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Optimizing The Management Of Used Cooking Oil In Free Nutritious Meal Kitchens Through The Use Of Environmentally Friendly Burner Technology

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A R T I C L E I N F O

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A B S T R A C T

The use of food ingredients in the Free Nutritious Meals (MBG) program continues to increase, resulting in ever-larger amounts of used cooking oil waste from participating kitchens. This study aims to evaluate the performance of a used cooking oil fueled burner equipped with an air blower powered by a solar panel system, a battery, and an inverter as an alternative to electricity from the national grid. The testing utilized used cooking oil from one of the kitchens at a nutritional service unit in Makassar, employing an experimental method based on the *Water Boiling Test* (WBT) using 2 kg of water and 0.05 kg of fuel. Three air velocity variations—2, 3, and 4 m/s—were tested for each condition. The test results showed thermal efficiencies of 27.2%, 29.1%, and 28.0%, with air-to-fuel ratios of 13.7, 20.5, and 27.3, respectively. Thus, the highest efficiency was achieved at an airflow velocity of 3 m/s. Consequently, the burner is capable of generating heat from used cooking oil at an air velocity of 3 m/s, thereby improving the quality and suitability of used cooking oil for recycling and reuse as an alternative fuel.

INTRODUCTION

The use of waste as an alternative energy source is an important approach to supporting more sustainable resource management. One type of waste with significant potential for development is used cooking oil, which is routinely generated by households, food service businesses, and large-scale food processing operations. In Indonesia, there is a substantial supply of used cooking oil, yet its management still faces various challenges. Discharging the oil directly into drainage systems or aquatic environments has the potential to cause environmental degradation, while reusing used cooking oil for consumption can also pose health risks (Asmoro et al., 2025; Manikandan et al., 2023; Foteinis et al., 2020). Therefore, developing alternative utilization pathways for used cooking oil is relevant, including its use as an energy source.

This potential is particularly compelling in the context of Free Nutritious Meals (MBG) kitchens, which routinely process food and are likely to generate used cooking oil. The oil produced from these activities requires an appropriate management system to prevent it from becoming an environmental burden. At the same time, the energy requirements for cooking processes present an opportunity to evaluate the reuse of some of the energy still contained in used cooking oil. However, this study does not assume that MBG kitchens experience energy shortages or supply disruptions. The use of used cooking oil in this study is positioned as an alternative energy option and a waste management approach. Technically, the use of used cooking oil as a fuel presents different challenges compared to gaseous fuels such as LPG. Used cooking oil has physical and chemical characteristics influenced by heating processes and repeated use, including changes in viscosity, free fatty acid content, and degradation products.

These characteristics can affect the atomization process, air–fuel mixing, flame stability, and heat transfer efficiency. One of the key parameters in controlling the combustion process is the air fuel ratio (AFR). Inadequate air supply can lead to incomplete combustion or increase energy loss through exhaust gases. Therefore, air supply control is a critical factor in evaluating the ability of UCO fuel burners to effectively generate and transfer thermal energy. Previous studies have demonstrated various approaches to utilizing vegetable oils and used cooking oil as fuels. Consequently, the development of combustion devices has been pursued through modifications to stoves, the use of porous burners, fuel blending, and changes to the air supply system design (Natarajan et al., 2008; Mustafa et al., 2015; Kaushik & Muthukumar, 2020; Dinesha et al., 2019). Other studies have also examined the effects of nozzle geometry, air velocity, and fuel variations on combustion characteristics (Hamim & Adiwidodo, 2024; Pranata et al., 2024; Mara et al., 2025). Nevertheless, the results of these studies indicate that device performance is highly dependent on the type of fuel, burner design, and operating conditions used. Consequently, results from one type of combustion system cannot be directly generalized to used cooking oil burner systems with different configurations.

