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Optimization of used engine oil Furnace Design with Initial Heater

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ABSTRACT

Used engine oil is a waste from various types of machinery that has potential as an alternative fuel. The viscous characteristics of used engine oil require viscosity adjustment to be utilized as fuel. Nowadays used engine oil burners are generally using an external heater as an initial preheater, which causes the thermal efficiency decreased. The aims of this study are optimizing the design of the used engine oil burner by adding an initial heater and to find the optimum operating conditions of the burner to improve thermal. The initial heater is a spiral-shaped heat exchanger around the flame inside the burner, using its heat to decrease the viscous of used engine oil, so the used engine oil can be used as burner fuel. This study is varying the combustion air flowrate at 3.2×10-3 kg/s, 4.6×10^{-3} kg/s, and 6.4×10^{-3} kg/s and fuel rates of 2.1×10^{-4} kg/s, 3.1×10^{-4} kg/s, and 4.3×10^{-4} kg/s so the best performance of the burner will be observed. The results were obtained the best burner performance air flowrate of 4.6×10^{-3} kg/s and fuel flow rate of 4.3×10^{-4} kg/s, producing flue gas heat of 544°C, useful energy of 2.69 kW, and a resulting thermal efficiency of 59.54%.

1. INTRODUCTION

Engine oil is essential in combustion engine construction, protecting the engine from corrosion. It is classified into two types: used in automotive machinery and industrial equipment (Grimmig *et al*., 2021). After use, the quality of the oil tends to degrade. Thus, it is referred to as used oil (Arif *et al*., 2021). Used engine oil is a lubricant waste from various types of machinery, which has potential as an alternative fuel that needs to be optimally utilized (Tahfifah *et al*., 2016). In Indonesia, the production of used engine oil waste reaches 520 million liters per year or 1,420 kiloliters per day. According to a study by Prayitno *et al.* (2021), in the Karang Anyar Village area, Tambora District, West Jakarta, 3,857 liters are recorded per month, and in Palm Oil Companies in West Kalimantan, 942 liters per year (Pangesti *et al*., 2022). This waste comes from various sources: generators, vehicles, heavy equipment, gearboxes, turbines, hydraulics, and fluid couplings. With such a significant amount of waste, the potential for environmental pollution becomes a real risk if not properly managed. The impact of used engine oil waste is very serious, as it contains heavy metals and chlorinated solutions, which can damage groundwater, soil, and marine ecosystems that are vital to life (Pratama *et al*., 2020). Dahlan *et al*. (2014) stated that used oil contains a higher metal content than new oil.

Used engine oil has high potential to be used as fuel (Tahfifah *et al.,* 2016). Table 1 shows the price comparison per kilocalorie of used engine oil with other fuels. From the table, it is evident that used engine oil is the cheapest fuel. The use of used engine oil as fuel can be an alternative that provides benefits in reducing operational costs for machines that require thermal energy. Used engine oil has high viscosity (100 mPa.s), so equipment is needed to reduce the viscosity to resemble that of other fuels. To achieve this condition, a preheating process is required (Prayitno *et al*., 2021). This process lowers the viscosity to 10.58 mPa.s at 100 °C, allowing the used engine oil to flow more easily towards the burner nozzle under air pressure (Kusnadi *et al*., 2020). Used engine oil burners present challenges, including unstable combustion temperatures, flames that gradually dim, and temperatures that tend to drop. This instability has the potential to cause pollution and requires careful management to maintain a constant temperature and air pressure, which influence the combustion process (Ramadhan & Basyirun, 2020).

Table 1. Comparison of Fuel Prices per Kilocalorie

Type of Fuel	Calorific Value (kcal/kg)	Price per (Rp/kg)	Price (Rp/kcal)
Used engine oil	10,684	2,907	0.272
Diesel fuel	10,755	18,023	1.676
Wood pellets	4,400	2,000	0.455
LPG gas	11,254	16,000	1.422

Currently, burners commonly rely on heaters as a preheating method to reduce the viscosity of used engine oil. The heating process with a heater is done by placing it inside an oil reservoir tank with a relatively large volume, which results in the heater requiring a high amount of electrical power. In addition, the existing burners still use an open-close valve system to regulate the flow of used engine oil, which can lead to inaccuracies in the oil flow rate delivered to the burner. Inaccurate oil flow rates affect the amount of oil supplied, which in turn impacts its thermal efficiency. Existing used engine oil burners still exhibit low thermal efficiency, as shown in the research by Kusnadi *et al* (2020), where the burner achieved only 4.98% efficiency, which is lower compared to kerosene stoves. This is one of the limiting factors in the use of used engine oil stoves in everyday life as a heat source for drying.

