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PURIFICATION AND CHARACTERISTICS OF WASTE LUBRICATING OIL AS DIESEL-LIKE FUEL

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Abstract: This study aims to utilize used lubricating oil (OLB) in diesel-like fuel. OLB is processed by distillation method, heating 600 watts for 120 minutes and varying stirring speeds of 0, 300, and 500 rpm. The results of the highest distillation temperature test at 500 rpm stirring and a molecular cracking reaction occurs so that the long chain is easily cracked. The characteristics of LLB obtained are flash point 144 (PMcc,0°C), density 858.3 (kg/m3), viscosity 3,107 (cSt), and calorific value 10,967 (kcal/kg).

KEYWORDS: Waste lubricating oil, Distillation, Stirring, Characteristics, Diesel-like fuel

1 Introduction

Utilization of fossil fuels such as petroleum has long been the main energy source in various industrial sectors [1, 2]. The increasing development of the industrial world today is proportional to the energy needs required [3]. Apart from high energy needs, the industrial sector also has waste problems that need to be resolved [4]. A large amount of industrial waste that can cause natural damage if not managed properly is lubricating oil. Lubricating oil can be damaged and become waste due to contact with additives, which are added at around 30% [5] and are a mixture of combustion products such as water, fuel, dust, metal wear, oxidation products in complex forms, and corrosive organic acids [6]. Lubricating oil has a useful life, so when it reaches its useful life and is damaged, it needs to be replaced and becomes waste [7]. Wastelubricating oil (WLO) is a type of hazardous waste, and its components are not easily degraded. If not disposed of properly, it will affect waterways, and if it is thrown into rivers or beaches, it will definitely endanger the environment and human health [8, 9]. So far, the use of WLO has not been maximized. Efforts have been made to deal with this waste, by disposing of it in rubbish dumps or buried in the ground, regenerating it into new lubricating oil and extracting WLO through the combustion process to be used as fuel [10].

Utilizing WLO as fuel is a good solution because, on average, crude oil has 3-8% base oil, and usually crude lubricating oil has 12-16% base oil [11]. Efforts to utilize WLO to be used as an alternative fuel have become a challenge for researchers. Various methods and

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technologies for recycling WLO have been carried out, such as distillation [12, 13], pyrolysis [14], hydrogenation [15], hydrocracking/ isomerization [16], and trans-esterification [17]. Distillation is a simple technology to separate WLO based on ease of evaporation to improve the properties of the oil [18], to be used as fuel oil. Distillation performance is influenced by several factors, such as temperature, viscosity, boiling point, condenser, oil volume, and reactor [19]. In the WLO distillation process, the raw material is heated and stirred to break down large molecules and enable better fuel oil characteristics to be obtained [20].

In this research, WLO distillation will be carried out using a heating process and stirring until a predetermined time to obtain DLF during the heating process. With this research, it is hoped that it can reduce the accumulation of waste oil from various industries, and the DLF results can be used as diesel engine fuel, thereby slightly reducing the use of fossil fuels. To ensure that DLF can be used in engines, the fuel characteristics are tested, such as density, viscosity, flash point, and heating value. Apart from that, the effect of the stirring of the raw material on the distillation temperature distribution was also reviewed. Increasing the distillation temperature will affect the characteristics of the DLF produced.

2 Materials and Methods

The material used in this research was WLO obtained from industry in the Probolinggo district, East Java Province, Indonesia. The WLO collected is dark black in color and is waste from gas turbine engines. The type of lubricant used in gas turbines is Shell Turbo T-46, which is the standard oil for industrial turbines. The physicochemical properties of Shell Turbo T-46 type oil are presented in Table 1.

Table 1. Physicochemical Properties of Shell Turbo T-46

Property			Method	T-46 Turbo Shell
Viscosity	40°C	cST	ASTM D445	46.0
Viscosity	100°C	cST	ASTM D445	6.90
Viscosity Index			ASTM D2270	105
Color			ASTM D1500	L 0.5
Density		kg/ m3	ASTM D4052	858
Pour Point		°C maximum	ASTM D97	-27
Flash Point (COC)		°C minimum	ASTM D92	220
Total Acid Amount		Mg KOH/g	ASTM D974	0.10
Air Release, Minutes	50°C	minute	ASTM D3427	4
Water Demulsibility		minute	ASTM D1401	15
Vapor Demulsibility		Second	DIN 51589	153

2.1 Material Preparation

Before distillation, the WLO obtained from industry is collected and filtered to separate the oil from the metals that are still mixed. The WLO raw material is fed into the reactor for distillation using the research scheme presented in Figure 1.

