Volume 11. Number 2. 255-265 OCTOBER 2022

Jurnal ilmiah pendidikan fisika Al-Biruni
https://ejournal.radenintan.ac.id/index.php/al-biruni/index
DOI: 10.24042/jipfalbiruni.v11i2.14291

P-ISSN: 2303-1832
e-ISSN: 2503-023X

Optimization of Oxygen Flow Valve Holes in Small Industrial Scale Husk Furnaces

Siti Hajar[1], Nazopatul Patonah Har[1], Irmansyah[1], Ardian Arif[1], Irzaman[1*]

[1] Department of Physics, Faculty of Mathematics and Natural Sciences, IPB University, Bogor, 16680, Indonesia

*Corresponding Address: *irzaman@apps.ipb.ac.id*

Article Info

Article history:

Received: August 11, 2022
Accepted: October 22, 2022
Published: October 30, 2022

Keywords:

Efficiency;
Husk Furnace;
Optimization;
Oxygen Flow Valve Hole;
Rice Husk.

ABSTRACT

The increasing use of fossil-based fuels causes an imbalance between energy demand and the availability of that energy. Therefore, the use of rice husk biomass as alternative energy was implemented through the use of rice husk furnaces. This research aims to optimize the efficiency of a small industrial-scale husk furnace by varying the oxygen flow valve holes and the mass of the heated water. The test on the husk furnace was carried out using the Water Boiling Test (WBT) method with the following test parameters: combustion time, FCR, input power, output power, power loss, radiant energy, and thermal conductivity of the pan and chimney of the husk furnace. Tests were carried out on four variations of the oxygen flow valve holes (horizontal: 18 x 36 cm^2 and 27 x 36 cm^2, vertical: 27 x 24 cm^2 and 27 x 12 cm^2) and three variations in the mass of heated water (6 kg, 12 kg, and 18 kg). The highest efficiency of the husk furnace was obtained at 18 kg of water, and based on each test parameter, the performance of the husk furnace was most optimal at the horizontal valve hole measuring 27 x 36 cm^2 with an average efficiency of 17.32%. The variation of the heated water mass and the variation of the oxygen flow valve hole in the husk furnace showed a significant effect on the efficiency of the husk furnace.

INTRODUCTION

Fossil fuels dominate in fulfilling national energy needs (Arutyunov & Lisichkin, 2017; Kholiq, 2015). However, fossil fuels are non-renewable energy sources, so their increasing demand from year to year causes an imbalance between energy demand and the availability of these energy sources (Agung, 2013). This encourages the presence of alternative energy sources and complementary energy sources. With these various energy sources, it is hoped that non-renewable energy can be minimized while increasing the utilization of energy sources still abundant in nature. One of the alternative energies is biomass (Makul et al., 2021; Nunes et al., 2020); biomass can generate heat and electricity without causing significant greenhouse effects on the atmosphere (Hung et al., 2018).

Rice husk is one of the biomasses that used to be major renewable resources for agriculturally based countries (Akhter et al., 2021; Mofijur et al., 2019; Pujotomo, 2017). Rice husks were selected by reviewing four main indicators of energy security: availability. Accessibility, affordability, and acceptability. Availability rice husk is available in large quantities, renewable, and sustainable (Nuzul, 2010). Accessible rice husk is very easy to obtain, especially in agricultural countries. Affordability, rice

How to cite Hajar, S., Har, N., P., Irmansyah, I., Arif, A., & Irzaman, I. (2022). Optimization of oxygen flow valve holes in small industrial scale husk furnaces. *Jurnal ilmiah pendidikan fisika Al-Biruni, 11*(2), 255-265.

husk has a high enough calorific value as a biomass energy source. Acceptability, rice husk was a product-by-product of the rice milling process, tends to be discarded or regarded as waste, so it won't be a burden community in terms of access (Dewi & Ardhitama, 2020; Syahira et al., 2016).

The sustainable energy utilization of rice husks was implemented through furnaces (Susana & Alit, 2020). The shape of the husk furnace design has now been widely developed with different shapes and variations (Darmasetiawan et al., 2010; Noor et al., 2017). The husk furnace is a biomass cooking tool that has great potential to be developed in various countries, especially agriculturally based countries (Nawafi et al., 2010), but the performance of the husk furnace still needs to be evaluated to create a husk furnace with optimum efficiency (Darmasetiawan et al., 2010).

