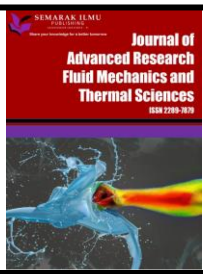
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 121, Issue 2 (2024) 37-47

SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Improving used Lubricant Oil Burner Performance: Effect of Swirled Flow of Internally Distributor Type on the Combustion and Flue Gas Temperature and Emission

Robert Silaban[1], Janter Pangaduan Simanjuntak[1,*], Mohd Zamri Zainon[2]

1 Mechanical Engineering Department, Faculty of Engineering, Universitas Negeri Medan, Jl. Willem Iskandar Psr. V. Medan Estate, Medan 20221, North Sumatera, Indonesia
2 Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 6 May 2024
Received in revised form 24 August 2024
Accepted 5 September 2024
Available online 30 September 2024

Keywords:
Used lubricant oil; combustion; burner; swirl flow; air distributor; thermal energy

ABSTRACT

This study aimed to experimentally investigate the combustion characteristics of used lubricant oil (ULO). A simple cylindrical burner of the natural draft vaporizing type, equipped with an internal air distributor, was designed and fabricated to achieve this objective. The burner's efficiency was evaluated based on combustion temperature, flue gas temperature, and concentration levels. The key feature of this burner lies in the swirled flow of air combustion and ULO vapor within the combustion chamber, facilitated by the swirled flow air distributor type. Various air-fuel ratios (ϕ), ranging from 0.5 to 4, were considered in characterizing the burner's performance. The results revealed increased combustion and flue gas temperatures in the radial airflow types. The highest temperatures achieved using the radial flow type are 930 ^oC and 410 ^oC for combustion and exhaust gas temperature, respectively. In contrast, the combustion chamber and exhaust gas temperatures are 980 ^oC and 465 ^oC for the swirled flow type, respectively. It was found that there is a decrease in the emission of CO and CO_2 by volume under optimum conditions. This decrement was attributed to the swirled flow effects, which promoted a better mixture of air combustion and ULO vapor during combustion.

1. Introduction

Currently, fossil-based fuels are the most important source of energy for humanity. They are also critical raw materials for many major industries. Unfortunately, fossil fuels are continuously decreasing. As a result, energy strategy and diversification are necessary for all countries, including Indonesia, as reported in the previous study [1]. Energy diversification involves utilizing multiple energy sources to fulfill a society's or economy's energy needs. Researchers advocate for energy diversification based on various compelling reasons. Kumar [2] stated that support energy including energy security. Kang *et al.,* [3] and Gitelman *et al.,* [4] argued that diversified energy is required to

* *Corresponding author.*
E-mail address: janterps@unimed.ac.id

https://doi.org/10.37934/arfmts.121.2.3747

mitigate climate change, while Navqi *et al.,* [5] argued that energy diversification brings economic benefits and contributes to environmental protection, as highlighted too by Li [6].

Researchers agreed that the increase in population and technological advancement has caused a rise in energy consumption, leading to decreased primary energy sources, global warming, and urgent environmental problems, as reported by Asif and Muneer [7]. Many studies have suggested using renewable energy sources like solar, hydro, and wind to tackle these issues [8]. Additional measures beyond renewable energy are required to tackle the environmental problems resulting from technological progress. For instance, Singhabandhu and Tezuka [9] proposed converting liquid waste, such as lubricating oil, into an alternative energy source.

Used lubricant oil (ULO) is not an ordinary waste. It is hazardous due to its toxicity and flammability. ULO often contains dangerous substances like heavy metals, chlorinated compounds, and polycyclic aromatic hydrocarbons (PAHs), which pose considerable environmental and health risks if not disposed of properly. That is why ULO is classified as hazardous waste, requiring special treatment under mandatory regulations in Indonesia. Recent environmental laws, including the Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management, emphasize the importance of adhering strictly to these regulations for the safe disposal of ULO.

ULO possesses a distinctive characteristic with a high calorific value, enabling the production of thermal energy and the extraction of other valuable products, including converting them back into base oil through recycling. Numerous investigations have been initiated to explore the recycling potential for creating diesel-like fuel, as outlined in the previous study [10-15]. Many enterprises, including those in the ceramic, cement, forging, and metallurgical industries, have expressed interest in using ULO as a fuel alternative in internal combustion engines and thermal plants to feed cogeneration processes, highlighting the promising benefits of ULO recycling.