The use of a blower provides the opportunity for more precise control of the air supply. However, increasing the air supply does not always result in improved thermal efficiency, as excessive airflow can increase heat loss and alter

energy transfer characteristics. Research on other combustion systems indicates that changes in air velocity can affect combustion conditions and emissions, but this relationship is strongly influenced by the type of fuel and stove technology used. Therefore, findings from biomass stoves or other combustion systems cannot be directly applied to explain the combustion behavior of used cooking oil. The gap in this study lies in the limited experimental data directly linking blower air velocity, the calculated air-to-fuel ratio, and the heat energy absorbed by water in a burner fuel by pure UCO. Based on a literature review, there is still a limited number of studies evaluating the relationship between these parameters within a single testing system using a low-power blower connected to a small-capacity solar panel system. Furthermore, some previous studies focused on burner design modifications or combustion characteristics without specifically comparing changes in air supply conditions with the system's ability to transfer energy to the heating medium. Given this gap, the novelty of this study lies in the integrated use of used cooking oil from kitchens as an alternative fuel, the control of blower air velocity which is varied as an operational variable and the analysis of the relationship between AFR and excess air on the heat energy absorbed by water and thermal efficiency. This study also utilizes a small capacity solar panel system as a power source to operate a low-power blower.

This approach provides an additional perspective on the potential for developing burner systems that are not entirely dependent on the PLN power grid. The objective of this study is to evaluate the initial thermal performance of a used cooking oil fuel burner under various blower air velocity conditions. Testing was conducted using a procedure based on the *Water Boiling Test* (WBT) with single use waste cooking oil obtained from one of the MBG kitchens in Makassar. Variations in air velocity were used to calculate the AFR and evaluate its effect on the rise in water temperature, the heat energy absorbed by the water, and thermal efficiency during a constant heating period. The analysis focused on identifying the operating conditions, among those tested, that demonstrated the most effective utilization of fuel energy. In practical terms, the research results can serve as a basis for developing technology to utilize used cooking oil as an alternative energy source in food processing activities. However, these test results should be understood as preliminary evidence regarding thermal performance, not as proof that the burner is safe or environmentally friendly for direct operation.

Demonstrating safety requires further testing of flame stability, fire risk, component temperatures, system reliability, and operational durability over a longer period. Similarly, claims of environmental friendliness require direct measurements of combustion emissions, such as CO, CO_2, NO_x, particulates, and other relevant environmental parameters. Thus, the main contribution of this research is to provide an experimental data foundation for the next stage of development, while safety and environmental impact validation are on the agenda for further research before the technology can be recommended for operational use in MBG kitchens.

LITERATURE REVIEW

Research on the use of used cooking oil as a fuel has evolved through various approaches, including direct use, blending with other fuels, gasification, and modifications to burner and stove systems. In general, previous studies have shown that the success of used cooking oil utilization is determined not only by the fuel's calorific value but also by its physical characteristics, atomization or vaporization mechanisms, adequate air supply, burner design, and the system's ability to transfer heat to the heated medium. Hamim and Adiwidodo (2024) and Mara et al. (2025) demonstrated that nozzle geometry and airflow conditions can influence flame characteristics and combustion temperatures in cooking stove systems fuel by used cooking oil. Pranata et al. (2024) reported a thermal efficiency of approximately 26% for a burner fuel by used cooking oil, indicating that UCO can generate thermal energy, but its energy utilization rate remains highly dependent on the burner's design and operating conditions. Meanwhile, Mahfouz et al. (2018) demonstrated that changes in the fuel-air mixture conditions affect flame characteristics, combustion efficiency, and emissions.

Collectively, these findings indicate that regulating the airflow rate is one of the critical design and operational variables in waste cooking oil-based liquid fuel combustion systems. However, previous studies differed in fuel type, burner configuration, air supply method, and measured output parameters. Therefore, the results of those studies cannot be directly generalized to used cooking oil burners with different configurations. This relationship forms the basis of the model in this study. The blower air velocity is used as an operational variable because it directly determines the flow rate and mass of air entering the system.

The air mass is then used to calculate the actual AFR and excess air based on the mass of fuel consumed. Furthermore, system performance is evaluated through measurable outputs, namely the increase in water temperature, the heat energy absorbed by the water, fuel consumption, and thermal efficiency. Thus, this study not only compares the relationship between air supply conditions and the resulting efficiency.

