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Efficiency Improvement, Design Optimization, and Expansion of Oxygen Flow Valve Holes in Small Industrial Scale Husk Furnaces

Rahmah Asri Nurani Hanifan[1], Siti Hajar[1], Nazopatul Patonah Har[1], Mahfuddin Zuhri[1], Erus Rustami[1], Siti Nikmatin[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*

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ABSTRACT

Indonesia has an abundant amount of industry. Production in large, medium, and small industries still uses gas and oil as fuel sources. The fuel sources used still come from non-renewable energy. There is a need for alternative use of renewable energy to reduce the use of non-renewable energy. One solution is the use of rice husk biomass as a fuel source. Rice husk is still often considered as waste despite its many utilizations. The utilization of rice husk waste must be improved to increase its beneficial value. Rice husk waste can be utilized as a fuel source in a husk furnace. A husk furnace is a cooking device in which the fuel (rice husk) is burned using direct combustion. This research aims to optimize the efficiency of the husk furnace by varying the size of the oxygen flow valve hole and the mass of water being heated. Tests were conducted on four variations of oxygen flow valve hole size, namely, 36x27 cm^2, 36x34 cm^2, 43x34 cm^2, and 50x34 cm^2, and two variations of water mass (6 and 18 kg). The research was conducted by heating water using the Water Boiling Test method with test parameters: heating time, fuel consumption rate, energy in, energy out, heat efficiency, heat transfer rate, and ash and charcoal yield. The significant efficiency value can be used as a reference for small-scale industrial rice husk furnaces. The most significant efficiency in the study was 54.99%, achieved by a 43x34 cm2 valve hole for heating 18 kg of water. Based on the most effective efficiency value gained, the expansion of the oxygen flow valve hole is sufficient to be used as a test parameter to test the optimization of small industrial-scale husk furnaces.

INTRODUCTION

Indonesia has a relatively abundant number of industries. Production in large, medium and small industries still uses gas and oil as fuel sources. These fuel sources are primarily from non-renewable energy dominated by fossil fuels (Azhar et al., 2018). The continued use of non-renewable energy will increase the risk of energy scarcity in the future. Based on the research of Aswadi et al., (2023), Indonesia is still very dependent on fossil energy consumption. Meanwhile, several forms of renewable energy have the potential to exist in Indonesia, namely geothermal, wind, and biomass (Adistia et al., 2020). Some biomass energy sources are palm oil, sugar cane, rubber, coconut, rice, corn, cassava, wood, livestock manure, and municipal waste (Primadita et al., 2020). Generally, biomass contains cellulose, hemicellulose, and lignin (Zhou et al., 2016). Rice husks contain 50% cellulose, 25-30% lignin, 15-20% silica, and 10-15% moisture content

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(Singh, 2018). The composition of rice husks follows the content of biomass. So, rice husks include biomass and can be an alternative energy source (Allo et al., 2018). Rice husks can produce energy in the form of heat (heat) when going through the combustion process. The heat energy is large, around 4,000 kcal/kg (Supit et al., 2015).

Based on data from the Central Statistics Agency, Indonesia's total rice harvest area in 2021 was 10.41 million hectares, resulting in a total rice production of 54.42 million tons of Milled Dry Grain (Khasanah & Astuti, 2022). In addition to the amount of rice produced abundantly, there is a by-product produced and often considered waste, namely rice husks. The rice husk is the outermost part of rice produced during the rice milling process. Although widely regarded as waste, rice husks have been used as planting media, red brick mixtures, and charcoal briquettes. Cholis et al., (2021) conducted training on using rice husk waste as alternative energy by processing rice husk waste into rice husk charcoal briquettes. Handayani et al., (2015) utilized rice husks as the primary material for making silica gel. One of the innovations still being developed in using rice husks is as fuel for chaff furnaces on a small industrial scale.

The husk furnace is an inverted pyramid-shaped chaff furnace with several holes in its walls. Demiyati (2010) explained that the husk furnace utilizes airflow during the combustion process, so the air hole's area dramatically affects the husk furnace's efficiency. The chaff furnace consists of two main parts: the cone and body parts. The conical part of the husk furnace is made of zinc plates. In the middle of the cone, placed in an inverted pyramid position, there is a clay jug whose top and bottom are hollow. A cylinder is installed in the centre of the jug chamber, whose entire side has been hollowed out (Irzaman et al., 2008). At the bottom of the husk furnace is an oxygen flow valve hole as a place for oxygen exchange and arrangement of rice husks that have been burned. Rice husks that have been burned will be removed through the hole. The husk that has not been burned will descend due to the earth's gravity and burn to touch the embers of the trash.