Kanokkantapong *et al.,* [16] presented six promising avenues for managing ULO. Among these, acid clay and solvent extraction stand out as effective treatment procedures for ULO recovery, with recycled used oil as the end product. The remaining four methods, the tiny boiler, vaporizing burner boiler, atomizing burner boiler, and a cement kiln, hold immense potential for energy recovery from ULO. Hamad *et al.,* [17] stated that recycling as a base lubricant oil has been shown to enhance fuel quality using a catalyst, while the previous researchers further underlined the promising future of ULO as a fuel source [18,19].

ULO has proven its versatility and efficiency as a fuel substitute in various applications. It has been successfully combined with diesel in internal combustion engines, as has been done by previous researchers [20-23]. According to Al-Omari [24], ULO can be co-fired with gas to supplement furnace fuel. ULO is adaptable and used in incineration in furnaces, boilers, and cement kilns, as demonstrated by Chen *et al.,* [25]. Past researchers have explored the use of sprayed or atomized techniques as a means to enhance its flammability [26-28]. In their study, Kim *et al.,* [29] and Silaban *et al.,* [30] prove that the vaporization technique increased the auto-ignition state of the ULO. ULO incineration is recommended as the most appropriate disposal method for the zero-waste principle. The incineration method oxidizes the hydrocarbons in the ULO and safely disposes of other contents at high temperatures. Tsai [31] reported that Taiwan's lubricant management encouraged the reuse of auxiliary fuels in well-designed utilities such as cement kilns, steel factories, and paper and pulp mill boilers.

As alternative fuels gain popularity in industry and transportation, the potential for ULO to play a significant role is evident. Substituting traditional hydrocarbon fuels with alternatives is projected to reduce greenhouse gas emissions. This technology is particularly relevant for the cement industry, a major contributor to carbon dioxide emissions. Therefore, using a fuel with a low carbon content, such as ULO, emerges as a primary alternative for CO_2 emission reduction. Consequently, partially substituting conventional fuels with waste-derived alternative fuels is an emerging option for enterprises to operate more efficiently and environmentally. Table 1 provides a chemical composition comparison of ULO with diesel, demonstrating the similarities that make ULO a suitable replacement for diesel.

Table 1
Elemental content of ULO and Diesel (wt.%)

Chemical content	ULO	Diesel
Carbon	83.90	86.14
Hydrogen	14.20	13.20
Oxygen	0.44	0.66
Nitrogen	0.70	0.00
Sulfur	0.76	0.1
HHV (MJ/kg)	43.1	45.13

ULO's high heating value makes thermochemical disposal, often known as waste to energy, an ideal method for disposing of hazardous chemicals. Hazardous wastes should not be recycled, reused, or disposed of in landfills due to their excessive toxicity or ability to transmit diseases. However, previous studies prove that thermochemical conversion such as combustion has emerged as a practical approach to solving solid and liquid waste [32,33]. This technology enables a notable decrease in the quantity and harmfulness of hazardous waste. However, there are specific challenges and disadvantages to using ULO as an alternative fuel, including purity, emissions, and regulatory compliance. However, employing ULO as a fuel alternative provides advantages in specific industries. It is important to analyze this method's quality, emissions profile, and regulatory considerations before proceeding. Simple burners are remarkable among the appliances that can generate energy from ULO. ULO may burn on a simple burner and reach a fire temperature of around 468 ^oC, as shown in Figure 1.

Fig. 1. A simple ULO burner

Burner technology, which utilizes specialized burners to burn waste materials safely and efficiently, has undergone rigorous testing to determine its performance and output parameters for emissions and energy generation, as reviewed by Arora and Jain [34]. The primary objective of this technique is to eliminate environmental and health risks, particularly those associated with energy recovery from hazardous waste. Burners employ gasification and combustion to generate fuel that may be used, thereby reducing reliance on fossil fuels and potentially saving money. However, it is essential to note the potential disadvantages of using burner technology for ULO combustion, including the high initial equipment cost, the need for specialized training for operation, and the likelihood of pollutants, ash, and other emissions. Therefore, it is essential to thoroughly evaluate the benefits and drawbacks of burner technology before considering it for ULO combustion, ensuring a well-informed decision.

