

Based on the various tests above, the biomass stove with the best results and efficiency can be determined. The best biomass stove is a furnace with 27-holes. Based on Figure 4 above, this furnace has the highest average heat of 320,524 kJ and the lowest emission yield of 1.5 ppm. However, this biomass furnace has the lowest thermal efficiency, at 9.42%. The stove with 27-holes has the highest combustion result, so the fuel needed is also increased. This can happen because the increased holes in the furnace lower the efficiency, which can lead to the occurrence of fuel wastage. Thus, in this case, the 27-hole furnace produces the highest heat but most wasteful combustion; therefore, the stove with 18-holes is a pretty good one with its efficiency, but the heat generated is better.

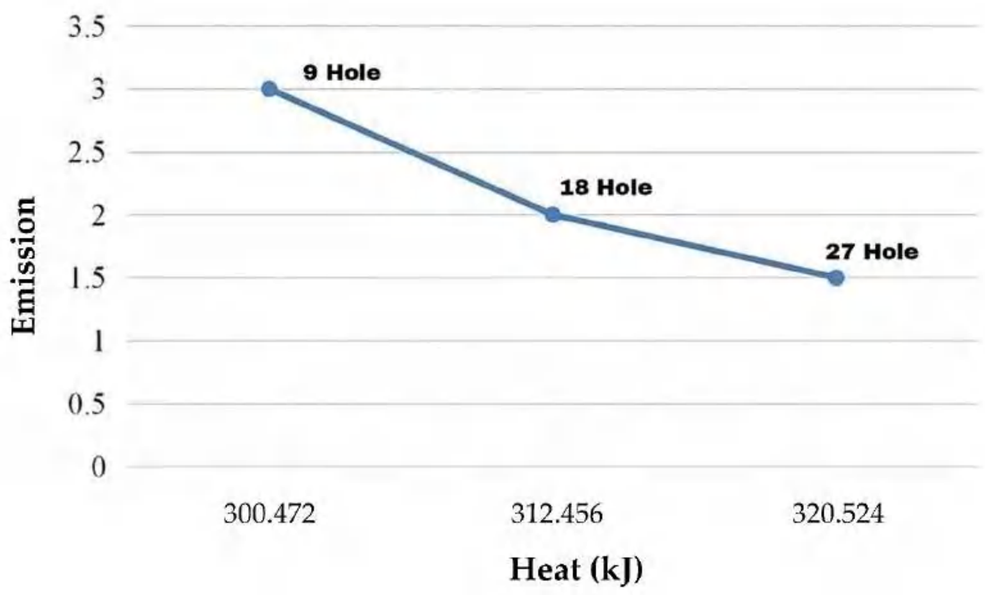

Figure 4. The efficiency of use of stoves.

4. Conclusions

Based on the results obtained by this research, the conclusion is that wind-based biopellet stoves can minimize briquette combustion emissions; the more holes in the furnace, the more significant the heat produced and the lower the thermal efficiency, which minimizes the emission gas produced. The furnace with nine holes had a heat of 302.748 kJ, the thermal efficiency of 10.85%, and a CO gas emission of 3 ppm. The furnace with 18-holes produced heat of 312.456 kJ, the thermal efficiency of 9.82%, and a CO emission of 2 ppm. The furnace with 27-holes had a heat of 320.524 kJ, the thermal efficiency of 9.42%, and a CO emission of 1.5 ppm. The best biomass stove is the 27-hole stove. This furnace stove has the highest heat output and lowest CO emissions, but the lowest thermal efficiency.

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