2.2 Distillation Experiment

The experiment was carried out on the distillation equipment presented in Figure 2. The equipment consists of a reactor, an electric stove, a driving motor, a condenser, and other supporting equipment. A description of the research is also explained elsewhere [21, 22]. The WLO that has been inserted into the reactor is heated and stirred with stirring variations of 0, 300, and 500 rpm. The distillation experiment used a 600-Watt electric stove heater, with the temperature maintained at up to 400 ^{0}C using a thermocontrol and carried out for 120 minutes. There are two type K temperature sensors placed on the reactor wall and inside the reactor to see the increase in temperature. Oil in steam form is condensed through condenser 1 and condenser 2 at a temperature of 5 ^{0}C. DLF produced from the distillation process is tested for characteristics including flash point, density, viscosity, and heating value. During the distillation process, temperature measurements are carried out every 5 minutes on the fluid (test material) and reactor walls using a temperature data logger so that the temperature distribution of the reactor walls and oil in the reactor can be known during the distillation process. The temperature results will be used to see the temperature distribution that occurs, which is associated with the mixing cycle of the raw material. In the testing process, the amount of energy required during the process is also calculated using temperature data from a temperature indicator connected to a type K temperature sensor placed on the combustion reactor wall (T1) and temperature data of the WLO raw material (T2) which is heated inside the reactor, forced convection heat transfer coefficient for the vertical tube surface (h), and the cross-sectional area of the reactor wall (A). To calculate the energy (q), use the equation [23]:

$$\boldsymbol{q = h.A.(T_1 - T_2)} \quad (1)$$

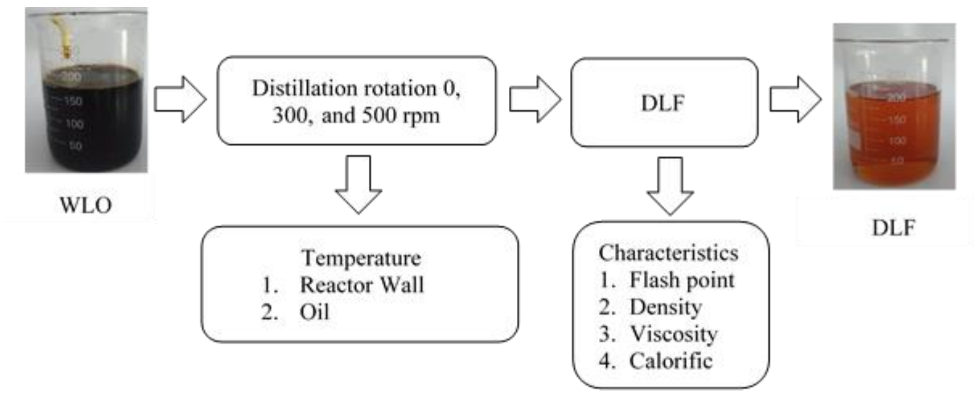


Fig. 1 Research scheme

3 Results and Discussion

3.1 Heat Transfer Analysis

Distillation is carried out using an electric stove heater with 600-Watt power. Heat transfer occurs during the distillation process through a heater until it reaches a temperature of 400 ^{0}C on the reactor walls and WLO liquid. The distillation process without stirring and with stirring at speeds of 300 and 500 rpm for 120 minutes obtained data on reactor wall temperature and fluid temperature, which are presented in Figure 3(a). Stirring with more rotation makes the heat distribution more even, resulting in a more significant increase in temperature as the distillation time progresses [24]. The temperature increase on the reactor walls is directly proportional to the temperature increase in the distillation liquid from the three tests. In distillation without stirring, the temperature of 400 ^{0}C is reached at 95 minutes, and for rotations of 300 and 500 rpm, the maximum temperature is reached at 90 minutes. The distilled WLO uses the same volume and composition, so the heat required to reach the desired temperature is not too different. Heat transfer in the distillation liquid is presented in Figure 3(b). The distillation reactor is not insulated to reduce heat losses to the environment [25]. Increasing the distillation temperature results in a molecular cracking reaction, resulting in the breaking of large saturated chains that produce smaller gas compounds [12] As the temperature at WLO increases, fuel oil yield also increases [26]. The increase in DLF yield was caused by an increase in normal paraffin hydrocarbons from the residual base oil fraction.