Previous research has been carried out on variations of the central hole in the stove body to obtain a simple chaff furnace design that has high efficiency (Maulana, 2009). The study got an efficiency of 18% for the size of the central hole in the stove body of 20 cm x 9 cm. Demiyati, (2010) varied the size of the husk furnace body wall and obtained a core hole size of 22 cm x 24 cm with an efficiency of 14.32%. Simorangkir, (2011) varied, using fins in chaff furnaces; the result was that chaff furnaces without fins had the highest efficiency, which was 19.92%. Variations of oxygen flow valve holes have been carried out in previous studies, namely in the research of Hajar et al., (2022), which obtained an efficiency of 17.32% with a valve hole size of 27 cm x 36 cm. The study showed the most excellent efficiency was obtained at the most significant oxygen flow valve hole. This is because the water heating process at that size occurs the fastest and consumes the lowest fuel. The husk furnace's large valve hole impacts the energy lost (Hajar et al., 2022). The energy lost in large valve holes is lower when compared to smaller valve holes. In this study, the performance of the husk furnace was more optimal in the husk furnace with the largest oxygen flow valve hole size.

The efficiency obtained is still relatively low compared to gas stoves' energy efficiency. Hasanah & Handayani, (2016) mentioned the energy efficiency of gas stoves by 38.55%. This shows the need for further research on chaff furnaces with different variations to obtain optimum efficiency. This study was conducted to determine the expansion of the chaff furnace oxygen flow valve hole, the influence of water mass variation on the efficiency value of the chaff furnace, and the effect of the expansion of the oxygen flow valve hole on other parameters during the water heating process. The research aims to optimize the efficiency of small industrial-scale chaff furnaces by expanding the oxygen flow valve holes and varying the mass of heated water.

Efficiency observations are made based on the combustion process. The combustion process occurs in the presence of a heat source and air. Complete combustion occurs only if there is a sufficient amount of oxygen supply. The need for oxygen in combustion is met by free air that has been preheated to increase efficiency (Triwibowo, 2013). Air flow rate can have a significant influence during the combustion process. In the research of Soukotta & Moniharapon, (2015), the airflow rate with a high volume produces a hotter temperature. Zulatama et al., (2021) researched the effect of oxygen flow rate on combustion time and combustion temperature. As a result, the oxygen flow rate affects the combustion rate, affecting the combustion temperature. During the efficiency observation process, heat transfer is caused by the combustion of rice husk as fuel. There are three main heat transfer processes: conduction, convection, and radiation (Forsberg, 2021).

METHODS

Husk furnace testing uses the Water Boiling Test (WBT) method, a simple simulation carried out by boiling water under certain conditions with the time needed to run the simulation. The test is performed at high power and lower boiling rates. WBT is generally done to quickly compare a given stove's performance under different conditions (Rani et al., 1992). During the water heating, temperature measurements are made of husk furnaces, pans, and chaff coals. Temperature measurement can only be done when the water heating occurs, and the husk embers are fully lit.

The materials needed in the study are dry rice husks as fuel for the husk furnace and water to boil during the test. Research requires tools in the form of infrared thermometers, pans, pan lids, measuring cups, scales, matches, stopwatches, and chaff furnaces with variations of oxygen flow valve holes: 36x27 cm^2, 36x34 cm^2, 43x34 cm^2, and 50x34 cm^2. Each valve hole size is proven using the WBT method with variations in water mass of 6 kg and 18 kg. Husk furnace testing is carried out by boiling water twice for each variation in the size of the oxygen flow valve hole and variations in water mass. Figure 1 shows the flow chart of this research.

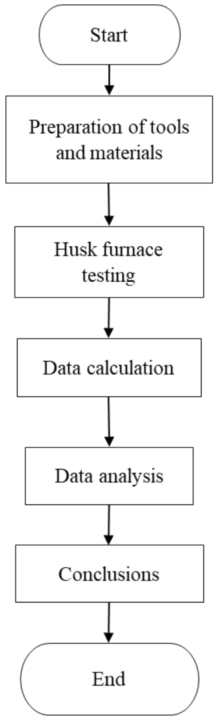

Figure 1. Research Flowchart

The effect of variations in the size of oxygen flow valve holes and water mass on the efficiency of chaff furnaces can be known through calculations and analysis of other parameters. This analysis can be calculated based on the parameters:

1. Boiling time is the time it takes to heat water, which is calculated by pouring water into the pan until it boils at a lower rate.