To address these issues, it is necessary to optimize the design of used engine oil burners by modifying the existing burner design. This research aims to optimize the design of used engine oil burners by adding an initial heater, determining the optimum combustion process conditions, and obtaining the thermal efficiency values of the modified combustion chamber. This research is expected to improve the efficiency and accuracy of used engine oil burner usage.

2. MATERIALS AND METHODS

This research was conducted from February 2024 to June 2024 at the Manufacturing Technology and Renewable Energy Engineering Laboratory, Department of Mechanical and Biosystem Engineering, IPB University. The raw material used was used engine oil obtained from conventional workshops in Dramaga District, Bogor Regency.

2.1. Determination of Design Criteria

The design criteria were determined based on the problem identification that had been conducted and adjusted to the testing equipment used for performance tests. The burner criteria are designed as follows: (1) Able to mix air and used engine oil effectively so that no used engine oil remains unburned; (2) Equipped with a device to reduce the viscosity of the oil to 10 mPa.s; (3) Has a minimum combustion efficiency of 55%; and (4) Produces maximum heat (> 2 kW).

The design approach was carried out by analyzing the used engine oil combustion system. The burner is specifically designed for used engine oil fuel, so technical analysis is conducted with an approach based on its characteristics.

Table 2. Characteristics of Used engine oil (Jafari & Hassanpour, 2015)

Characteristics	Unit	Value
Density	15 kg/ℓ	0.82-0.92
Viscosity	cSt	100-170
Calorific Value	kJ/ℓ	8000
Water Content	(%)	>3
Sulfur Content	(%)	0.5-0.9
Flash Point	˚C	75-90
Solid Content	(%)	0.5

2.2. Functional Design

The design of the used engine oil burner is created with attention to its function for burning used engine oil at a specified feed rate. The design of each component can be seen in Table 3.

Table 3. Functional design

No.	Function	Component Alternatives	Selected Component
1	Reducing viscosity	Heating in storage tank Heating in spiral pipe in burner Electric heating wrapped around oil supply pipe	Heating in spiral pipe in burner
2	Oil delivery	Gravity system with elevated tank Pump system	Pump system
3	Air delivery	Vertically Cyclone Directly with several holes at the pipe end	Cyclone
4	Air source	Ambient air Blower Compressor	Blower

2.3. Design Analysis

2.3.1. Combustion Characteristics Calculation

a. Air-Fuel Ratio

The chemical formula of used engine oil has a structure of $C_{18}H_{38}$, so the combustion reaction is as follows:

$$C_{18}\,H_{38} + 27.5\,(3.76\,N_2 + O_2) \rightarrow 18CO_2 + 19H_2O + 103.4N_2$$

Based on the calculation of air composition for used engine oil combustion, it requires 14.83 kg of air per kg of fuel. This air flow will be provided in a cyclone manner in the combustion chamber.

2.3.2. Oil Pipe Design

1. Heat Exchanger

Several equations from Holman (2001) were used in the heat exchanger design.

1. Finding Reynolds Number (Re) and Nusselt Number (Nu)

$$Re = \frac{(\rho \times V \times Dd)}{\mu} \tag{1}$$

$$Nu = 3.66\,\frac{0.0688 \times (Dd/l) \times Re \times Pr}{[1+\left(0.04 \times \left(\frac{Dd}{l}\right) \times Re \times Pr\right)]} \tag{2}$$

where ρ is density (kg/m³), V is used engine oil speed (m/s), D_d is the inner diameter of pipe (m), μ is kinematic viscosity ($kg.m^{-1}.s^{-1}$), l is pipe length (m), and Pr is Prandlt number

2. Finding the convection heat transfer coefficient (h_i) in the pipe

$$h_i = Nu \times k/D_d \tag{3}$$

where k thermal conductivity of used engine oil exhaust gas (W/mK)

3. Finding the convection heat transfer coefficient (h_c) of copper material

$$hc = k/x \tag{4}$$

where k is thermal conductivity of copper (W/m K), and x is thickness of copper pipe (m).

