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The Effect of Air Velocity Variations on the Fire Characteristics and Water Heating Time in Used Oil-Fired Multifuel Stoves

Muhammad Satya Putra Gantada*, Yudi Setiawan, Saparin, Eka Sari Wijianti
Universitas Bangka Belitung, Indonesia
Email: gantasatya51@gmail.com*

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ABSTRACT

One of the uses of used oil is as fuel for *multifuel* stoves. A *multifuel* stove is a stove that has flexibility in its fuel selection. In the operation of a *multifuel* stove, the air supply plays an important role in the combustion process. This study discusses the influence of air velocity on fire characteristics and water temperature during the heating process. In this study, three variations of air velocity were used, namely 13 m/s, 12 m/s, and 11 m/s. Based on the tests that have been carried out, it was found that the speed of air blown into the combustion chamber can affect the temperature and duration of the flame. The faster the speed of air that is blown into the combustion chamber, the higher the temperature of the flame will be, but the faster the fire will be extinguished. This is because more oxygen is supplied into the combustion chamber, causing the combustion process to take place more quickly and intensely. Meanwhile, regarding the water heating time, the time required by the three variations of air speed to heat 0.5 kg of water to boiling is 1.5–2 minutes, which surpasses the performance of gas stoves and conventional electric stoves.

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INTRODUCTION

The use of alternative energy from waste is a strategic solution to address the challenges of energy availability and environmental issues. One type of waste that has great potential but is still not used optimally is used oil. Every year, the amount of used lubricating oil produced by the automotive and industrial sectors continues to increase, with an estimated 18 million liters of used oil produced nationally each year (Central Statistics Agency, 2019 & Sasmita, et al., 2024). However, most of this *waste oil* is not managed sustainably and ends up polluting the environment. In fact, with its fairly high heat value—almost approaching the calorific value of diesel, which is around 40 MJ/kg and ease of access, used oil has significant potential as an alternative fuel, especially for home-scale *multifuel* stoves, particularly in remote and *3T* (*Disadvantaged, Frontier, Outermost*) areas in Indonesia (Bencheikh et al., 2019; Kipkorir et al., 2021; Kumar et al., 2016; Mahmood et al., 2022; Mohan & Sarojini, 2023).

Multifuel stoves are designed to operate using various types of fuels, including kerosene, biodiesel, and used oil (Surono, A., 2012). In the operation of this type of stove, the air supply plays an important role in the combustion process, as air contains oxygen, which is the main element in combustion. The speed of air entering the combustion chamber directly affects the mixing of fuel with oxygen, the stability of the flame, the temperature of the fire, and ultimately the thermal efficiency of the stove.

Although the design of *multifuel* stoves continues to develop, research on the effect of air speed variations on the combustion performance of used oil is still limited. In fact, *waste oil* has different physical and chemical characteristics compared to conventional fuels, such as

higher viscosity, carbon residues, and heavy metal content (Nisah, K., & Hilman, M. Z., 2024); these conditions make achieving perfect combustion more difficult. Therefore, proper airspeed regulation is a key factor in optimizing combustion efficiency and flame stability.

Some studies show that excess air can reduce thermal efficiency because some of the heat is wasted along with the residual air. On the other hand, too low an air supply can cause incomplete combustion, producing smoke, odors, and carbon buildup (Sidiq, A., et al., 2023; Puspitasari, C. W., Yuliati, L., & Winarto, 2022). Therefore, it is important to conduct systematic research to determine the quantitative relationship between air speed variations and stove thermal performance, such as heat transfer rate, fire temperature, and boiling time of water.

This study aims to fill this knowledge gap by conducting controlled experiments on used oil-fueled *multifuel* stoves, varying the air speed supplied to the combustion chamber. By measuring performance indicators such as thermal efficiency, flame temperature, and fire stability, it is hoped that optimal design and operation recommendations will be obtained, especially for independent energy needs in areas with limited commercial energy access. Through this research, it is expected that an efficient *multifuel* stove design can be developed, as well as to encourage the wider use of used oil waste within the framework of a sustainable energy transition.