2. Fuel Consumption Rate (FCR) compares the mass consumption of rice husks with heating time (Prasetya et al., 2015).

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

3. Radiant energy is the heat emitted by an energy source. The radiant energy is affected by the Stefan-Boltzmann constant, heating time, area from coals to the pan, emissivity of the pan, the temperature of the chaff coals, and temperature of the outer surface (Forsberg, 2021).

$$Q_{rad} = \varepsilon_{pan} \sigma t A_{CP} (T_C^4 - T_{OP}^4) \quad (2)$$

4. Water absorption energy is the heat needed to heat water. The mass of water influences this energy, the heat of the type of water, and changes in water temperature.

$$Q_{water} = m_{water} \times c_{water} \times \Delta T_{water} \quad (3)$$

5. Combustion heat efficiency is the ratio of heat released to heat received from fuel.

$$\eta = \frac{Q_{out}}{Q_{in}} \times 100\% \quad (4)$$

$$\eta = \frac{Q_{rad} + Q_{water}}{m_{RH} \times Calorific\ Value_{RH}} \times 100\% \quad (5)$$

The input energy is determined based on the husk's mass and the rice husk's calorific value. The calorific value in plants is an important parameter to determine the energy possessed by biomass. There are several parameters to assess biomass energy, one of which is the calorific value of rice husks (Piskier, 2017).

6. The heat transfer rate is the heat that propagates during the water heating process. The heat transfer rate is influenced by radiation energy and water heating time.

$$H = \frac{Q_{rad}}{t} \quad (6)$$

7. The yield compares combustion with the initial rice husks' mass (Karamoy et al., 2019). The yield is written in percentage. The ash yield is the percentage of husk ash mass with the husk's initial mass. Charcoal yield is the percentage of husk charcoal mass with initial husk mass (Miller, 2011).

$$Yield_{ash}\ (\%) = \frac{m_{ash}}{m_{RH}} \times 100\% \quad (7)$$

$$Yield_{charcoal}\ (\%) = \frac{m_{charcoal}}{m_{RH}} \times 100\% \quad (8)$$

RESULTS AND DISCUSSION

Boiling Time and Fuel Consumption Rate (FCR)

Boiling time is when it takes to heat water to a lower boiling level based on the WBT (Water Boiling Test) method. Table 1 shows the heating time of water (in seconds) in a given mass of water against the size of the oxygen flow valve hole. The heating time undergoes an increase when the water mass is enlarged. The heating time at a water mass of 18 kg is more extended than at a water mass of 6 kg. The increase in heating time occurs when heating a larger mass of water requires a longer heating process. The variety of heated water masses affects the heating time.

The heating time varies depending on the size of the valve hole. The increase and reduction in heating time indicate that changes in valve hole size can affect airflow across the chaff furnace. The research of Mulyanto et al. (2016) explains that the airflow rate influences heating time. The airflow rate can be affected by the size of the air hole. Good airflow can speed up the heating process because more air enters, and the heating process is faster (Mulyanto et al., 2016). However, a fast airflow can slow the heating process because too much air enters the chaff furnace and inhibits combustion. Table 1 shows the average boiling time to oxygen flow valve hole size by water mass.

Table 1 Average boiling time to oxygen flow valve hole size by water mass

			Water Mass (kg)	
	Sample	**Oxygen Flow Valve Hole Size (cm^2)**	**6**	**18**
Boiling Time (s)	A	36x27	588,20 ± 40,87	1052,90 ± 72,97
	B	36x34	659,65 ± 103,73	996,25 ± 13,36
	C	43x34	624,00 ± 72,41	1221,20 ± 57,84
	D	50x34	515,90 ± 13,58	1334,20 ± 172,39

FCR (Fuel Consumption Rate) is fuel consumption every second. FCR is determined by dividing the mass of used husks by the heating time. Table 2 shows that the larger the mass of heated water, the smaller the FCR. A decreased FCR to the water mass indicates that fuel consumption is slowed to the heated water mass. This is influenced by the increased heating time against the increasing water mass. Based on equation (1), FCR is inversely proportional to warm-up time, so FCR decreases as warm-up time increases. Thus, variations in water mass caused by increased heating time affect FCR. Variations in valve hole size can influence FCR. At 6 kg of water heating, there is a decrease and then an increase in FCR. Decreased and increased FCR can be caused by the size of the oxygen flow valve hole and the warm-up time. Table 2 shows the average FCR to oxygen flow valve hole size by water mass.