4. Finding the convection heat transfer coefficient outside the pipe (h_o)

$$h_o = Nu \times k/D_o \tag{5}$$

where D_o is outer diameter of pipe (m)

5. Calculating thermal resistance in the pipes (R_i)

$$R_i = 1/h_i \tag{6}$$

6. Calculating thermal resistance of copper material (R_c)

$$R_c = x/k \tag{7}$$

7. Calculating thermal resistance outside the pipe (R_o)

$$R_o = 1/h_o \tag{8}$$

8. Finding the overall heat transfer coefficient (U)

$$U = R_i + R_c + R_o \tag{9}$$

9. Finding the total area of the heat exchanger (A)

$$A = \frac{\dot{Q}}{U \times LMTD} \tag{10}$$

where $\dot{Q}$ is heat transfer rate (W), and $LMTD$ is log mean temperature difference (°C)

10. Finding the length of HE (heat exchanger) pipe (l)

$$l = A/[(4)(\pi)(Dl)] \tag{11}$$

2. Research Matrix

Combustion testing was carried out using the treatments presented in Table 3. The data obtained was analyzed to determine the treatment with the best burner performance. From the matrix in Table 4, the air and fuel ratio (AFR) is obtained, which was presented in Table 5.

Table 4. Testing matrix

Air Rate (A)	Used engine oil Rate (B)	Code
0.0032 kg/s (A1)	0.00021 kg/s (B1)	A1B1
	0.00031 kg/s (B2)	A1B2
	0.00043 kg/s (B3)	A1B3
0.0046 kg/s (A2)	0.00021 kg/s (B1)	A2B1
	0.00031 kg/s (B2)	A2B2
	0.00043 kg/s (B3)	A2B3
0.0064 kg/s (A3)	0.00021 kg/s (B1)	A3B1
	0.00031 kg/s (B2)	A3B2
	0.00043 kg/s (B3)	A3B3

Table 5. AFR values for each treatment

	A1B1	**A1B2**	**A1B3**	**A2B1**	**A2B2**	**A2B3**	**A3B1**	**A3B2**	**A3B2**
AFR (kg/kg)	15.24	10.32	7.44	21.9	14.84	10.70	30.48	20.65	14.88

2.4. Performance Test

2.4.1. Experimental Set-up

Figure 1 shows the temperature measurement conducted in the combustion chamber, the anemometer used to measure air velocity, the clamp meter for measuring electrical current usage, and the submersible pump for pumping the fuel.

2.4.2. Viscosity

To achieve optimal viscosity, preliminary research was conducted with the following steps: used engine oil was heated using a heater with varying temperatures to determine the optimal temperature for reducing the viscosity of the used engine oil, which was then measured with a viscometer to determine the viscosity of the used engine oil (Khatimah *et al.,* 2016).

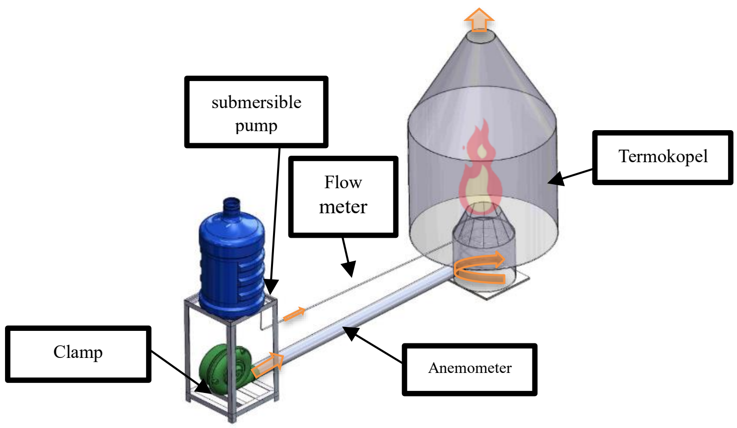

Figure 1. Exsperimental set-up.