Previous research has shown that husk furnaces require maximum airflow for combustion (Darmasetiawan et al., 2010; Demiyati, 2010; Maulana, 2008). The results of Maulana's research show that the optimum efficiency is obtained by treating one air intake hole measuring 20 x 9 cm^2 with an efficiency of 18% (Maulana, 2008). In another previous study, (Darmasetiawan et al., 2010; Demiyati, 2010) varied several hole sizes on the body wall of the husk furnace. The efficiency of a hole size of 22 x 8 cm^2 was 12.92%, a hole size of 22 x 16 cm^2 was 12.87%, and a hole size of 22 x 24 cm^2 had an efficiency of 14.32%. These research studies still produce efficiency values that tend to be low. That problem can be caused by the incomplete combustion process in the husk furnace, which is influenced by the airflow entering the husk furnace that was not optimal.

Further study and evaluation need to be done to get a more optimal value of husk furnace efficiency. Therefore, this study was carried out to evaluate and determine the size of the oxygen flow valve hole that can optimize the efficiency of the husk furnace by varying the oxygen flow valve hole in the husk furnace and varying the mass of the heated water used in testing.

METHODS

This research was carried out using the Water Boiling Test (WBT) method, which is a test used to determine the performance of a furnace on a laboratory scale where climatic conditions, fuel, and how to operate the furnace were maintained the same throughout the test (Mulyanto et al., 2016). The statistical analysis method was also carried out using the two-way ANOVA test using the SPSS 25.0 for Windows program with an error degree (α) of 5%.

The materials used in the study were rice husks, which were used as fuel for the husk furnace, and water for the boiling test. The tools used include infrared thermometers, pans, pan lids, measuring cups, stopwatches, matches, scales and balances, and husk furnaces with variations of horizontal oxygen flow valve holes: 18 x 36 cm^2 and 27 x 36 cm^2, and vertical oxygen flow valve holes: 27 x 12 cm^2 and 27 x 24 cm^2. The mass of boiling water varied as much as 6 kg, 12 kg, and 18 kg. Figure 1 shows the flow chart of this research.

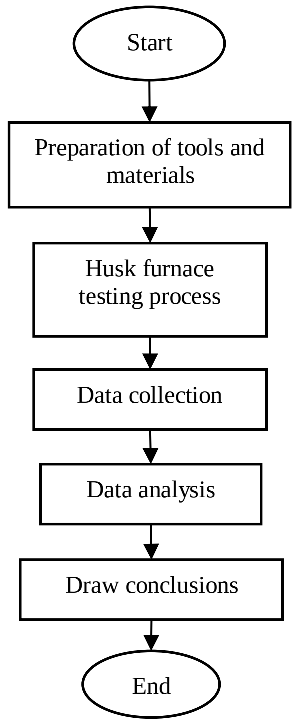

Figure 1. Research Flowchart

To increase the reliability of the measurements, each variation of the water mass used at the boiling test and each variation of the oxygen flow valve hole were tested twice. In the process of measuring the boiling time of water, temperature measurements were also carried out in several parts of the husk furnace, such as the husk coal temperature, the inner drum temperature, the outer drum temperature, the inner pottery wall temperature, the outer pottery wall temperature, the inner chimney wall temperature, the outer chimney wall temperature, the temperature of the inner wall of the frying pan, and the temperature of the outer wall of the frying pan. That data collection was carried out to determine and calculate the value of rice husk furnace efficiency by analyzing the following test parameters, such as:

1. Combustion time was measured from the beginning of putting the pan until the water boiled at a temperature of 100 ^{0}C.