Table 2 Average FCR to oxygen flow valve hole size by water mass

			Water mass (kg)	
	Sample	**Oxygen flow valve hole size (cm^2)**	**6**	**18**
FCR (kg/s)	A	36x27	$(4,43 \pm 0,31) \times 10^{-3}$	$(3,03 \pm 0,33) \times 10^{-3}$
	B	36x34	$(3,60 \pm 0,46) \times 10^{-3}$	$(2,81 \pm 0,25) \times 10^{-3}$
	C	43x34	$(5,65 \pm 0,65) \times 10^{-3}$	$(3,10 \pm 0,32) \times 10^{-3}$
	D	50x34	$(5,61 \pm 0,67) \times 10^{-3}$	$(2,76 \pm 0,41) \times 10^{-3}$

The boiling time is affected by the airflow rate. In this case, the heating time can affect the FCR so that the higher the air flow rate, the more air entering, and the combustion process will be faster, resulting in the fuel burning faster (Mulyanto et al., 2016). Erratic wind factors can cause the flow rate of incoming air during the heating process. In equation (1), FCR is the result of dividing between the mass of rice husks burned and the heating time. The amount of FCR produced is also influenced by the mass of rice husks used as fuel.

Heat Analysis

Heat is energy that can move in a system caused by temperature differences. Naturally, heat moves from objects with high temperatures to objects with low temperatures (Zelviani et al., 2020). The transfer process in the husk furnace system occurs by radiation. This happens because of the heat waves that are emitted (Stewart, 2021). Thermal cameras and infrared thermometers then receive the emitted heat waves. The radiation process in combustion systems is complex (Xu, 2010), so using a thermal camera to see the heat distribution is necessary to facilitate data collection. The heat distribution process can be seen using a thermal camera. In the husk furnace system, heat moves from the chaff coals to the pan's surface (Figure 2). A yellowish-fiery red colour characterizes high temperatures. High temperatures are emitted from the embers of the husks, then move towards the pan's surface, and there is a movement of hot temperatures in the pan. Temperature movement causes heat transfer from the husk embers to the pan's surface, called a radiation event.

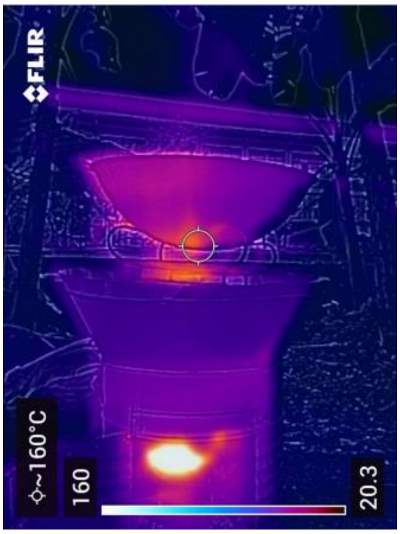

Figure 2. Photo of Heat Distribution Using a Thermal Camera

The variation in the size of the oxygen flow valve hole exerts an influence on radiation energy. Radiant energy increases and decreases at oxygen flow valve holes with different sizes, but this energy change is not linear. The flow rate of incoming air can cause a difference in radiant energy. The airflow rate influences the heating time, which means it influences the temperature of the fire that is produced. According to Mulyanto et al., (2016), the resulting flame temperature can increase when the air flow rate gets bigger. The temperature of the fire influences the temperature of the embers, husks, and the surface of the outer pan, thus affecting the radiation energy.