Previous studies have primarily focused on fuel comparison or combustion technology, yet limited attention has been given to the quantitative analysis of how variations in air velocity specifically affect the fire characteristics and heating efficiency in used oil-fired stoves. This gap underscores the need for a more nuanced understanding of airflow control as a design parameter.

The novelty of this research lies in its experimental approach to determine the optimal air velocity for achieving maximum thermal efficiency, flame stability, and water heating performance in used oil-fueled *multifuel* stoves. Unlike prior studies that addressed fuel type or burner design in isolation, this study integrates precise measurements of flame temperature, heat transfer mechanisms, and water boiling time across different air velocity settings.

The objectives of this research are to examine how variations in air velocity affect flame temperature and fire duration, analyze the relationship between air velocity and water heating time, and identify the optimal airspeed for maximizing thermal efficiency and combustion quality in used oil-based *multifuel* stoves.

METHOD

This study uses a combination of experimental studies, literature studies, and field surveys. The use of a combination of these three methods aims to obtain valid results that are in accordance with the predetermined subject matter. In this study, three tests were carried out for each variable of air velocity, then the average value of each variable was taken, resulting in a total of nine tests. For the measurement of the temperature of the heated water, measurements were taken every 30 seconds until the water boiled, with the amount of heated water being 0.5 kg (500 ml) (Gantada, M. S. P., et al., 2025).

In the literature study, data were collected through document studies and references, including books, scientific articles, journals, and other reliable sources that discuss theories, concepts, and results of previous research related to *multifuel* stoves and the use of used oil as

fuel. Data collection was carried out by selectively choosing credible and relevant sources to provide a comprehensive and in-depth overview. Data obtained from testing, literature studies, and field surveys were then processed using quantitative analysis methods.

The supporting equipment used in this study includes a thermometer, anemometer, *gun thermometer*, and stopwatch. The stove used in this study is shown in the following figure:

The experiment utilized a thermometer, *gun thermometer*, anemometer, and stopwatch as measuring instruments. Data obtained included flame temperature, water temperature, flame duration, and boiling time. These results were used to calculate the types of heat transfer (*radiation*, *conduction*, and *convection*) and to evaluate thermal performance.

Figure 1. Multifuel stove
Source: Data taken by researchers

RESULTS AND DISCUSSION

Research Results

Based on the research that has been conducted, the following data was obtained:

Table 1 Test Result Data

Air Velocity (m/s)	Average Water Temperature Change (°C) Every 30 seconds					Average Water Boiling Time (minutes)	Average Fire Temperature (°C)	Average Flame Length (Minutes)
	0	30	60	90	120			
13	31	56	82,6	100	100	1,5	719.2	16,92
12	31	50,8	73,7	100	100	1,5	687.2	17,31
11	31	45	61,2	79	100	2	671.3	17,74

Source: Processed Data

Based on the table above, it can be seen that boiling water in the rangetime 1 minute 30 seconds to 2 minutes so it can be said that multifuel stoves have been able to exceed the performance of gas stoves and conventional electric stoves, which gas stoves and conventional electric stoves require on averagetime more than 6 minutes to heat water (Battery Equivalent, 2023). In addition, it was also found that the resulting flame was good, which was

characterized by a fire that burned stably and could continue to burn as long as the water was heated to boil (Syarief, A., et al., 2020; Fauzi, 2020).

Effect of Air Velocity on Fire Characteristics

Based on the data in the table above, it can be seen that the air speed can affect the length of time of the flame and the temperature of the fire produced. The faster the speed of air that is blown into the combustion chamber, the higher the temperature of the flame will be, but the faster the fire will be extinguished. This is because more and more oxygen is supplied into the combustion chamber, so that the combustion process takes place faster and more intensely (Dongoran, I, I., 2025) (Naryanto, R, F., 2021).