2. Fuel consumption rate (FCR) to analyze the consumption rate of rice husk fuel or the ratio between the amount of fuel used and the time required for combustion. Can be calculated by the equation from Barlin (2012):

$$FCR = \frac{m_t}{t} \quad (1)$$

$$m_t = m_0 - m_1 \quad (2)$$

3. The input power (P_{in}) to analyze the heat energy contained in the rice husk fuel divided by the combustion time. The equation can calculate the pin:

$$P_{in} = \frac{m_t \ x \ HVF}{t} \quad (3)$$

4. Power out (P_{out}) to analyze the ratio of energy used to heat the water and the length of time for the water to boil. Can be calculated by the following equation: (Belonio, 2005).

$$P_{out} = \frac{m_f c\Delta T}{t} \quad (4)$$

5. Power loss (P_loss) to analyze the loss of energy during the combustion process can be calculated by the equation:

$$P_{loss} = P_{in} - P_{out} \quad (5)$$

6. Radiant energy
Thermal radiation is electromagnetic radiation emitted by an object due to its temperature (Usman et al., 2017). Calculate with the theory of relativity and statistical thermodynamics according to Stefan Boltzmann's Law:

$$H = e\sigma\Delta AT^4 \quad (6$$

$$\frac{Q}{t} = e\sigma A\Delta T^4 \quad (7$$

$$\frac{Q}{t} = e\sigma A_L(T1^4 - T2^4) \quad (8$$

$$Q = e\sigma tA_L(T1^4 - T2^4) \quad (9$$

7. The thermal conductivity of the pan and the thermal conductivity of the cylindrical (chimney) plane of the husk furnace
Thermal conductivity measures a substance's ability to conduct heat (Hakim, 2016). Fourier's Law equation calculated the thermal conductivity of the pan:

$$Q = kA\left(-\frac{dT}{dx}\right) \quad (10)$$

$$Q = kA_w\left(-\frac{dT}{dx}\right) \quad (111)$$

$$Q = -kA_w \frac{(T_{lp} - T_{dp})}{dx} \quad (12)$$

$$k = -\frac{Q}{A_w \frac{(T_{lp}-T_{dp})}{dx}} \quad (13)$$

The thermal conductivity of the chimney (cylindrical section) of the husk furnace is calculated by Fourier's Law equation:

$$Q = kA\left(-\frac{dT}{dx}\right) \quad (14)$$

$$Q = kA_c\left(-\frac{dT}{dx}\right) \quad (15)$$

$$Q = kA_c\left(-\frac{(T_{lc}-T_{dc})}{(D_{lc}-D_{dc})}\right) \quad (16)$$

$$k = -\frac{Q}{A_c \frac{(T_{lc}-T_{dc})}{(D_{lc}-D_{dc})}} \quad (17)$$

8. The efficiency of the husk furnace (η) to analyze the performance of the husk furnace or the ratio between the net power used in the combustion process and the combustion power of the fuel. Can be calculated by the equation: (Mulyanto et al., 2016)

$$\eta = \frac{P_{out}}{P_{in}} \; x \; 100\% \quad (6)$$

RESULTS AND DISCUSSION

A. Husk Furnace Efficiency Analysis

1. Boiling Time and Fuel Consumption rate (FCR)

a) Comparison of FCR and combustion time according to the difference in mass variation of heated water

The rice husk fuel consumption rate was analyzed by comparing the ratio between the amount of fuel used and the time required for combustion, as shown in Figures 2 and 3. Figure 3 shows that the length of combustion time is directly proportional to the amount of mass of water heated. According to the equation by (Barlin, 2012), the FCR value is inversely proportional to the combustion time, as can be seen by comparing the results in Figures 2 and 3, which show that the greater the fuel consumption rate (FCR), the faster the combustion time.

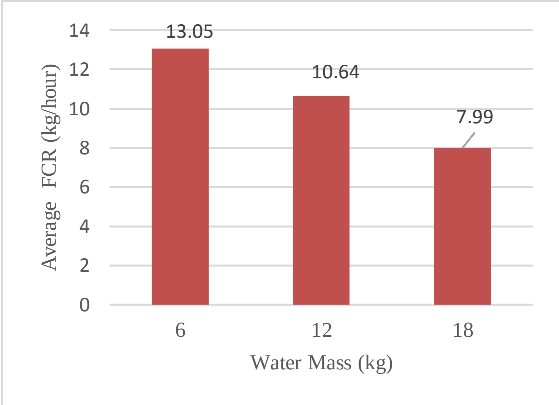

Figure 2. The comparison of average FCR according to the difference in mass variation of heated water