2.1 Used Cooking Oil

Used cooking oil is cooking oil that has been used and heated during food preparation and is therefore no longer recommended for repeated consumption. During the frying process, the oil can undergo hydrolysis, oxidation, and polymerization reactions. These reactions result in changes to the oil's chemical composition, including an increase in free fatty acids, the formation of oxidation products, and the formation of compounds with higher molecular weights. These chemical changes alter the oil's physical characteristics, particularly its color, viscosity, density, and thermal stability. Variations in these characteristics are important in combustion research because liquid fuels must undergo heating, vaporization, or atomization before they can mix effectively with air and react in the gas phase. In general, vegetable oils and used cooking oil consist primarily of triglycerides—ester compounds formed from glycerol and fatty acids. This structure contains carbon and hydrogen, which can release energy during oxidation, but it also contains oxygen within the fuel molecules. These

characteristics distinguish used cooking oil from LPG, which generally consists of light hydrocarbons such as propane and butane.

Table 1. Differences in the combustion characteristics of LPG and used cooking oil

Aspek	LPG	Used cooking oil
Phases of atmospheric conditions	Gas	Cair
Main compounds	Propane and butane	Triglycerides, free fatty acids, degradation products
Viscosity	Very low	High (far above diesel and kerosene)
Processes leading up to ignition	Mixes immediately with the air	It must be atomized or vaporized first
Soot tendency	Low	Higher if air mixing is poor

These differences indicate that burner designs for used cooking oil must take into account the characteristics of liquid fuels, particularly the fuel's ability to flow, vaporize or atomize, and mix with air. Thus, fuel characterization is not merely supplementary information but serves as the foundation for determining operating conditions and interpreting burner test results.

2.2 Combustion Technology

Combustion is a rapid oxidation reaction between a fuel and an oxidizer in this case, oxygen from the air that releases heat. Complete combustion produces carbon dioxide and water vapor. Incomplete combustion, on the other hand, produces carbon monoxide (CO), unburned hydrocarbons, and soot. Proper combustion requires three conditions, often referred to as the "fire triangle" sufficient fuel, sufficient oxygen, and activation energy or a heat source. In liquid fuels, the combustion process occurs in several stages: heating, vaporization or atomization, mixing of fuel vapor with air, and the gas-phase combustion reaction. Because used cooking oil has high viscosity, the vaporization and mixing stages are the most critical factors determining the quality of combustion.

2.2.1 Air Fuel Ratio and Equivalence Ratio

The air fuel ratio (*air fuel ratio*) is defined as the ratio of the mass of air to the mass of fuel delivered. The stoichiometric AFR is the AFR value at which the available air is exactly equal to the theoretical requirement for complete combustion (Turns, 2012). The equivalence ratio (*equivalence ratio*, φ) and excess air ratio (λ) are expressed as:

$$\varphi = \text{stoichiometric AFR} / \text{actual AFR, and } \lambda = 1/\varphi$$

A λ value greater than 1 indicates a lean mixture (excess air), while a λ value less than 1 indicates a rich mixture (insufficient air). Too little air causes incomplete combustion, while excess air increases heat loss through the exhaust gases and lowers the flame temperature, thereby reducing the efficiency of energy transfer to the heated medium. Mahfouz et al. (2018) demonstrated that

the air-fuel ratio affects flame characteristics, combustion chamber efficiency, and emissions during the combustion of used cooking oil. Therefore, the AFR is a critical parameter in evaluating burners fueled by used cooking oil. For triolein ($C_{57}H_{104}O_6$), a representative vegetable oil triglyceride, complete combustion ($C_{57}H_{104}O_6 + 80\ O_{2/\ a1>} \rightarrow 57\ CO_2 + 52\ H_2O$) requires approximately 12.5 kg of air per kg of oil, assuming the air contains about 23.2% oxygen by mass; the value 12.45 is used as the reference AFR_{st} in this study. UCO is a mixture whose composition varies depending on usage, so the actual AFR_{st} of the sample may differ slightly.