An essential ULO burner utilizes natural draft vaporizing technology. The vapor produced during heating is ignited at the top of the burner with a lighter while it meets with oxygen. Figure 2 shows a process schematic for burning ULO vapor in a simple vaporizing burner. Using ULO vapor as fuel in a burner has various advantages. It offers a safe and effective way to dispose of used oil, sometimes categorized as hazardous waste. Furthermore, it provides an economical and sustainable energy source for cooking and heating purposes. Finally, it can reduce extra pollutants and greenhouse gas emissions from traditional fossil fuel sources.

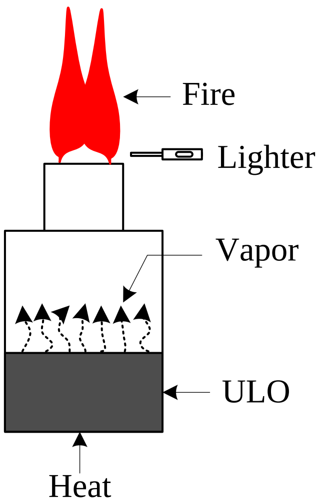


Fig. 2. Schematic illustration of a basic ULO vaporizing burner

The combustion of ULO vapor in a simple burner often requires a design that accommodates the fuel’s peculiar properties. It may be necessary for the burner to be constructed to ensure adequate airflow, allowing for complete combustion of the vapor formed during heating. Furthermore, the burner’s construction materials shall be carefully selected to withstand the fuel’s high temperatures and corrosive nature. Stoichiometric air combustion is critical for burning ULO because it ensures the precise amount of air required for complete combustion and avoids surplus oxygen or fuel post-reaction. This process involves the vapor and air interacting in a particular ratio, often given by the chemical equation for the combustion reaction. When stoichiometric air is used for burning, the resulting flue gas is only CO_2 and H_2O vapor, with no surplus O_2 or unburned fuel. Stoichiometric combustion is thus crucial for enhancing fuel efficiency and reducing emissions in various industrial applications, including power generation and combustion engines.

The crux of the matter lies in achieving an optimal blend of ULO vapor and combustion air. This challenge necessitates meticulous control over fuel and air supply, as stated by Mehetre *et al.,* [35]. Many researchers have embarked on initiatives to enhance energy efficiency in biomass cookstoves, bolstering fuel economy. Methods such as staged air supply have been explored to improve combustion performance, as done by Simanjuntak *et al.,* [36]. Furthermore, Simanjuntak *et al.,* [37] have also tried to devise an internally straight-flow air distributor to increase turbulence in the combustion chamber.

However, studies on swirl flow combustion air provision remain relatively scarce. Air swirl flow is the circular motion of the air-fuel mixture in the combustion chamber. The whirling flow can substantially impact combustion by improving mixing and extending the residence duration of the air-fuel mix within the combustion chamber. This research aims to evaluate the performance of a used lubricant oil combustion burner with a swirl flow air distributor type.

2. Methodology

2.1 Materials

Used lubricant oil (ULO) was used as fuel in this study. The ULO can ignite since most of its constituent components are hydrocarbon species. This material is identical to that utilized by Silaban *et al.,* [30] and was taken from the motorcycle repair workshop around the research area at no cost. This material contains many impurities, including heavy metals, organic compounds, and other pollutants. If the ULO is not handled and disposed of appropriately, these contaminants can endanger human health and the environment. A hand-emission gas analyzer was used to measure gaseous emissions pollutants such as CO and CO_2.

2.2 Swirled Flow in the Combustion Chamber

Swirled flow in the combustion chamber considerably impacts both combustion efficiency and emissions. Swirled flow has multiple beneficial effects, such as enhancing the mixing of air and oil vapor, increasing turbulence flow to break up fuel droplets for more efficient mixing of reactants, extending residence time for improved combustion efficiency by allowing more time for fuel to react with oxygen, and ultimately reducing emissions. The type of air distributor utilized will determine how well the swirled flow works. As a result, it is critical to carefully design an air distributor that encourages the swirled flow pattern in the combustion chamber. In this investigation, the main combustion chamber and air distributor pipe were arranged concentrically, with diameters of 20 cm and 5 cm, respectively. The primary combustion chamber is 40 cm in height, while the distributor pipe measures 16 cm in height. Swirled flow is generated by eight 3 mm-diameter orifices that form a 45° swirl angle. Figure 3 and Figure 4 show the radial and swirled flow schematics and the type of air distributor used.