The fire temperature ratio of each of the air velocity variations can be seen in the following figure:

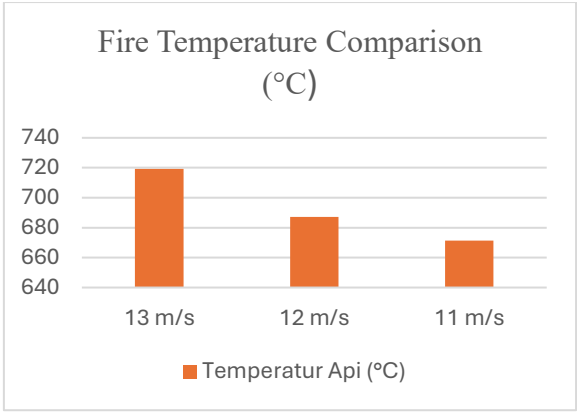

Figure 2 Comparison of Fire Temperature

Source: Processed Data

Meanwhile, based on the color of the fire, there is no difference in the color of the fire produced. This is because the color of the fire produced from the three variations of air speed has the same color, namely reddish blue. The color of the flame produced in the heating process can be seen in the following image:

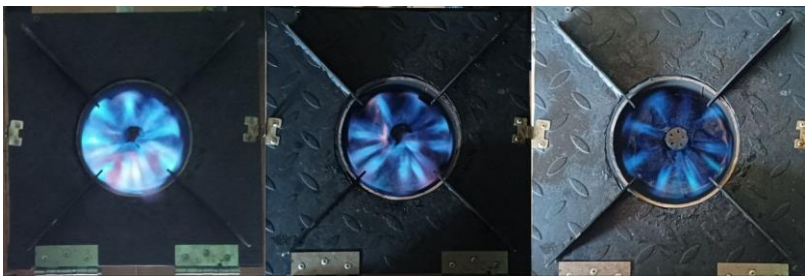

Figure 3 Colors of Fire Produced at Speeds of 13 m/s (Left), 12 m/s (Center), and 11 m/s (Right)

Source: Processed Data

Heat Transfer During Water Heating Process

In the process of heating water in this test, there are 3 types of heat transfer processes, namely radiation, convection, and conduction. The various heat transfers in the water heating

process can be seen in the water heating process can be seen in the following image (Gantada, M, S, P., 2024)

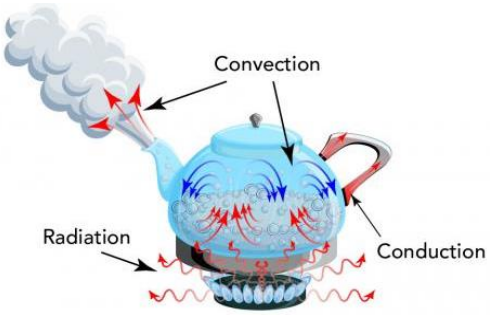

Figure 4. The Heat Transfer Process During the Water Heating Process
Source: Processed Data

To calculate the magnitude of heat transfer by radiation, the formula can be used:

$$Q = \varepsilon \times \sigma \times A \times \Delta T^4$$

Where:
Q: Total heat transferred (J)
ε: Pan Emissivity (0.5)
σ: Stefan-Boltzmann constant (5.67 $\times^{10\text{-}8}$ W/m2. K4)
A = Surface area (m2)
ΔT^4: Water temperature difference (°K)

To calculate the magnitude of heat transfer by conduction, the formula can be used:

$$Q = \frac{k \times A \times \Delta T}{d}$$

Where:
Q: Total heat transferred (J)
k: Thermal conductivity of materials (202 W/m^2. (K)
A: Surface area in contact with water (m2)
ΔT: Water temperature difference (°C)
d: Pan thickness (0.001 m)

To calculate the magnitude of heat transfer by convection, the formula can be used:

$$Q = h \times A \times \Delta T$$

Where:
Q: The amount of heat transferred (J)
h: Heat transfer coefficient (10 W/m2. K)
A: Surface area (m2)
ΔT: Water temperature difference (°C)