2.2.2 Liquid Fuel Burners and Stoves

Liquid fuel burners can generally be classified based on how the fuel is prepared: wick (capillary) burners, vaporizing burners, atomizing burners using pressurized air or steam, and porous-media burners. Wick burners are simple, but the wick can easily become clogged by residue from viscous fuels. Atomizing burners produce a good flame, but the nozzle can become clogged and requires air or steam pressure. Vaporizing burners heat the fuel until it vaporizes before mixing with air, making them suitable for viscous fuels as long as the heat from the flame is reused to vaporize the fuel.
The shroud (*shroud*) on the burner serves to direct the flow of air and hot gas, maintain flame stability, and improve heat transfer to the bottom of the pot.

2.2.3 Water Boiling Test, Stove Performance Standards, and Uncertainty

WBT is a laboratory protocol for comparing stoves, in which a specific mass of water is heated and the heat absorbed is compared to the fuel energy consumed (Global Alliance for Clean Cookstoves, 2014). Testing protocols vary by region, and results have been compared for forced-draft stoves (Chen et al., 2016). Variability in WBT results can be reduced by limiting water evaporation (L'Orange et al., 2012), and while three replicates are common, they are not always sufficient (Wang et al., 2014). Asmoro et al. (2025) applied the WBT to a UCO gasification stove and reported an average thermal efficiency of 54.4%, above the 50% minimum threshold in SNI 8660:2018, although the stove required 430.1 W of electrical power. Efficiency and electrical power requirements should therefore be considered together. Thermal efficiency alone does not indicate that a stove is clean or safe. Harmonized laboratory testing protocols such as ISO 19867-1 combine efficiency with pollutant emissions (CO and fine particulate matter), safety, and durability, and ISO/TR 19867-3 defines performance levels based on these results (International Organization for Standardization [ISO], 2018a, 2018b). The WHO Indoor Air Quality Guidelines provide emission rate targets for the combustion of household fuels to protect health (World Health Organization [WHO], 2014).

2.3 Photovoltaics

Photovoltaic (PV) cells convert direct solar radiation into direct current (DC) electrical energy through the photovoltaic effect in semiconductor materials, typically silicon. Absorbed photons generate electron-hole pairs that are separated by an electric field at the p-n junction, thereby generating a current

in the external circuit. Solar modules are rated by their peak power (Wp), measured under standard test conditions: an irradiance of 1000 W/m², a cell temperature of 25 °C, and the AM 1.5 spectrum. Under field conditions, the actual power output is generally lower due to lower irradiance, higher cell temperatures, shading, dust, and cable losses.

Monocrystalline and polycrystalline silicon modules are the most common types used in small-scale systems. The conversion efficiency of commercial silicon modules typically ranges from the teens to the low twenties percent. The solar cell system used in this study as an alternative to electricity from the national grid to achieve environmentally friendly energy independence consists of the following five main components:

a. **Solar panels**, as a source of DC electricity.
b. **Solar charge controller (SCC)**, which regulates battery charging, prevents overcharging, and generally protects against over-discharging. Common types of SCCs are PWM and MPPT; MPPT can draw more power from the panels, but is more expensive.
c. **Battery**, which stores energy to keep the load running during periods of low radiation or at night. In lead-acid batteries, the depth of discharge (*depth of discharge*) is limited—typically to about 50%—to preserve the battery's service life.
d. **Inverter**, which converts direct current (DC) from the battery into alternating current (AC) so that AC loads can be powered just like with utility power.
e. **Load**, in this study, refers to a blower that supplies combustion air and is powered by an inverter and an electrical outlet.

In this study, the solar panel system served only as a substitute for PLN electricity to power the blower. The duration of sunlight exposure, the panel's output power, and the battery charge status were not measured; therefore, the performance of the photovoltaic system was not evaluated.