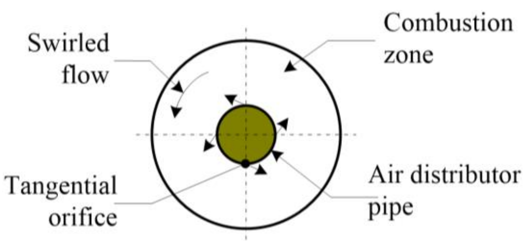
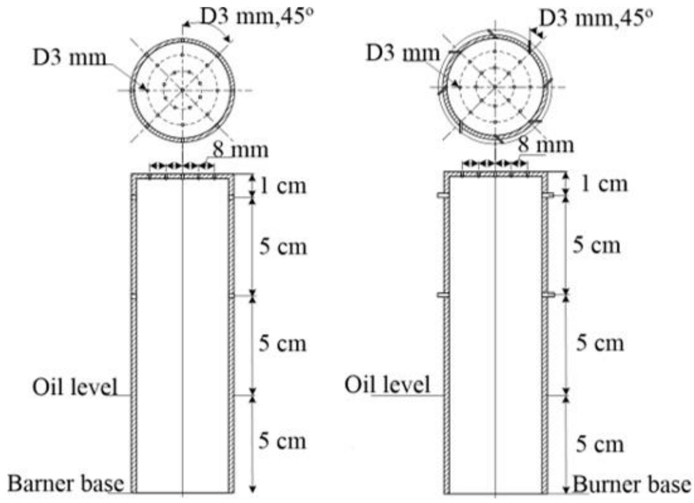


Fig. 3. The swirled flow diagram in the combustion zone of a burner



(a) (b)

Fig. 4. Prototype of air distributor pipe; (a) Radial type flow, (b) Swirled type flow

2.3 Experimental Test Section and Procedures

Figure 5 depicts the test facility used in this investigation. The facility was housed in the mechanical engineering workshop of the State University of Medan in Indonesia. The equipment includes an air blower, an air regulator valve, an oil tank, an oil level meter, an oil regulator valve, an air distributor with orifices, a combustion chamber where the ULO was combusted, a thermocouple port at the combustion chamber, and the top of the chimney for exhaust measurement at a height of 100 cm above the burner base. The furnace was designed to be cylindrical. For each run, the combustion chamber contains around 250 cc of ULO. The process of initiating combustion started with cold start-up combustion, where tissue was placed in the combustion chamber, submerged in ULO, and lit using a lighter. During start-up heating, the temperature in the combustion chamber gradually increased, and the ULO began to evaporate. This vapor mixed with the air and started burning, causing the temperature to rise dramatically.

The experiment was conducted with a systematic approach to ensure the reliability of the results. The blower was turned on, and the airflow was gradually increased by opening the air regulator to raise the temperature. The airflow rate test settings range from 10 to 55 m^3/h, while the ULO flow rate is kept constant at approximately 1 liter/hour, comparable to 10.27 kWth. Once the fire had stabilized, the temperature in the combustion chamber and the exhaust gas temperature were measured every minute. The experiment's test duration was set to 30 minutes. After collecting temperature data, the burner was shut down by turning off the air supply and allowing it to cool down. The data was then meticulously analyzed and presented on a graph, demonstrating the impact of different airflow types on burner performance, particularly regarding combustion chamber temperature, exhaust gas, and its constituents.