The distillation results are presented in Figure 4. The test results without stirring produced a DLF of 162 ml; for stirring at 300 rpm, it produced a volume of 210 ml; for stirring at 500 rpm, it produced a DLF of 231 ml. The volume produced is proportional to different temperatures and the influence of the rotation size of the WLO raw material. The effect of stirring makes long-chain molecules more easily cracked, so that higher conversions are achieved at relatively similar temperatures [27].

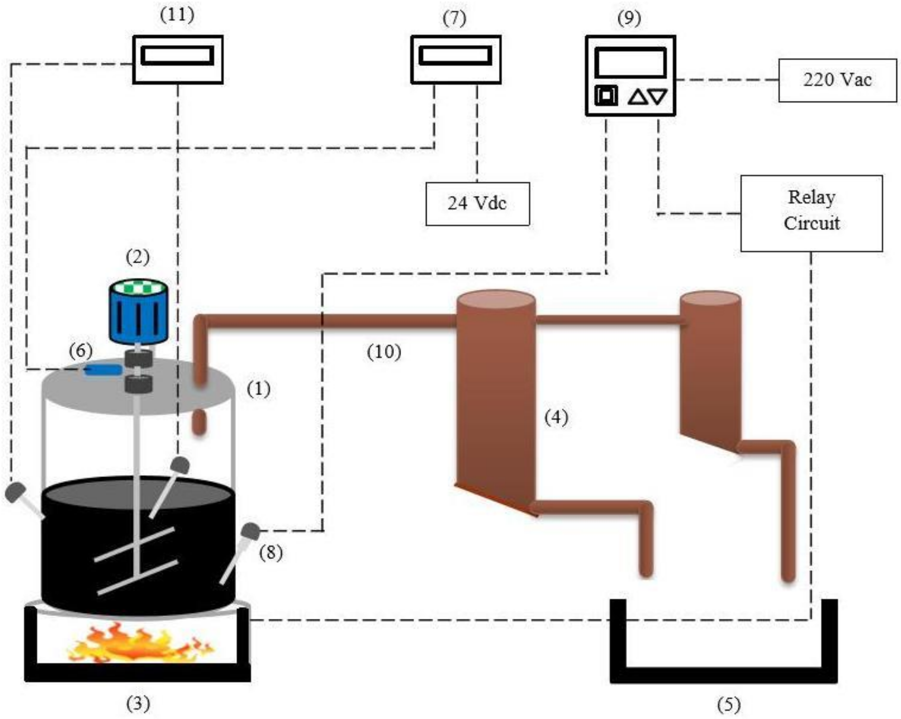
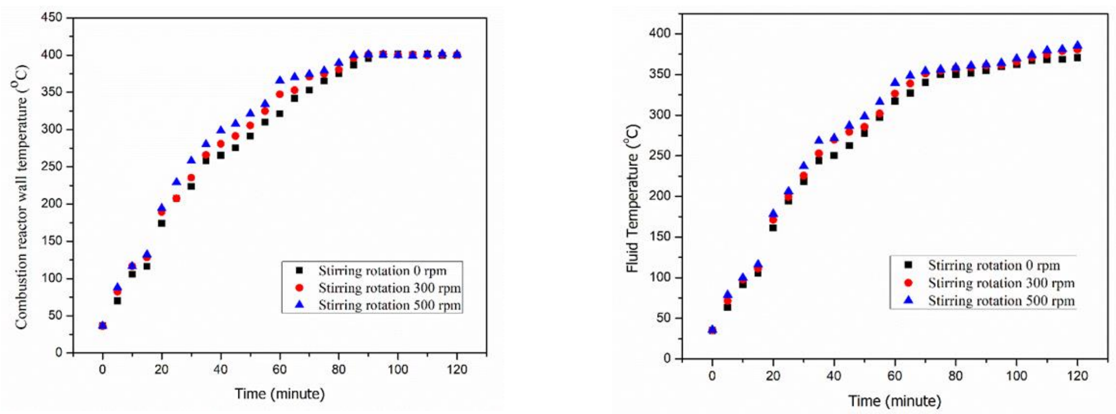