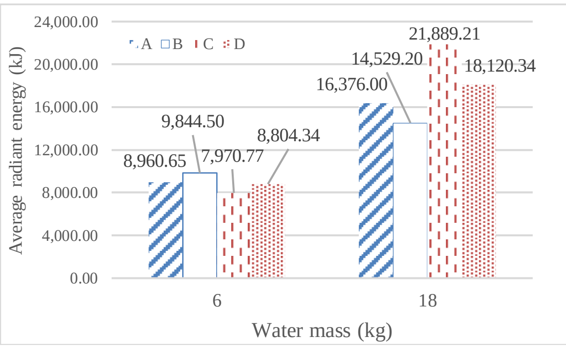

Figure 3. Comparison of the Average Radiant Energy to the Mass of Water Based on the Size of the Oxygen Flow Valve Hole

The efficiency of the chaff furnace results from the ratio of outgoing energy (output) and incoming energy (input). Outgoing energy needs to be identified individually based on the energy lost. The identification of lost energy is carried out due to heat transfer mechanisms during the water heating process, including complex (Widodo, 2015). The energy lost in this system is identified as radiant energy and water absorption energy. Water absorption energy is distinguished by the mass of water heated because it is the same value for each mass of water. The heat produced at heating 6 and 18 kg of water is 1.080,19 and 3.240,58 kJ. The absorbent energy of water and radiant energy are then summed and defined as outgoing energy. Based on Figure 3, variations in water mass exert an influence on outgoing energy. The heat output produced is greater when heating water at 18 kg compared to 6 kg. More incredible radiant energy and water absorption energy are directed at heating water with a mass of 18 kg, so the outgoing energy produced at heating water is 18 kg, which is the highest.

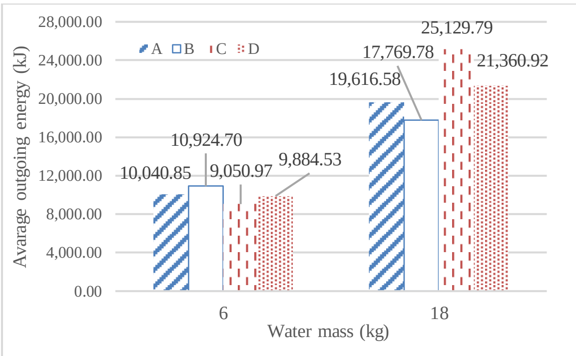

Figure 4. Comparison of the Average Outgoing Energy to the Mass of Water Based on the Size of the Oxygen Flow Valve Hole

The variation in the size of the oxygen flow valve hole exerts an influence on the outgoing energy, although it is not linear. The increase and decrease in outgoing energy were shown to be non-linear; this could have occurred because of the influence of other factors that were not observed during the research process. The heat transfer mechanism during the water heating process is relatively complex, so the energy out can be affected by many things. The outgoing energy is obtained through radiant energy and water absorption energy. The radiant energy can be affected by the temperature difference between the husk coals and the outer surface of the pan, and the water absorption energy is affected by the mass of water heated.

Incoming energy (input) is identified as the energy produced by fuel (rice husks). The energy is influenced by the mass of water and the calorific value of rice husks. The calorific value of rice husks is obtained based on laboratory test results using a calorimeter bomb device. Bomb calorimeters are designed to withstand the significant pressures generated inside the calorimeter due to the reaction or combustion of fuel (Babu & Anand, 2019). The incoming energy is affected by variations in the mass of water. The incoming energy at heating water is 18 kg greater than that of 6 kg of water. The incoming energy is the product of the mass of rice husks by the calorific value of rice husks. The more rice husks burned, the greater the incoming energy value.

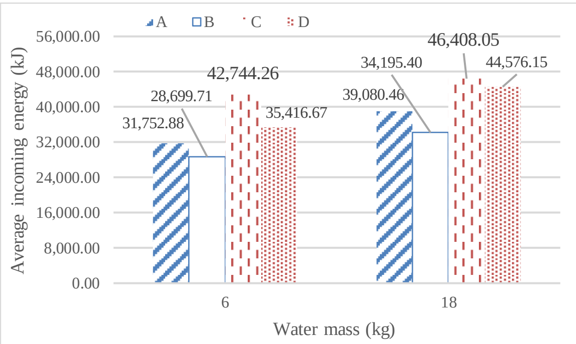

Figure 5. Comparison of the Average Incoming Energy to the Mass of Water Based on the Size of the Oxygen Flow Valve Hole

The incoming energy decreases and increases in valve holes of different sizes. The incoming energy is affected by the mass of burnt rice husks. The mass of rice husks burned can be affected by the flow rate of air entering during the combustion process. When the air flow rate increases the fuel combustion process, the fuel required will burn faster and increase combustion so that the required fuel increases.