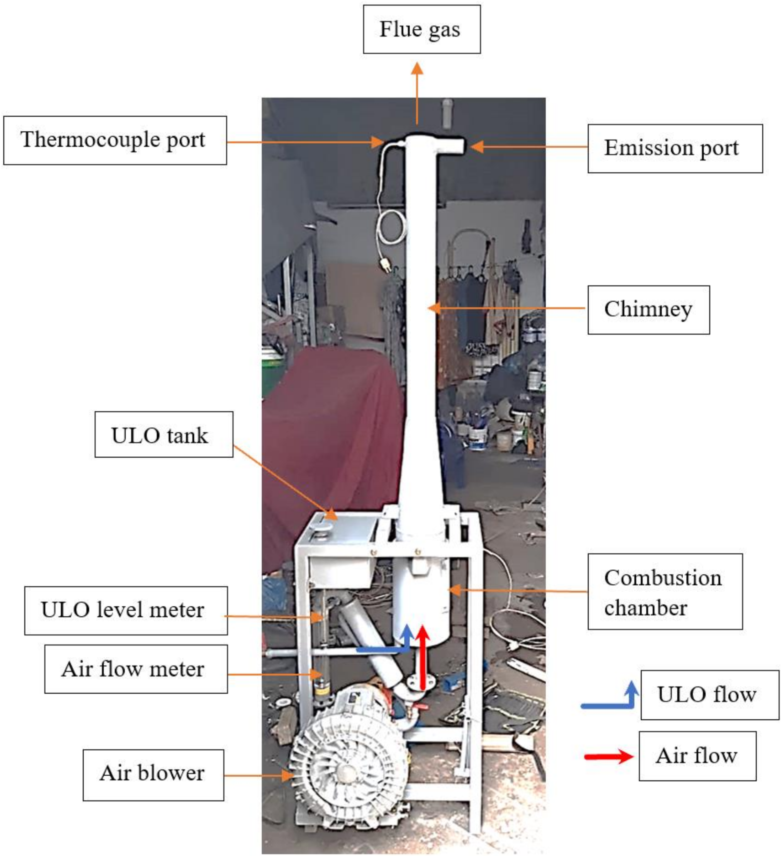


Fig. 5. Experimental facility for the ULO combustion

3. Results and Discussion

3.1 Flame Appearance

Flame stability is one of the preliminary requirements for any burner intended for high-temperature combustion. Increasing the equivalence ratio will lead to increased air flow rate and turbulence. A better vapor-air mixture was obtained, and the flame spread was observed in the combustion chamber. Figure 6 shows the flame appearances achieved by burning ULO purely on primary air at the highest combustion chamber temperatures of about 980 ^{o}C. From the picture, it can be seen that the color of the flame produced is yellow. Yellow flames typically indicate an imperfection in combustion, in which part of the fuel does not burn completely. There are multiple reasons for this issue: (1) insufficient oxygen supply, (2) an incorrect air-fuel ratio leading to incomplete combustion and a yellow flame, and (3) substandard fuel quality. The presence of a yellow flame signals an issue within the combustion process that requires attention, like problems with the incineration system, insufficient ventilation, or low-quality fuel.

(a) (b)

Fig. 6. Flame appearance at the highest temperature: (a) Radial flow distributor, (b) Swirled flow distributor

3.2 Effect of Swirled Flow on Burner Performance

Swirled flow can significantly influence burner performance, especially combustion and exhaust gas temperatures. In this study, the primary influence of swirled flow on combustion temperature and exhaust gas can be seen in the graphs in Figure 7 and Figure 8. In this study, the air-fuel ratio (ϕ) ranged from 0.5 to 4, exceeding the stoichiometric combustion ratio of air-fuel. The proportion was set to ensure the right amount of oxygen for the combustion reaction connected to the burner's construction. The graph shows that the highest temperature can be reached at ϕ = 2.84, meaning that combustion occurs with excess air. The graph shows that swirl flow produces higher temperatures than radial flow due to the swirled flow, which can create turbulence for effectively mixing air and ULO vapor in the combustion chamber [38,39]. Another factor contributing to the high temperature recorded in this study is the establishment of a uniform temperature distribution within the combustion chamber.