This method is determined based on Poiseuille's law using an Ostwald viscometer. The measurement is done by recording the time required for the liquid to flow through a capillary tube from point a to point b. A certain amount of liquid, whose viscosity is to be measured, is placed into the viscometer. The liquid is then drawn up to point a using a pump. The liquid is allowed to flow downwards, and the time taken to flow from point a to point b is recorded using a stopwatch. The viscosity is calculated using the Poiseuille equation:

$$\frac{\eta 1}{\eta 2} = \frac{\rho 1 \times t1}{\rho 2 \times t2} \tag{12}$$

where η is the viscosity, ρ is the density, and *t* is time. Subscript 1 and 2 referred to water and used engine oil, respectively.

2.4.3. Oil Debit

Fluid flow rate is the volume of fluid that flows through a given area in a certain amount of time. In this research, the speed of used engine oil flow is controlled by varying the pressure, which affects the fuel flow rate from the pump. The flow rate of the oil is related to the amount of oil flowing through a channel or pipe. The speed of the pump plays a key role in regulating the pressure of the used engine oil. By utilizing Bernoulli's principle, efficient management of the oil flow rate can be achieved.

The factors that influence this continuity principle include flow velocity and cross-sectional area. Flow rate (Q) was calculated from the velocity (V) of fluid that flows through a specific cross-sectional area (A) as the following:

$$Q = V.A \tag{13}$$

2.4.4. Combustion Air Requirement

Measurements can be carried out using an anemometer to measure air velocity. Place the anemometer at a specific point that can represent the conditions in the pipe. To obtain the air mass flow rate ($\dot{m}$), it can be calculated using the following equation:

$$\dot{m} = \rho \times A \times V \tag{14}$$

2.4.5. Heat Energy

To determine the thermal energy produced by the burner, it can be calculated using the following equation:

$$Qg = \dot{m}_{air} \times Cp_{air} \times (T_{out\ air} - T_{in\ air}) \tag{15}$$

2.4.6. Combustion Efficiency

To determine the combustion efficiency (η_{th}) in the burner, it can be calculated using the following equation:

$$\eta_{th}\,(\%) = (Qg/Qin) \times 100\% \tag{18}$$

where $Qg = Qout$ and $Qin = \dot{m}_{oil} \times$ calorific value of oil

3. RESULTS AND DISCUSSION

3.1. Used engine oil Burner Design

Design a used engine oil burner with an initial heater with a capacity of 1 liter per hour. This device uses a continuous heating mechanism to reduce the viscosity of the used engine oil for easier combustion. The procedure for delivering the used engine oil involves using a submersible pump to transfer the material from the reservoir to the initial heater. The used engine oil and oxygen will mix in the combustion chamber (Hakim, 2020), with the air supplied in a cyclone manner to ensure proper mixing of used engine oil and oxygen, resulting in complete combustion as indicated by the absence of unburned fuel in the combustion chamber.

The initial heater is designed in a spiral shape, considering the conduction heat transfer occurring in the fuel, resulting in an appropriate heat exchanger (HE) calculation. This can reduce the energy input required to preheat the oil using a heater, as demonstrated by Madhusudan *et al.* (2017). The initial heater consists of a long pipe formed in a spiral (HE). This shape is chosen to prolong the residence time of the used engine oil inside the initial heater, making heat exchange more effective and achieving the desired viscosity, similar to the approach used by Madhusudan *et al*. (2017). For this purpose, a pipe length of 2912 mm is required, with a pipe diameter of 8 mm and a thickness of 1 mm. The air delivery pipe has a diameter of 73 mm, while the burner has a diameter of 203.2 mm and a height of 350 mm. The equipment design is modeled using CAD, and the detailed design can be seen in Figure 2. The specifications of the used engine oil burner can be seen in Table 6.

Figure 2. Tool design using CAD

Table 6. Used engine oil burner specifications

No	description	Specifications
1	*Burner*	height 350 mm, Ø 210 mm
2	*Initial heater*	length 2912 mm, Ø 7 mm
3	Oxygen supply pipe	length 1000 mm, Ø 73 mm
4	Fuel supply pipe	length 1000 mm, Ø 7 mm
5	Blower	½ In
7	Frame	200 x 200 x 500 mm
8	Used engine oil container	12 L

3.2. Viscosity Characteristics of Used engine oil

Viscosity is a measure that indicates the degree of thickness in used engine oil (Siskayanti & Kosim, 2017), The characteristics of used engine oil based on viscosity content were tested in preliminary research using used engine oil from collectors in the Dramaga area, with an Ostwald viscometer. The preliminary research aims to identify the viscosity characteristics of used engine oil in order to determine the appropriate viscosity for combustion. Used engine oil tends to have a high viscosity, so a proper formula is needed as a basic reference for designing a used engine oil burner. Testing was conducted using an Ostwald viscometer with temperature variations of 80°C, 90°C, 100°C, 110°C, 120°C, 130°C, 140°C, 150°C, 160°C, 170°C, 180°C, 190°C, and 200°C. The results of the preliminary research is seen in Figure 3.