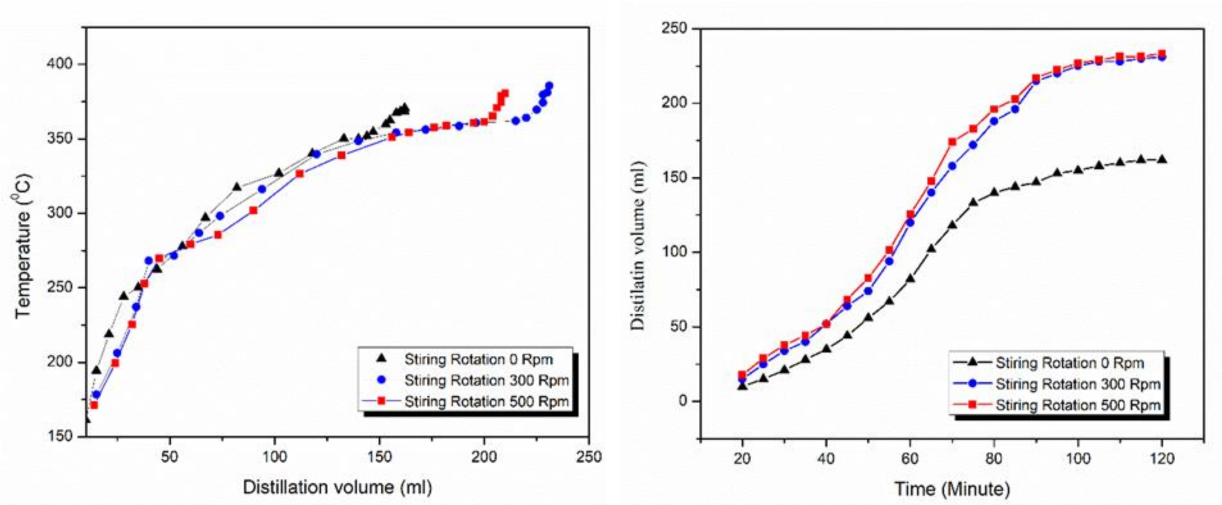
Fig. 2 Description of the distillation scheme. (1) reactor, (2) drive motor, (3) heater, (4) condenser, (5) storage tank, (6) rotation sensor, (7) rotation indicator, (8) type K thermocouple, (9) Thermocontrol, (10) distribution pipes, and (11) temperature indicators.



(a) (b)

Fig. 3 Temperature distribution (a). distillation reactor wall, (b). oil in the distillation reactor

From the results of experiments and calculations carried out, temperature data on the reactor walls and distillation fluid is known to determine the amount of heat energy in the heated fluid. The heat energy produced from heating the fluid without stirring is known to have the highest heat energy of 35776 joules at the 115th minute and the lowest heat energy of 1376 joules at the 15th minute, which is presented in Figure 5(a). In a reactor wall without a stirring process, heat accumulates in the reactor for a certain time before being distributed evenly throughout the volume. This phenomenon is known as inertial heating [28]. In the 15-minute experiment, the average reactor wall reached a temperature above 100 ^{0}C and reached a temperature of 400 ^{0}C at the 95th minute.



(a) (b)

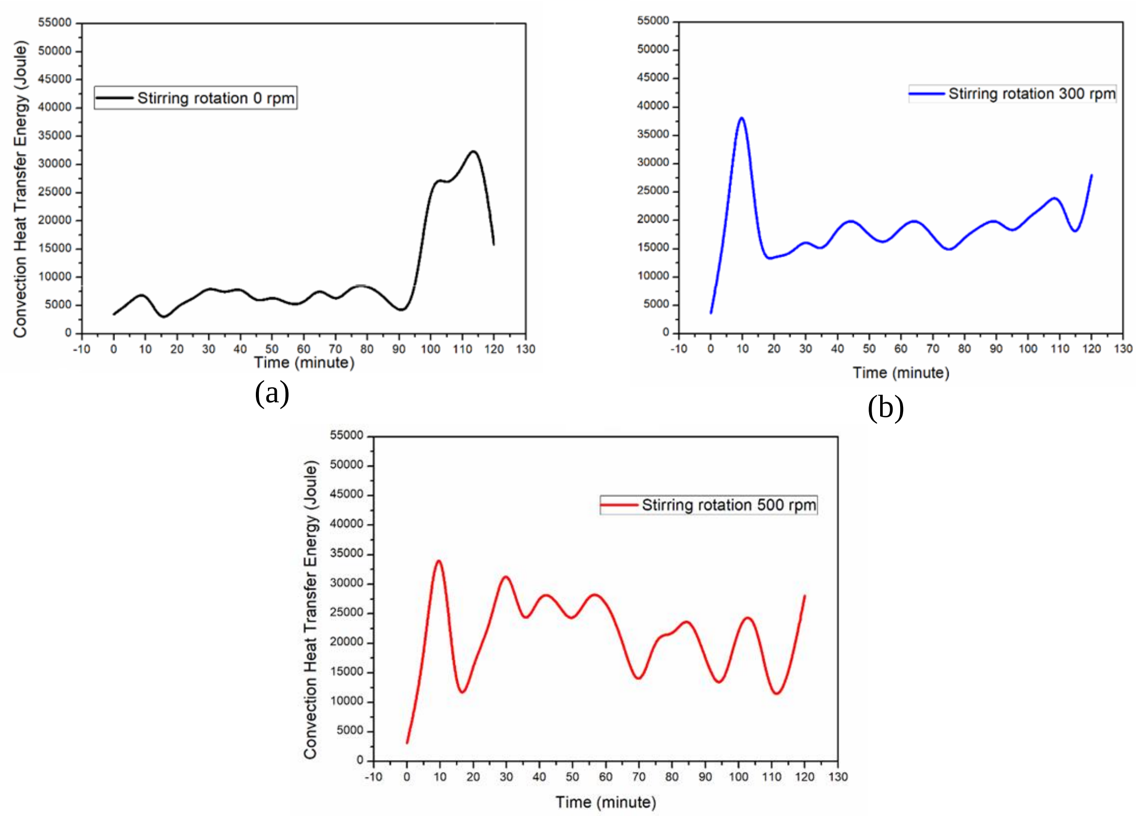
Fig. 4 Distillation volume (a). Volume vs temperature curve, (b). Volume vs time curve.