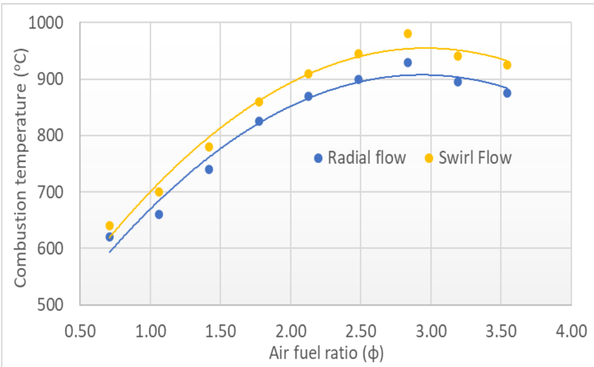


Fig. 7. Effect of swirled flow on combustion temperature

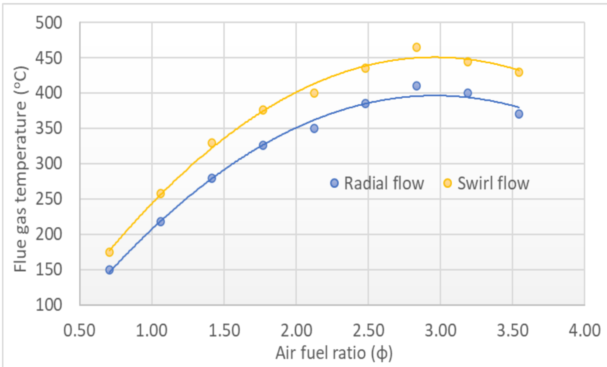


Fig. 8. Effect of swirled flow type on flue gas temperature

According to Deng *et al.,* [40], swirled flow affects the temperature distribution in the combustion chamber, as they did research through an injector. A similar conclusion was drawn by Belal *et al.,* [41]. In a burner, a mixture of air and fuel with a swirling flow produces an even fire, which results in higher temperatures. In Figure 6(b), it can be observed that the fire spread in the combustion chamber is distributed almost uniformly. Swirl flow also affects the reduction of burning time, as seen in Figure 9. Improved air and fuel mixing is facilitated by a swirling flow, which can quicken the combustion process. When the mixture of air and fuel burns faster, the combustion temperature is higher. By creating more efficient and supportive combustion conditions, swirled flow can help improve overall combustion efficiency. Higher efficiency usually means more energy is generated from the combustion process, which can affect the combustion temperature. Swirled flow is commonly utilized in various applications to enhance the efficiency and performance of combustion systems, including generating elevated combustion temperatures for specific purposes like burning fuels with high calorific values or minimizing emissions as shown Figure 10.

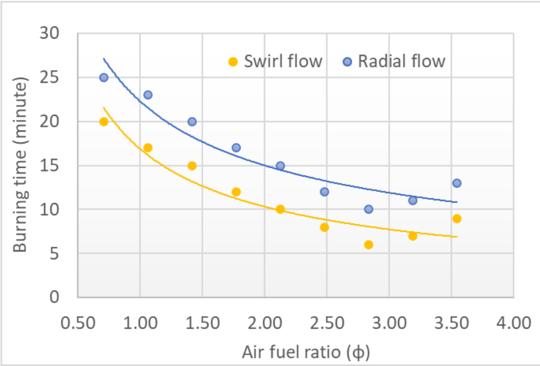


Fig. 9. Effect of swirled flow on burning time

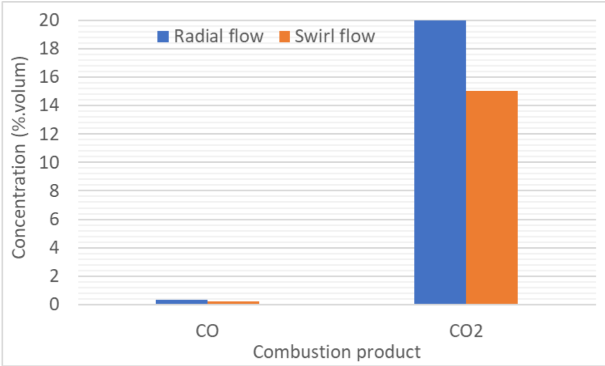


Fig. 10. Effect of swirled flow on exhaust concentration at high temperature

4. Conclusions

The combustion of ULO was investigated using a vaporizing-type burner. In this research work, ULO was burned in a swirled burner at different primary air combustion rates. Results were compared with those of the radial flow type of air distributor to assess the possibility of using air distributor swirl-type flow for domestic burner operation. The self-vaporization and complete combustion of ULO can be achieved by auto-preheating, utilizing the heat during combustion. It can be concluded that the swirling airflow can enhance turbulence within the combustion chamber, leading to improved mixing of combustion air and ULO vapor for more efficient burning, as indicated by the temperatures in the combustion chamber and exhaust gases. The finding provides academic data for scholars to use in forthcoming studies on managing ULO with an energy recovery method. Lubricating oil can be an alternative fuel in burners, boilers, and furnaces. The affordability and reduced reliance on traditional fuels make ULO a preferable choice.

Acknowledgments
The presented work is the result and contribution of the project entitled Design and Testing of B3 Waste Combustion Furnace as an Alternative Fuel for Pyrolysis Process Using a Flow Air Distributor. The authors would like to thank Universitas Negeri Medan through the Institute for Research and Community Service (LPPM) for funding support through contract number 0137/UN33.8/KPT/PPT/2023. Two final-year diploma students, workshop employees, and research partners were also thanked for supporting this research.

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