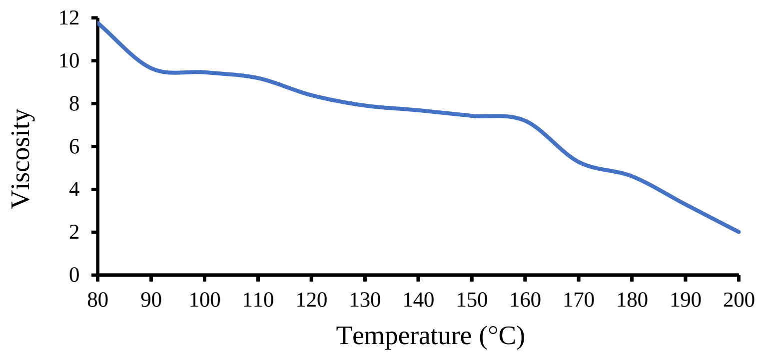

Figure 3. Viscosity graph

Based on Figure 3, the preliminary test results show that viscosity decreases as the oil temperature increases. At a temperature of 80°C, the viscosity is 11.76 mPa^{-s}, while at 200°C, the value is 2.01 mPa^{-s}. To ensure proper atomization, low viscosity of the used engine oil is required in the preheater as the initial heater in the burner. In measurements using the Ostwald viscometer, the type of fluid being measured is typically considered a Newtonian fluid, where the viscosity is not time-dependent or shear-dependent. The viscosity of a Newtonian fluid remains constant regardless of how fast the fluid flows or how long it takes to flow.

This is consistent with the research conducted by Kusnadi *et al.* (2020), which found that the higher the temperature, the lower the viscosity of used engine oil. This occurs because an increase in temperature leads to a decrease in the viscosity of the used engine oil. As the temperature rises, the kinetic energy of the fluid molecules increases, weakening the intermolecular forces and allowing the molecules to move more easily relative to one another. Furthermore, used engine oil that has been contaminated and chemically degraded during use undergoes changes in molecular structure, which further accelerates the reduction in viscosity as the temperature increases. As a result, the used engine oil becomes thinner. Lower viscosity makes it easier for the oil to flow from the initial heater to the end of the pipe (Azharuddin *et al.,* 2020). From this graph, the viscosity used as a reference in the design of the used engine oil burner is at a temperature of 150°C with a viscosity value of 1.2 cSt, as the temperature in the feeder heater ranges between 150 - 200°C.

3.3. Fuel and Air Flow

The results of the flow rate calculations for used engine oil and air can be seen in Table 7. It shows that as the air flow rate increases, the air temperature decreases (over-aeration). However, the higher the used engine oil flow rate, the better the combustion produced. The test results show that treatment A2B3 produces a high hot air temperature with an average of 538°C. This is supported by the research of Mahardhika *et al.* (2020) which states that an increase in fuel flow rate affects the combustion temperature.

3.4. Hot Air Profile

Hot air temperature is the result of combustion, which is a chemical reaction between fuel and air (Paraschiv *et al.,* 2020). This process begins with ignition at the top layer of the fuel, which then propagates through radiation from the flame and the walls of the combustion chamber (Bauer *et al*., 2010). Figure 4 shows the temperature profile of flue gas

Table 7. Flow rates of used engine oil and air

	Treatment	Debit
Air	A1	4.00×10^{-3} m^3/s
	A2	4.20×10^{-3} m^3/s
	A3	4.40×10^{-3} m^3/s
Used engine oil	B1	2.47×10^{-7} m^3/s
	B2	3.61×10^{-7} m^3/s
	B3	4.72×10^{-7} m^3/s

over the combustion time of used engine oil in all treatments. Flue gas is a combustion product that carries hot air from the burner to the chimney. The A1B1 test at constant combustion temperature reached 398°C. The average output temperature during the A1B1 test at constant combustion was 349°C. In the A1B2 test, the average combustion temperature at constant reached 385°C, while the average output temperature during constant combustion reached 314°C. In the A1B3 test, the average combustion temperature inside the combustion chamber at constant reached 448°C, and the average output temperature during constant combustion reached 410°C.