Husk Furnace Energy Efficiency

The energy efficiency of a chaff furnace shows the ratio of outgoing energy and inlet energy produced by rice husks. High efficiency can occur when the heat energy stored in rice husks is appropriately used and turned into outgoing energy. The mass of heated water influences the heat efficiency of the chaff furnace. Heating 18 kg of water produced greater efficiency than heating 6 kg due to the influence of outgoing and incoming energy generated during the heating process. The energy out at heating water 18 kg is greater, thus affecting the efficiency of the chaff furnace.

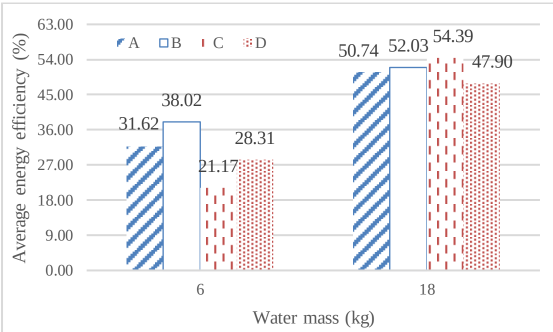

Figure 6. Comparison of average energy efficiency to water mass based on oxygen flow valve hole size

In this study, the largest valve hole size did not achieve the most efficiency. In 6 kg water heating, the most ideal efficiency is shown in a valve hole measuring 36x34 cm^2; in heating 18 kg, the most excellent efficiency is produced in a valve hole measuring 43x34 cm^2. Efficiency influenced by water mass also occurred in the research (Hajar et al., 2022). This study achieved the most excellent efficiency in 18 kg water heating, which amounted to 18.97%. There are horizontal and vertical oxygen flow valve holes. The efficiency of the most enormous oxygen flow valve hole is produced at 27x36 cm^2, which is horizontal, with an efficiency value of 17.32%. The geometry of the oxygen flow valve hole can influence the heat efficiency of the husk furnace.

Combustion efficiency can be improved by paying attention to the flow pattern formed when air, combustion gases, and combustion products through the fire started, as well as the geometry of the combustion chamber and air intake holes, which also affect the airflow pattern (Mirmanto et al., 2018). The geometric shape of the oxygen flow valve hole in this study involves the heat efficiency of the chaff furnace. The oxygen flow valve hole of the chaff furnace is rectangular with different lengths and widths. The efficiency of the chaff furnace varies for each size of the oxygen flow valve hole, so the increase in size in the hole's length and width affects the husk furnace's efficiency.

Heat Transfer Rate

The heat transfer rate is energy transfer through heat over a certain period (Moran & Shapiro, 2004). The difference in heat transfer rate at each valve hole is caused by the different average radiation energy in each valve hole. Putra et al., (2022) said that the surface area is one of the parameters used to determine the heat transfer rate. This corresponds to the radiant energy affected by the pan's surface area. The heat transfer rate is proportional to the radiant energy and inversely proportional to the heating time. The greater the radiant energy, the greater the heat transfer rate. The longer the heating time, the lower the heat transfer rate. Table 3 shows the average heat transfer rate based on the oxygen flow valve hole size.

Table 3. Average Heat Transfer Rate Based on the Size of the Oxygen Flow Valve Hole

Sample	Oxygen Flow Valve Hole Size (cm^2)	Average Heat Transfer Rate (kJ s^{-1})
A	36x27	15,48 ± 2,71
B	36x34	14,77 ± 0,73
C	43x34	15,37 ± 3,07
D	50x34	15,42 ± 2,61

The most significant heat transfer rate occurs in the oxygen flow valve hole measuring 36x27 cm2. The valve hole has the fastest heat transfer compared to other sizes. Variations in the oxygen flow valve hole can provide differences in heat transfer rates. The heat transfer rate greatly influences the air velocity during the combustion process. The higher the air velocity, the higher the heat transfer rate (Sulaiman & Ilham, 2018). However, the combustion process is one of the most challenging processes to handle in nature. The combustion process generally involves a set of simultaneous three-dimensional multiphase fluid dynamics, heat transfer (conduction, convection, and radiation), chemical kinetics, and the turbulent mixing of different species. These factors can cause differences in heat transfer rates during combustion (Xu, 2010).