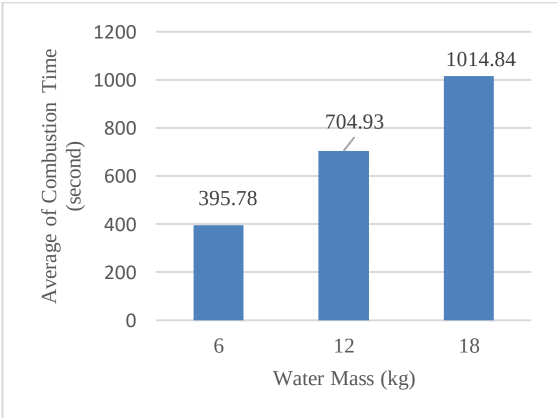

Figure 3. The comparison of average boiling time according to the difference in mass variation of heated water

b) Comparison of FCR and boiling time based on the different variations of oxygen flow valve hole

Variations of the oxygen flow valve hole in the husk furnace affect the flow of air that can enter and come in contact with rice husk fuel (Ale et al., 2009). From Figure 4, it can be seen that the rate of fuel consumption (FCR) in the horizontal valve hole with a size of 27 x 36 cm^2 is 9.45 kg/hour greater than the husk furnace with a smaller horizontal valve hole, which is 18 x 36 cm^2, with a fuel consumption rate of 8.79 kg/hour. Likewise, the average FCR results in husk furnaces with vertical valve holes. This shows that the larger the valve hole size, the greater the flow of air that can enter the combustion chamber, so the fuel consumption rate (FCR) is higher.

The results of the average combustion time for each variation of the oxygen flow valve hole are related to the fuel consumption rate (FCR). The greater the fuel consumption rate (FCR), the faster the combustion time. This is because the more airflow passes through the rice husk fuel, the faster its fuel runs out, and the faster burning time goes faster.

Figure 5 shows that the fastest combustion is at the horizontal valve hole of 27 x 36 cm^2 with an average boiling time of 680.86 seconds, and the longest boiling time is at the vertical valve hole of 27 x 24 cm^2 with an average combustion time of 730.24 seconds.

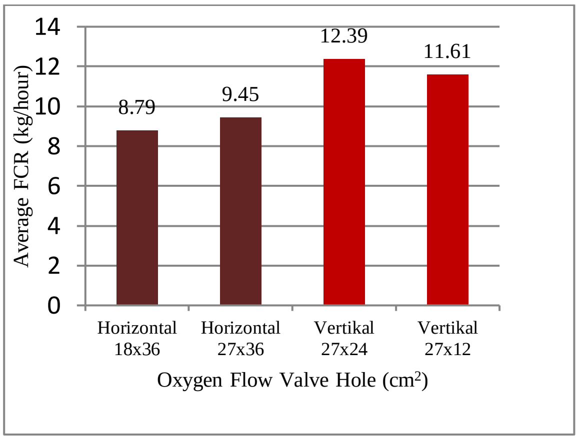

Figure 4. The comparison of average FCR based on the different variations of oxygen flow valve hole

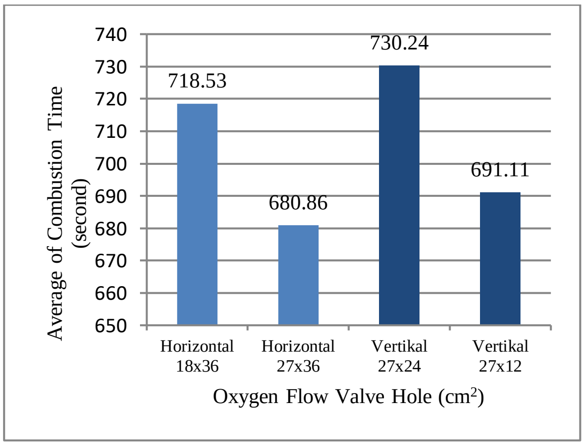

Figure 5. The comparison of the average of the boiling time based on the different variations of oxygen flow valve hole

2. Power Input (P_{in}), Power Output (P_{out}), and Power Loss (P_{loss})

Figure 6 shows the power input, power output, and power loss decreased in proportion to the amount of boiled water. The amount of input power depends on the fuel used in the combustion process (Mulyanto et al., 2016); the more fuel burned, the more energy the rice husk fuel will release. The larger the size of the valve hole, the greater the flow of air that enters and makes contact with the fuel, so the power input (P_{in}) was greater. This can be seen in Figure 6, which shows the results of the average input power in a husk furnace with a horizontal valve hole of 27 x 36 cm^2: 28345.0 kcal/hour, which was greater than a husk furnace with a horizontal valve hole with a smaller valve hole of 18 x 36 cm^2: 26307.5 kcal/hour, likewise, in husk furnaces with vertical valve holes.