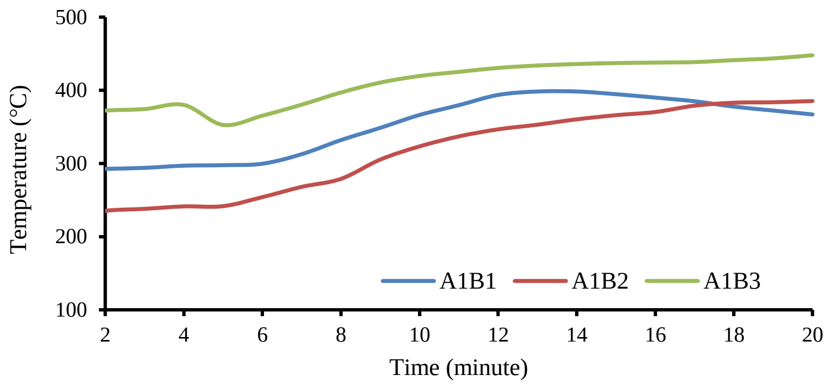

Figure 4. Temperature versus low air velocity.

The research showed that at a low airspeed of 0.95 m/s (Figure 4), the mixing of air and fuel in the A1B1 treatment resulted in slow combustion. The fuel evaporated gradually until stable combustion was achieved. Therefore, the temperature trend increased without significant fluctuations. The low temperature resulted from incomplete mixing of used engine oil and O_2 (air) due to the low flow rate of used engine oil and oxygen supply, leading to a temperature drop. In the A1B2 treatment, the combustion rate occurred slowly, and the temperature trend tended to increase. In this condition, not all of the fuel burned because of a slight shortage of O_2, preventing the complete mixing of O_2 with the fuel flow, leading to the production of toxic carbon monoxide (CO), soot, and unburned hydrocarbons. Additionally, the energy generated was low because not all of the fuel's energy was converted into heat. The A1B3 treatment showed that the combustion rate occurred steadily, with a higher amount of used engine oil supplied, resulting in an increase in hot air temperature up to 480°C. This occurred because of the good mixing of O_2 and used engine oil.

The A2B1 test at constant combustion temperature reached 333°C. The average output temperature during the A2B1 test at constant combustion was 317°C. In the A2B2 test, the average combustion temperature at constant reached 450°C, while the average output temperature during constant combustion reached 441°C. In the A2B3 test, the average combustion temperature inside the combustion chamber at constant reached 544°C, and the average output temperature during constant combustion reached 538°C. At a moderate airspeed of 1 m/s, the A2B1 treatment showed a constant temperature distribution. However, the temperature produced was lower compared to the A1B1 treatment. This occurred because of the increased air supply, which caused the amount of air provided to exceed the amount of used engine oil supplied. This condition shows that increasing the air supply does not increase the temperature.

In the A2B2 treatment, the temperature distribution was constant and better compared to the lower airspeed. This occurred because the addition of air showed that combustion occurred quite well due to a higher ratio of used engine oil to O_2 compared to A1 (0.95 m/s). In the A2B3 treatment, the highest combustion temperature was achieved, reaching up to 544°C. In this condition, optimal combustion produced carbon dioxide (CO_2) and water (H_2O) as the main products. This can increase energy efficiency and reduce harmful emissions. Hidayat & Basyirun (2020), obtained an ideal temperature of 963°C, but this difference occurred due to different measurement methods, where they measured direct flame temperature, while this study measured flue gas (hot air).