Ash and Charcoal Yield

Yield is the percentage of comparison of the amount of residual combustion with the amount of raw material before going through the combustion process (Karamoy et al., 2019). Rice husks are the primary fuel for rice husk furnaces. The burning of rice husks produces ash and charcoal of rice husks. This study produced a greater percentage of ash yield than charcoal yield. Based on this, burning rice husks produces more ash than charcoal as the rest of burning. Table 4 shows the average ash and charcoal yield based on oxygen flow valve hole size.

Table 4. Average Ash and Charcoal Yield Based on Oxygen Flow Valve Hole Size

Sample	Oxygen Flow Valve Hole Size (cm^2)	Average Yield (%)	
		Ash	Charcoal
A	36x27	21,69 ± 2,83	8,75 ± 4,90
B	36x34	21,28 ± 1,72	12,81 ± 2,85
C	43x34	28,03 ± 4,66	7,58 ± 3,70
D	50x34	22,20 ± 0,63	9,85 ± 2,33

The highest ash yield was produced in the combustor with a valve hole of 43x34 cm^2, and the lowest was produced in the size of 36x34 cm^2. Meanwhile, the highest charcoal yield was produced in the combustor with a valve hole size of 36x34 cm^2 and the lowest in the size of 43x34 cm^2. Ash yield and charcoal yield have an inversely proportional relationship. If a large ash yield is produced, a small charcoal yield will be produced, and vice versa. Ash and charcoal yields are obtained based on the remaining ash and charcoal produced from the combustion process during water heating. Ash and charcoal are often referred to as combustion residue. Ash and charcoal are produced based on the incomplete combustion process. The darker the colour of the combustion residue produced, the higher the remaining carbon content due to incomplete combustion.

There is a law in chemical reactions, namely the 'Law of Conservation of Mass' (Lomonosov-Lavoisier Law). According to this law, the mass before and after the reaction will be the same (Zul, 2009). The combustion process does not only produce visible combustion residues. The percentage of mass that does not include ash and rice husk charcoal has changed into other materials. Other combustion products include carbon dioxide and water vapour. The average percentage yield does not reach 30%, meaning that most of the combustion products have been transformed into other materials that are not visible and become heat energy during the combustion process.

CONCLUSION AND SUGGESTION

The expansion of the size of the oxygen flow valve hole and the variation of the mass of water heated influence the chaff furnace's efficiency. The highest chaff furnace efficiency was achieved at a valve hole measuring 43x34 cm2 at 18 kg water heating with an efficiency value of 54.39%. The efficiency value of the husk furnace can be used as a reference for the use of small industrial scale husk furnaces in small industries in rice husk-producing areas so that rice husk waste can be utilized more. Further research can be done by varying other parts of the husk furnace, such as the diameter of the husk reservoir, the thickness of the furnace insulator (jug), and the diameter of the zinc cylinder. Expansion of the valve hole size is sufficient to optimize the efficiency of the husk furnace.

NOMENCLATURES

FCR = Fuel Consumption Rate (kg/s)
m_{RH} = The mass of rice husks used in combustion (kg)
t = The burning time (s)
Q_{rad} = The radiant energy (Joule)
ε_{pan} = The emissivity of pan
σ = The Stefan-Boltzmann constant ($5,67 \times 10^{-8}$ W m^{-2} K^{-4})
A_{CP} = The surface area from coals to pan (m^2)
T_C = The temperature of chaff coals (^0C)
T_{OP} = The temperature of the outer pan surface (^0C)
Q_{water} = The water absorption energy (Joule)
m_{water} = The mass of water (kg)

c_{water} = The specific heat of water (4,187 x 10^3 J kg^{-1} $^0C^{-1}$)
ΔT_{water} = The change in water temperature (^{0}C)
η = The husk furnace heat efficiency (%)
Q_{out} = The outgoing energy (Joule)
Q_{in} = The incoming energy (Joule)
$Calorific\ Value_{RH}$ = the calorific value of rice husk (1,22 x 10^7 J kg^{-1})
H = The heat transfer rate (Joule/s)
$Yield_{ash}$ = The yield of the ash (%)
$Yield_{charcoal}$ = The yield of the charcoal (%)
m_{ash} = The mass of the ash (kg)
$m_{charcoal}$ = The mass of the charcoal (kg)

AUTHOR CONTRIBUTIONS

IRZ: Conceptualization, project administration, and methodology.
SN: Supervision and resources.
MF and ER: Formal analysis and writing the review.
RANH: Writing original draft and project administration
SH and NPH: Writing review, editing, and validation.
All authors have read and agreed to the published version of the manuscript.

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