The output power (P_{out}) in combustion with a husk furnace shows the ability of the furnace to produce energy that will be used to heat water (Mulyanto et al., 2016). The amount of output power is directly related to the efficiency of the husk furnace; the greater the output power (the power used to heat water), the higher the value of the resulting efficiency.

The power from the fuel (P_{in}) that is not used in heating the water (P_{out}) is assumed to be the power lost. Loss of power (P_{loss}) is caused by a flame that spreads or is not focused on the water heating container (pan); besides that, it can be caused by the airflow rate, which can reduce heat transfer both by conduction and radiation (Mulyanto et al., 2016).

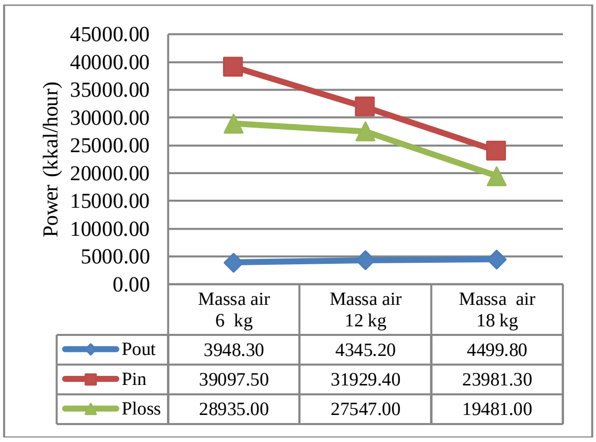

Figure 6. The comparison of the power input (p_{in}), power output (p_{out}), and power loss (p_{loss}) according to the difference in mass variation of heated water

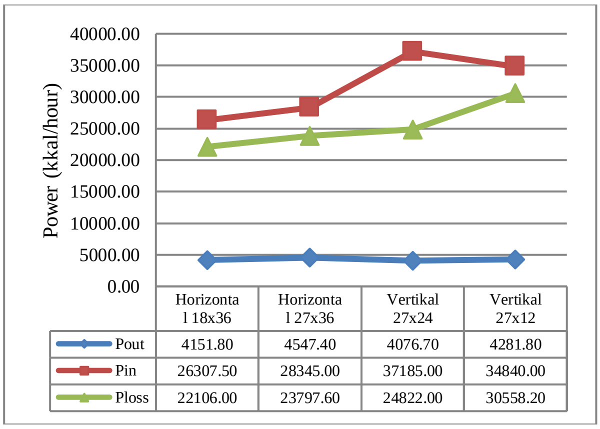

Figure 7. The comparison of the power input (p_{in}), power output (p_{out}), and power loss (p_{loss}) according to the different variations of oxygen flow valve hole

3. Radiant Energy, Pan Thermal Conductivity, and Husk Chimney Thermal Conductivity

Based on Figure 8, it can be seen that the highest average radiation energy occurs when the husk furnace has a horizontal valve hole of 18 x 36 cm^2 with an average of 1965.75 joules, and the lowest average radiation energy occurs when the vertical valve hole is 27 x 12 cm^2 with an average of 966.11 joules. The amount of radiation energy affects the efficiency of the husk furnace; the more energy radiated, the lower the value of the resulting efficiency. It happened because energy radiation will be greater due to the greater energy lost during combustion, which will cause the energy absorbed by water for the heating process to be less, so the efficiency of the husk furnace will be low.

Based on Figure 9, the pan's thermal conductivity results can be seen. The highest thermal conductivity was in the husk furnace with a horizontal valve hole of 18 x 36 cm^2 and an average of 0.63 W/mK, and the lowest in a husk furnace with a horizontal valve hole of 27 x 36 cm^2 and an average of 0.31 W/mK. Figure 10 shows the comparison of the thermal conductivity of the husk furnace chimney for each variation of the oxygen flow valve hole. The highest thermal conductivity is in husk furnaces with horizontal valve holes of 18 x 36 cm^2 and an average of 1.00 W/mK; the lowest is in husk furnaces with horizontal valve holes of 27 x 36 cm^2 and an average of 0.58 W/mK. The average thermal conductivity in the chimney of the husk furnace is higher than the average thermal conductivity in the frying pan. The amount of thermal conductivity varies because thermal conductivity is a function of temperature, which will be higher at high temperatures. Differences influence the value of thermal conductivity in temperature, type of material, length of material, and type of cross-section. The thermal conductivity value affects heat energy loss (Nirwana et al., 2018). When the thermal conductivity of a material is low, the heat loss will also be lower, which will increase the efficiency of the husk furnace.