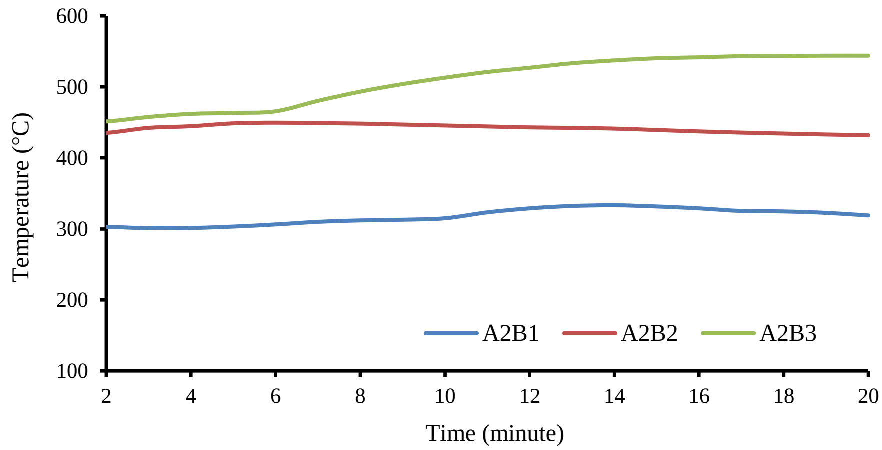

Figure 5. Temperature versus medium air velocity.

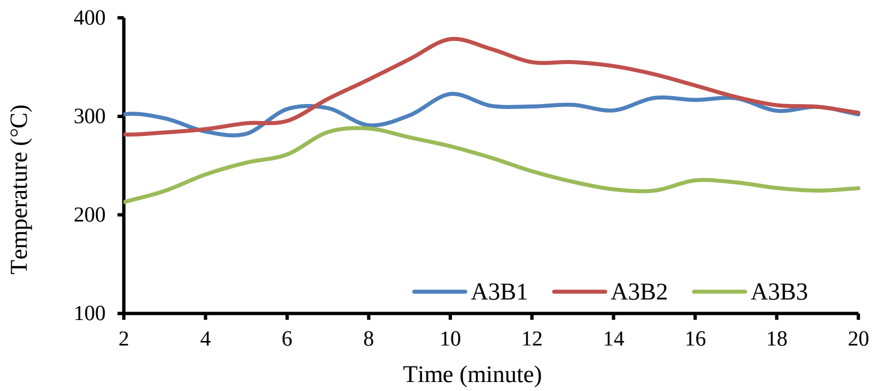

Figure 6. Temperature versus high air velocity.

In the A3B1 test, the constant combustion temperature reached 319°C. The average output temperature during the A3B1 test at constant combustion was 305°C. In the A3B2 test, the average combustion temperature at constant reached 355°C, while the average output temperature during constant combustion reached 323°C. In the A3B3 test, the average combustion temperature inside the combustion chamber at constant reached 288°C, and the average output temperature during constant combustion reached 242°C.

At a high airspeed of 1.05 m/s (Figure 6), the hot air temperature was low, and the temperature trend fluctuated. When excess air is supplied, the combustion temperature in the waste oil burner tends to be low and fluctuating. This phenomenon is known as over-aeration. Over-aeration occurs because too much air flows through the combustion chamber, resulting in excessive cooling and inefficient mixing between air and fuel. This causes a drop in combustion temperature because much of the heat energy produced by combustion is used to heat the excess air rather than raising the temperature. Additionally, excess air can disrupt flame stability, causing temperature fluctuations and reduced combustion efficiency. As a result, the combustion process becomes less efficient. Research by Lekpradit & Namkhat (2017), states that excess air leads to a decrease in hot air temperature due to the imbalance between the oxygen supply and the fuel provided.

3.5. Heat Energy

Thermal energy is calculated based on the sensible heat of air. The calculation of sensible heat of air involves using the temperature difference between the air entering and exiting the burner during the combustion process. The tests show that as the flow rate of used engine oil increases, the resulting temperature also increases. However, this is different from the air flow rate, where an increase in air velocity leads to a decrease in the resulting hot air temperature. This occurs because an excess air supply results in incomplete utilization of the air, thereby reducing the effectiveness of the heat generated. The optimal air velocity is found to be 1 m/s (A2B3) with heat output (Qg) of 2.69 kW.