2.4 Synthesis of the Literature Review and Research Design

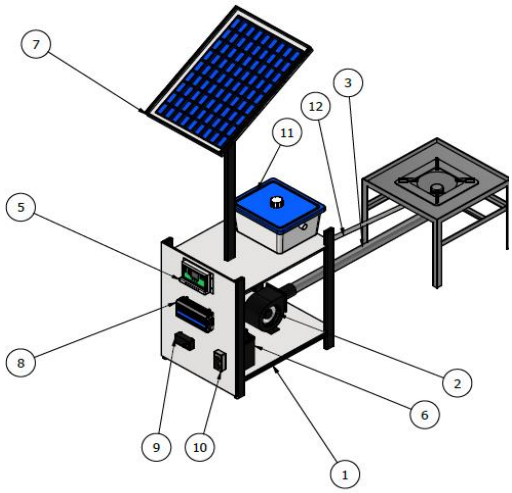
Based on the above review, the design and measurable outcomes of this study are defined as follows. First, because the combustion of used cooking oil depends on the air-fuel mixture and the air-fuel ratio (AFR) (Mahfouz et al., 2018), the blower air velocity was selected as the controlled variable, along with the AFR. Second, since fan speed affects stove performance (Arora et al., 2014; Bentson et al., 2022) and designs requiring high electrical power are less suitable for locations with limited access to electricity (Asmoro et al., 2025), a low-power blower powered by a solar panel system was used as an alternative to grid electricity. Third, since WBT is a common benchmark for comparing stoves (Global Alliance for Clean Cookstoves, 2014), thermal efficiency and water temperature rise, as well as testing limitations (Wang et al., 2014), were considered. Fourth, because standards require data on emissions and safety (ISO, 2018a, 2018b; WHO, 2014), these two factors were recorded as outcomes that were not measured in this study.

METHODOLOGY

1. Research design and fuel

This study employed an experimental design and methodology with one independent variable—blower airflow velocity at 2, 3, and 4 m/s and dependent variables consisting of final water temperature, heat absorbed by the water, thermal efficiency, and calculated AFR and λ values (Table 2). The fuel used was used cooking oil collected from one of the MBG kitchens in Makassar. The used cooking oil sample was collected from an MBG kitchen in Tamalanrea Indah, Makassar, in August 2026; it originated from the frying pans in the MBG kitchen after one cycle of use. The used cooking oil was then collected in a clean, dry container. Before use, the oil was allowed to settle for one hour to separate solid particles and water. The top layer of oil was filtered using a strainer to remove any remaining food debris. Water was separated by settling, and the cleaned oil was stored in a sealed container at room temperature until testing. Combustion air is supplied by a blower with an outlet diameter of 2.5 cm. The blower's rated power is 14.4 W (12 V × 1.2 A). Power for the blower is supplied by a 20 Wp solar panel connected via a 10 A solar charge controller (SCC) to a 12 V, 7 Ah battery. DC power from the battery is converted to alternating current (AC) by an inverter and delivered through an outlet to the blower (Figure 1). This solar panel system serves as an alternative to utility power. However, the duration of sunlight exposure, panel output, and battery charging conditions were not measured or analyzed within the scope of this study.

This test used the WBT method, in which a known mass of water is heated and the temperature increase is recorded (Global Alliance for Clean Cookstoves, 2014). The procedure used was a simplified single-phase version; the full WBT 4.2.3 sequence—including the cold-start, hot-start, and simmer phases—was not performed. In each test, 2 kg of water with an initial temperature of 30 °C was heated for 10 minutes, and the final temperature of the water was recorded. The blower air velocity was set to 2, 3, and 4 m/s, and the air velocity at the blower outlet was measured using an anemometer. The overall system design is shown in Figure 1, and the test conditions and experimental data are presented in Tables 2 and 3 below.



PARTS LIST	
ITEM	PART NAME
1	Machine Frame
2	Blower
3	Stove (Burner)
4	Blower Pipe
5	SCC (Solar Charge Controller)
6	Battery
7	Solar Panel
8	Inverter
9	Power Control
10	Socket (Power Outlet)
11	Oil Tank
12	Pipe Funnel