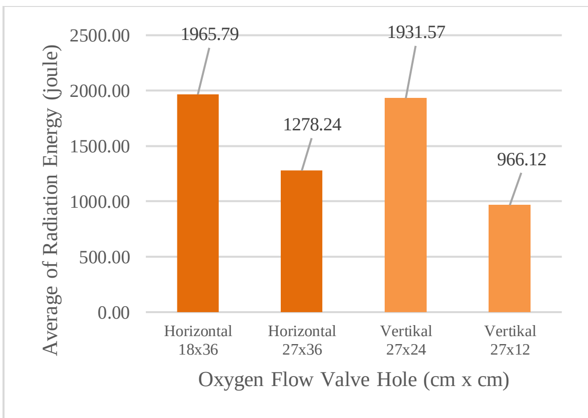

Figure 8. The comparison of radiation energy according to the different variations of oxygen flow valve hole

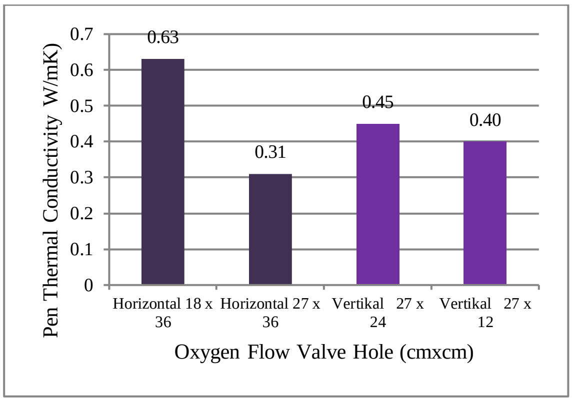

Figure 9. The comparison of pen thermal conductivity according to the different variations of oxygen flow valve hole

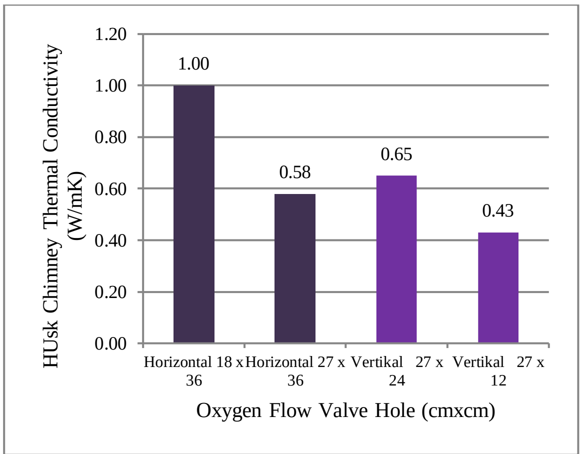

Figure 10. The comparison of husk chimney thermal conductivity according to the different variations of oxygen flow valve hole

4. Husk Furnace Efficiency

The efficiency of the husk furnace is the ratio between the energy required to boil water and the heat energy contained in the fuel, or defined as the ratio between the net power used to heat water and the combustion power of the fuel (Mulyanto et al., 2016). Figure 11 compares the average efficiency of the husk furnace for each variation of the heated water mass, with the average efficiencies for heating the water masses of 6 kg, 12 kg, and 18 kg, respectively, being 11.72%, 13.94%, and 18,97%. The average efficiency of the husk furnace is highest when heating 18 kg of water. The greater the mass of water that is heated, the tendency for efficiency to increase. This is due to the greater the mass of water that is heated, the longer the time required for combustion; combustion time and the amount of airflow affect the perfection of the combustion process (Ajis et al., 2015).