The data from the calculation of the three types of heat transfer processes that occur during the water heating process can be seen in the tables below:

Table 2. Heat transfer that occurs during the heating process

Air Velocity 13 m/s			
Time(s)	Heat Transfer		
	Radiation (J)	Conduction (J)	Convection (J)
0	0	0	0
30	8,55	479.750	23,75
60	20,06	990.204	49,02
90	29,17	1.324.110	65,55
120	29,17	1.324.110	65,55
Air Speed 12 m/s			
Time(s)	Heat Transfer		
	Radiation (J)	Conduction (J)	Convection (J)
0	0	0	0
30	6,61	379.962	18,81
60	15,93	819.413	40,56
90	29,17	1.324.110	65,55
120	29,17	1.324.110	65,55
Air Speed 11 m/s			
Time(s)	Heat Transfer		
	Radiation (J)	Conduction (J)	Convection (J)
0	0	0	0
30	4,54	286.660	13,3
60	10,60	617,918	30,59
90	18,37	921.120	45,6
120	29,17	1.324.110	65,55

Source: Processed Data

The heat received by water during the heating process

To calculate the amount of heat received by the water during the heating process can be used the following formula:

$$Q = m \times c \times \Delta T$$

Where:

Q: The amount of heat received by the water during the heating process (J)

m: Mass of heated water (0.5 kg)

c: Heat type water (4200 J/kg)

ΔT: Temperature change (°C)

Meanwhile, to calculate the amount of heat received by water during the heating process, the following formula can be used:

$$P = \frac{Q}{t}$$

Where:

Q: Heat power (J)

Q: The amount of heat received by the water during the heating process (J)

t: Time(s)

The data from the calculation of the amount of heat value and heat power received by water during the heating process can be seen in the table below:

Table 3. Calculation Results of Calorific and Calorific Value

Air Velocity 13 m/s					
m (kg)	c (J/kg)	ΔT(°C)	Q (J)	t(s)	P (J/s)
0,5	4.200	0	0	0	-
0,5	4.200	25	52.500	30	1.750
0,5	4.200	51,6	108.360	60	1.860
0,5	4.200	69	144.900	90	1.610
0,5	4.200	69	144.900	120	1.270,5
Air Speed 12 m/s					
m (kg)	c (J/kg)	ΔT(°C)	Q (J)	t(s)	P(J/s)
0,5	4.200	0	0	0	-
0,5	4.200	19.8	41,580	30	1.386
0,5	4.200	42,7	89.670	60	1.494,5
0,5	4.200	69	144.900	90	1.610
0,5	4.200	69	144.900	120	1.270,5
Air Speed 11 m/s					
m (kg)	c (J/kg)	ΔT(°C)	Q (J)	t(s)	P (J/s)
0,5	4.200	0	0	0	-
0,5	4.200	14	29.400	30	980
0,5	4.200	32,2	67.620	60	1.127
0,5	4.200	48	100.800	90	1.120
0,5	4.200	69	144.900	120	1.270,5

Source : Processed Data

In the table above, it can be seen that to heat 0.5 kg of water it takes 90 seconds to 120 seconds. At 0 seconds it is obtained ΔT = 0, with a heat amount of 0 J and a power of 0 j/s, it is assumed that at 0 seconds there has been no heating so that there has been no heat transfer.

CONCLUSION

Based on the experimental findings, it can be concluded that variations in air velocity significantly influence the temperature and duration of the flame in used oil-fired *multifuel* stoves, with higher air speeds resulting in greater flame temperatures but shorter flame durations due to more intense combustion from increased oxygen supply. However, air velocity does not significantly affect the color of the flame, which remains reddish-blue, nor the boiling time of water, which consistently ranges from 1.5 to 2 minutes—surpassing the performance of conventional gas and electric stoves. For future research, it is suggested to investigate the long-term efficiency and emission impacts of using different types of used oils under varying air pressures and combustion chamber designs, as well as to evaluate stove performance under real-world conditions in off-grid communities.

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