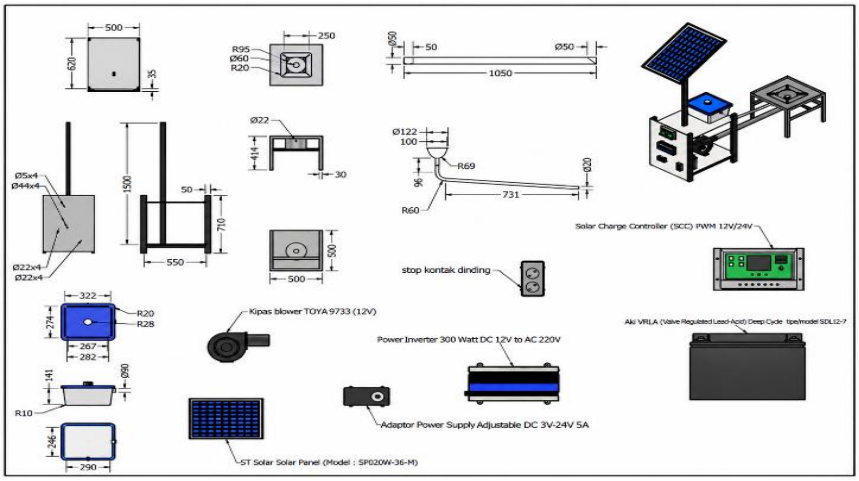


Figure1. Overall System Design

The heat absorbed by water is calculated using Equation (1), with the specific heat capacity of water set at 4.186 kJ/kg-K (Çengel & Boles, 2015). The energy supplied by the fuel and the thermal efficiency are obtained from Equation (2) and Equation (3), neglecting the heat absorbed by the pot as well as losses due to evaporation; these two neglected terms cause the calculated efficiency to be lower than the actual heat received by the pot–water system. Qw and ηth are calculated from the measured final temperature of the water, and Equation (2) applies to the entire 0.05 kg of fuel burned.

$$Q_w = m_w\, c_{p,w}\, (T_f - T_i) \quad (1)$$

$$Q_f = m_f \times \mathrm{LHV} \quad (2)$$

$$\eta_{th} = (Q_w \,/\, Q_f) \times 100\% \quad (3)$$

where Q_w is the heat absorbed by the water (kJ), m_w is the mass of the water (kg), $c_{p,w}$ is the specific heat capacity of water, T_i and T_f are the initial and final temperatures of the water (°C), m_f is the mass of fuel (kg), and η_{th} is the thermal efficiency (%).

The fuel flow rate from the tank is considered constant because the fuel tank valve opening is kept constant; the fuel mass flow rate is calculated from the fuel mass and the test duration (Eq. (6)) and is not measured directly. The air flow rate is calculated based on the cross-sectional area of the blower outlet and the air velocity measured with an anemometer. The cross-sectional area of the outlet is determined by Eq. (4), the air mass flow rate by Eq. (5) assuming an air density of 1.16 kg/m³ (air at a temperature of approximately 30 °C), and the fuel mass flow rate by Eq. (6) with t = 600 s, which assumes that 0.05 kg of fuel is burned at a constant rate for 10 minutes. The AFR and air excess coefficient are obtained from Eq. (7) and Eq. (8), with AFR_{st}= 12.45. Here, d is the outlet diameter (m), v is the air velocity (m/s), ρ_a is the air density, and the dot denotes mass flow rate (kg/s).

$$A = \pi\, d^2 \,/\, 4 \quad (4)$$

$$\dot{m}_a = \rho_a\, v\, A \quad (5)$$

$$\dot{m}_f = m_f \,/\, t \quad (6)$$

$$AFR = \dot{m}_a / \dot{m}_f \quad (7)$$

$$\lambda = AFR / AFR_{st} \quad (8)$$

RESEARCH RESULT

At air flow speeds of 2 m/s, 3 m/s, and 4 m/s. The final water temperatures are 90.5, 94.7, and 92.3 °C at air velocities of 2 m/s, 3 m/s, and 4 m/s, respectively, which correspond to temperature increases of 60.5, 64.7, and 62.3 °C over a 10-minute period. The heat absorbed by the water was 506.5, 541.7, and 521.6 kJ, with a fuel energy input of 1,861.6 kJ (0.05 kg × 37,231 kJ/kg). This resulted in thermal efficiencies of 27.2%, 29.1%, and 28.0%. Fuel consumption, calculated from the fuel mass and test duration, is 0.30 kg/h, equivalent to a combustion rate of 3.10 kW.