Figure 12 compares the average efficiency of the husk furnace for each valve hole variation. Based on Figure 14, it can be seen that the highest efficiency of husk furnaces was achieved in those with horizontal valve holes of 27 x 36 cm^2 with an average of 17.32%, followed by those with horizontal valve holes of 18 x 36 cm^2 with an average of 16.01 %, husk furnaces with vertical valve holes of 27 x 12 cm^2 with an average of 13.52%, and husk furnaces with vertical valve holes of 27 x 24 cm^2 with an average of 12.6 %. A horizontal oxygen flow valve hole creates a wider combustion chamber volume. In addition, the horizontal flow valve hole also allows more airflow to enter from the sides of the husk furnace.

Variations in the oxygen flow valve hole influence the performance of the husk furnace; on average, in each variation of the oxygen flow valve hole, the wider the valve hole size, the greater the heating rate, fuel consumption rate (FCR), and the thermal efficiency of the husk furnace (Anggara et al., 2019). According to each test parameter, the optimum condition of the husk furnace was when the horizontal valve hole variation: was 27 x 36 cm^2, which has a large heat rate and high thermal efficiency, the fastest time for boiling water, and a low amount of fuel consumed. The amount of heat energy and thermal conductivity in the pan and the chimney of the husk furnace were low, so the amount of lost energy was lower, and the performance of the husk furnace was optimum.

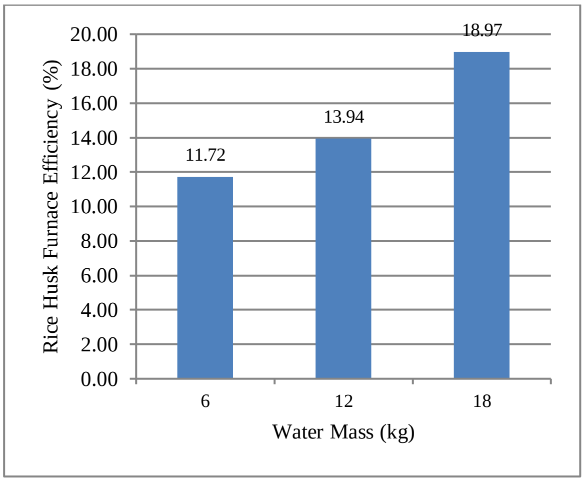

Figure 11. The comparison of husk furnace efficiency according to the difference in mass variation of heated water

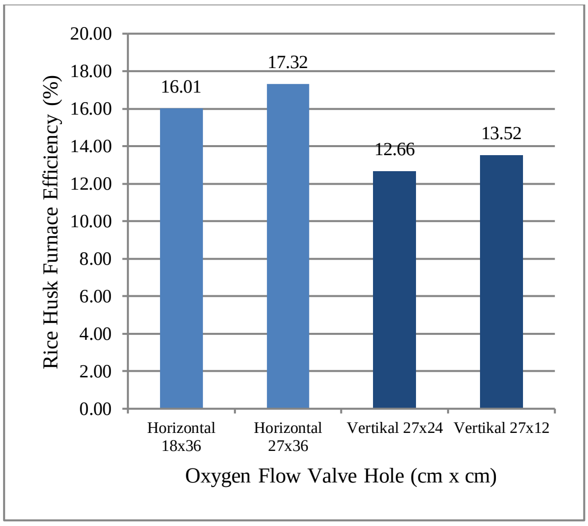

Figure 12. The comparison of husk furnace efficiency according to the different variations of oxygen flow valve hole

B. Data Statistical Analysis

Statistical analysis was carried out on the data of the husk furnace efficiency to determine the effect of the variation of the mass heated water and the variation of the oxygen flow valve hole on the husk furnace efficiency. The data obtained from the husk furnace efficiency values are primary data and ratio scales, so quantitative analysis can be carried out using the two-way ANOVA test using the SPSS 25.0 for Windows program with an error degree (α) of 5%.

A two-way ANOVA test can be done if it fulfills the assumption that the data is normally distributed and homogeneous so that the normality and homogeneity tests are carried out before the two-way ANOVA test. The normality test was carried out using the Shapiro-Wilk test. Table 1 shows that in the normality test, a significance value of 0.653 was obtained, which is greater than the value of 0.05. Based on decision-making on the normality test, it can be stated that the data is normally distributed. The homogeneity test was carried out using Levene's test, and the homogeneity test obtained a significance of 0.447, greater than the value of 0.05, so based on the basis for making decisions on the homogeneity test, it can be stated that the data are homogeneous.