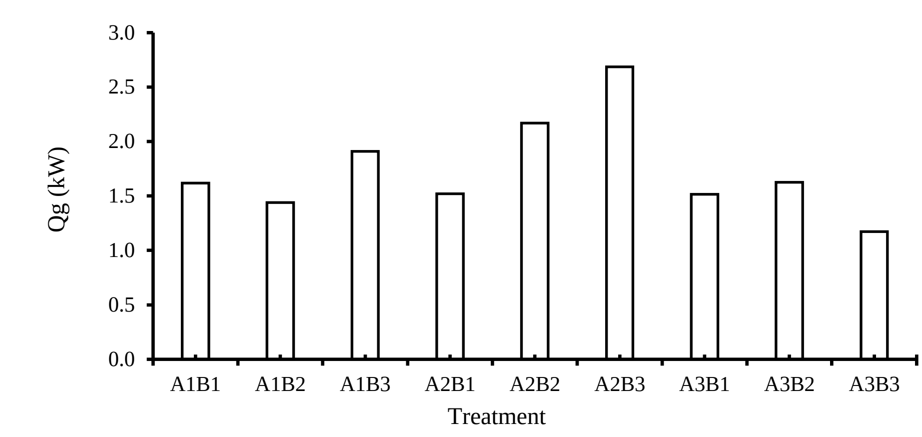

Figure 7. Graph of *Qg* for all treatments

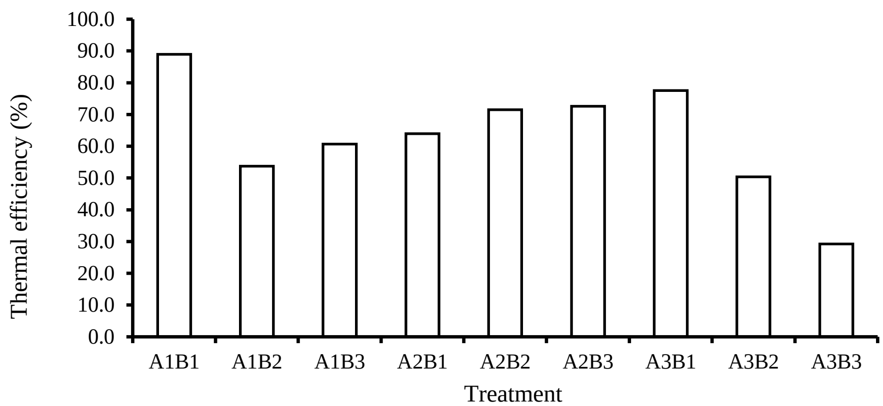

Figure 8. Effect of excess air on thermal efficiency

3.6. Burner Thermal Efficiency

Figure 8 presents the thermal efficiency of used engine oil combustion in the burner. A thermal efficiency of 59.54% was achieved under treatment A2B3, which meets the target set at 55%. The thermal efficiency shows an increasing trend with each variation in fuel flow rate. The testing resulted in an average burner efficiency of 51.77% for used engine oil combustion. The graph indicates that the addition of air affects thermal efficiency. Treatment A2B3 shows a thermal efficiency of 59.54%. Treatment A1B1 demonstrates that the air-to-fuel ratio (AFR) and used engine oil reach a peak with an efficiency value of 65.63%. Compared to the study by Kusnadi *et al.* (2020), which achieved only a 4.94% combustion efficiency for used engine oil, the burner efficiency obtained in this study is significantly higher. The graph above shows that the results of the A2B3 test represent a test with good thermal efficiency, with the highest usable energy value of 2.69 kW.

4. CONCLUSION

The designed used engine oil burner includes an initial heater as a continuous pre-heater, a submersible pump to control the used engine oil flow rate, and air distribution through a cyclone with an air distribution pipe placed at the side of the burner. The burner consists of 8 functional components: a hopper for collecting used engine oil, a used engine oil distribution pipe, an initial heater, an air distribution pipe, a combustion chamber, a frame, a submersible pump, and a blower. The initial heater has been designed according to the design criteria. The testing using used engine oil with a calorific value of 9090.91 kJ/kg. The burner was tested with 9 trials based on a 3x3 matrix (3 fuel flow rates and 3 air flow rates). The optimal fuel mixing was achieved with an air flow rate of 4.20×10^{-3} m³/s and a used engine oil flow rate of 4.72×10^{-7} m³/s, reaching the design target (2 kW) within the range of 1-2.69 kW. Based on the experiment results, the best thermal efficiency value is 59.54%.

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