Table 2. Water heating performance and thermal efficiency

Air velocity (m/s)	T_f (°C)	ΔT (°C)	Q_w (kJ)	η_{th} (%)
2	90.5	60.5	506.5	27.2
3	94.7	64.7	541.7	29.1
4	92.3	62.3	521.6	28.0

The air flow rate in this section is calculated from the measured air velocity and the outlet duct geometry (Eqs. (4)–(8)). The cross-sectional area of the blower outlet duct is $4.91 \times 10^{-4} m^2$. Therefore, the air flow rate increases from 0.98 L/s at a velocity of 2 m/s to 1.47 L/s at a velocity of 3 m/s and 1.96 L/s at a velocity of 4 m/s, which corresponds to air mass flow rates of 1.14, 1.71, and 2.28 g/s. With a fuel mass flow rate of 0.083 g/s, the air–fuel ratio (AFR) is 13.7, 20.5, and 27.3, or an air excess coefficient of 1.10, 1.65, and 2.19 (Table 4). Figure 2 shows that the highest thermal efficiency occurs at the medium air setting among the three air velocity tests. Meanwhile, the calculated AFR increases gradually as the air velocity increases.

Table 3. Air flow, air fuel ratio, and excess air coefficient

Air velocity (m/s)	Air flow (L/s)	Air mass flow (g/s)	AFR	λ
2	0.98	1.14	13.7	1.10
3	1.47	1.71	20.5	1.65
4	1.96	2.28	27.3	2.19

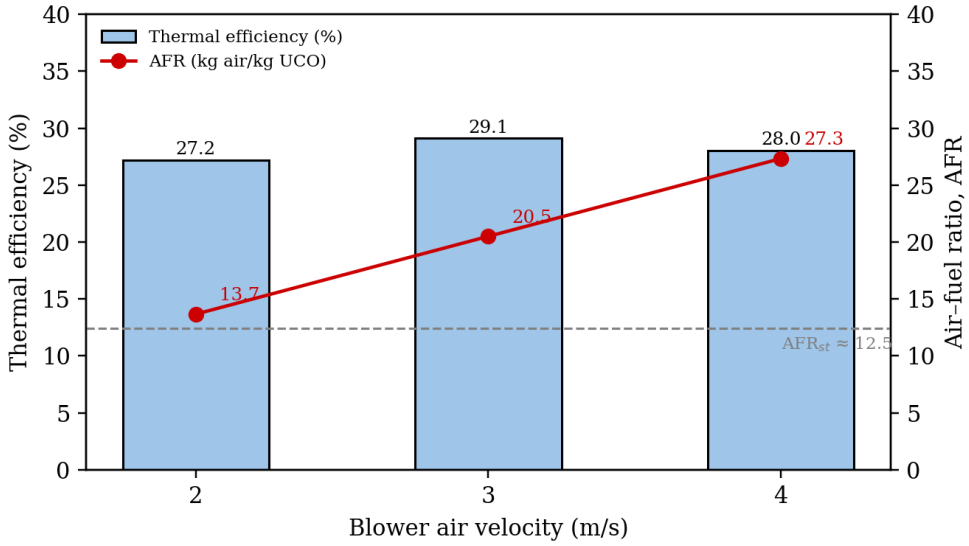


Figure 2. Thermal efficiency and AFR at different blower air velocities

The blower's rated power of 14.4 W (12 V × 1.2 A) is equivalent to approximately 72% of the 20 Wp solar panel's capacity. This figure represents only the rated power, since the blower's current at each airspeed, the panel's output, and the inverter's power consumption were not measured. A 12 V, 7 Ah battery stores a nominal energy of 84 Wh, so theoretically it can operate the blower at its nominal power for about 5.8 hours, or about 4.7 hours if only 80% of its capacity is utilized. This calculation does not account for unmeasured inverter losses. A 10-minute test at rated power requires a maximum of 2.4 Wh of energy, or about 2.9% of the battery's rated capacity. Since the panel serves as a substitute for utility power and no data on irradiance, battery voltage, or the charging process was recorded, these figures merely indicate that the blower's load is relatively small compared to the rated storage capacity.