Table 1. Statistical Analysis Test Result

No	Statistic Test	Factor Variable	A	Sig	Interpretation
1	Normality test		0,05	0,653	Sig > α, data was normally distributed
2	Homogeneity test		0,05	0,447	Sig > α, data was homogeneous
3	*Two-way ANOVA test*	Oxygen flow valve hole	0,05	0,001	Sig < α, oxygen valve hole variations had a significant effect on the husk furnace efficiency value.
		Water mass	0,05	0,000	Sig < α, there was a significant effect of water mass variations on the husk furnace efficiency value.

No	Statistic Test	Factor Variable	A	Sig	Interpretation
		Oxygen flow valve hole*water mass	0,05	0,000	Sig < α, there was a significant effect of oxygen flow valve hole variations and water mass variations on the husk furnace efficiency value.

Based on Table 1, it can be seen that the significance value for the variation of the heated water mass is 0.000 less than 0.05, so based on the decision-making basis for the two-way ANOVA test, it can be stated that there is a significant effect on the results of the husk furnace efficiency value based on variations in the mass of the heated water. The significance value for the variation of the husk furnace valve hole is 0.001, smaller than (0.05), also indicating that there is a significant effect on the results of the husk furnace efficiency value based on the variation of the oxygen flow valve hole. Likewise, the combination of variations in the valve hole of the husk furnace with variations in the mass of heated water also shows a significant effect on the efficiency of the husk furnace. Based on the statistical analysis, it can be concluded that the variation in the mass of heated water and the variation of the oxygen flow valve hole in the husk furnace significantly affect the efficiency of the husk furnace.

CONCLUSION AND SUGGESTION

The variation of the heated water mass and the variation of the oxygen flow valve hole in the husk furnace showed a significant effect on the efficiency of the husk furnace. The average efficiency of the husk furnace is highest when heating 18 kg of water, and based on each test parameter, the performance of the husk furnace is most optimal at the horizontal valve hole measuring 27 x 36 cm^2 with an average efficiency of 17.32%, better than any relevant previous study. Further research is expected to minimize the heat energy loss in the husk furnace so that the efficiency of the husk furnace can be more optimum.

NOMENCLATURES

FCR = Fuel Consumption Rate (kg/hour)
m_t = the mass of rice husks used in combustion (kg)
m_0 = the initial mass of rice husks (kg)
m_1 = the final mass of rice husks (kg)
t = the burning time (hours).
m_t = the mass of rice husks used in combustion (kg)
c = the specific heat of water (kcal/kg ^{0}C)
ΔT = the change in water temperature (^{0}C).
P_{loss} = the power loss in the husk furnace (kcal/hour)
P_{in} = the power produced by the fuel (kcal/hour)
P_{out} = the power used in the combustion process (kcal/hour)
H = the energy per unit time (J/s or watts)
Q = the radiant energy or energy emitted by the surface of the object (Joules)
e = the emissivity of the material
σ = the Stefan-Boltzmann constant which is 5.6703 x 10- 8 W/m^2 K^4
A = the surface area (m^2)
A_L = the surface area of the husk furnace envelope (m^2)
T_1 = the temperature on the coal husk (K)
T_2 = the temperature on the outside of the frying pan (K)
A_W = the surface area of the pan (m^2) with a diameter of 84 cm, a height of 25 cm, and a thickness of 5 mm
dT = the change in temperature (K)
T_{lp} = the temperature on the outside of the pan (K)
T_{dp} = the temperature on the inside of the pan (K).

T_{lc} = the temperature at the outside of the chimney (K)
T_{dc} = the temperature at the inside of the chimney (K)
dx = the chimney thickness (m)
Ac = the area of the chimney (m^2) with a length of 34 $x10^{-2}$ m
η = the efficiency of the husk furnace (%)
HVF = Heat Value Fuel is the calorific value of rice husk fuel (kcal/kg) with a 3000 kcal/kg (Nawafi et al. 2010).

AUTHOR CONTRIBUTIONS

IRZ: Conceptualization, project administration, methodology; AA: formal analysis; IRM: supervision, resources, SH; writing—original draft, project administration, NPH; writing—review and editing, validation. All authors have read and agreed to the published version of the manuscript.

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