DISCUSSION

Thermal efficiency reached its highest value at 3 m/s (29.1%) among the three settings tested, and was lower at 2 m/s (27.2%) and 4 m/s (28.0%). At 2 m/s, the burner operated close to stoichiometric conditions (λ = 1.10); one possible cause of the lowest efficiency is incomplete local mixing of the liquid fuel with a small oxygen margin, so that some of the oil may have burned incompletely. At 4 m/s, the burner operated with more than twice the stoichiometric air ratio (λ = 2.19), and this excess air may have cooled the flame and carried heat away through the exhaust gases. This study is consistent with the general finding that the combustion performance of used cooking oil flames depends on the equivalence ratio (Mahfouz et al., 2018), observations that fan speed affects the emission performance of fan-assisted stoves (Arora et al., 2014), and test reports showing that airflow alters the flame temperature of used cooking oil stoves (Hamim & Adiwidodo, 2024; Mara et al., 2025). Therefore, this study has limitations in that it did not examine exhaust gas composition, exhaust gas temperature, and flame temperature.

The differences between the settings were relatively small—4.2 °C in final water temperature and 1.9 percentage points in efficiency—between the highest

and lowest settings. Each setting was tested once, and the sensitivity calculations in the Methodology section show that a 5% change in fuel energy alone shifts efficiency by approximately 1.3–1.5 percentage points, which is comparable to the observed difference. The airflow speed setting of 3 m/s on the blower produced the best results among the three airflow speed variations. These results indicate a statistically significant trend or definite ranking, although this is common practice in WBT testing (Wang et al., 2014). More importantly, the efficiency of 27–29% is far below the 54.4% reported for a waste cooking oil gasification stove by Asmoro et al. (2025), which also exceeds the minimum threshold of 50% as specified in SNI 8660-2018, and is lower than the 48.9% obtained from a modified kerosene stove burning used vegetable oil (Natarajan et al., 2008). However, this value is close to the 26% efficiency reported for a waste cooking oil fueled burner in another study in Indonesia (Pranata et al., 2024). These results cannot be directly compared because the stove types, water volumes, and testing protocols differ, but they indicate that this burner produces useful heat yet still loses a significant portion of that heat, likely through the open pot, exhaust gases, and the absence of a pot shield. Since the water temperature remained below the boiling point, losses due to evaporation—a source of WBT variability (L'Orange et al., 2012) are unlikely.

From a practical standpoint, the research results show that a low-power blower powered by a solar panel system is capable of sustaining the combustion of used cooking oil, which raised the temperature of 2 kg of water to over 60 °C in 10 minutes in this study, with a nominal blower power of 14.4 W. This indicates that the concept warrants further testing. Since the fuel is a byproduct generated by the kitchen itself and the blower's power supply no longer depends on the PLN grid, this aligns with the president's vision of energy independence.

CONCLUSIONS AND RECOMMENDATIONS

A used cooking oil burner with a solar-powered blower can generate heat useful for water heating in preliminary tests using used cooking oil from the MBG kitchen. At blower air velocities of 2, 3, and 4 m/s, the thermal efficiencies were 27.2%, 29.1%, and 28.0%, respectively, with calculated AFR values of 13.7, 20.5, and 27.3, each from a single test. The highest efficiency occurred at 3 m/s (AFR ≈ 20.5, $\lambda \approx 1.65$). Recommended next steps include studying efficiency improvements—such as pot shields, heat recovery, or fuel preheating—along with assessments of fire safety and exhaust gas emissions.

LIMITATIONS AND FUTURE RESEARCH

This study has several limitations, which are listed in order of priority for future research. (1) Each air velocity test was conducted at three different air velocities—2, 3, and 4 m/s—using the WBT testing method. (2) Exhaust gas emissions (CO, soot, NO_x) as well as flame or exhaust gas temperatures were not measured; therefore, no conclusions can be drawn regarding combustion quality or environmental performance. (3) Used cooking oil was sourced from a single kitchen and used only once. (4) The solar panel–battery–inverter system served only as a substitute for PLN electricity, and its performance was not evaluated; monitoring of panel output, battery condition, inverter consumption, and blower

current over several days is required. (5) This study utilized solar energy as an electricity source—a form of environmentally friendly technology—in line with President Prabowo Subianto's directive on energy and food self-sufficiency. Follow-up research should also test a wider range of air velocities with smaller differences, compare the burner with an LPG burner using the same protocol, and assess fire safety and durability prior to field use, as well as exhaust gas emissions.

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