The heat energy produced from heating the fluid with a stirring rotation of 300 rpm is known to have the highest heat energy of 49364 joules in the 10th minute and the lowest heat energy of 3612 joules in the first minute, which is presented in Figure 5(b). Meanwhile, the heat energy produced from heatingthe fluid with a stirring rotation of 500 rpm is known to have the highest heat energy of 45,408 joules in the 10th minute and the lowest heat energy of 1376 joules in the first minute, which is presented in Figure 5(c). In testing using the stirring process, the energy produced was highest at the beginning of the process and then experienced a steady decrease and increase. This is because the agitator functions to mix the fluid better. This can cause a more rapid increase in temperature at the start of the process. This initial temperature increase may be caused by an increase in heat transfer efficiency in the reactor due to good stirring. Continuous stirring helps maintain an even temperature distribution in the reactor [13]. This avoids significant temperature differences in various parts of the reactor and keeps the temperature stable after the initial phase

3.2 Characteristics of Distilled Fuel

It is important to know the characteristics of any type of fuel in order to look at the perspective in deciding whether the fuel can be used for the desired application [30]. It is hoped that the resulting fuel characteristics from this research can be applied to diesel engine fuel. Fuel characteristics from the results of distillation research with stirring at 0 rpm (WLO 0 rpm), 300 rpm (WLO 300 rpm), and 500 rpm (WLO 500 rpm) using heating to a temperature of 400 0C in 120 minutes, are presented in Table 2 together with the standard value of biodiesel fuel. The fuel characteristics, including flash point, density, viscosity, and heating value, show conformity with the biodiesel standard compared with several research results on similar fuels from previous researchers.

The color of fuel is not directly related to its quality; the color of fuel oil varies depending on the source of the crude oil the refining method, and the use of dyes [31]. The color of the distilled fuel is determined by the temperature. The higher the temperature, the clearer the color of the fuel will be. From Figure 6, it can be seen that the DLF raw material for WLO is dark black in color. After being purified using the distillation method, the resulting oil changes color to a clear yellow. If you look closely, there is a difference in the distillation results due to the effect of stirring. At 500 rpm the DLF results in a clearer without any black lumps. Stirring makes the temperature more even, and there is an increase in temperature during the prolonged distillation process in the reactor, thus forming an agglomeration of polymerized products [32].



(a) (b) (c)

Fig. 5 Heat Transfer Energy (a) Stirring rotation 0 rpm; (b) Stirring rotation 300 rpm; (c) Stirring rotation 500 rpm

The flash point is the lowest temperature of a substance that produces vapor in sufficient quantities to form a flammable mixture. At this temperature, the vapor pressure reaches a certain limit, so it is flammable. If the vapor stops burning, if the ignition source is removed again. Flash point is used as one of the descriptive characteristics of liquid fuels but is also used to describe liquids that are not used intentionally as fuel [13]. Fuels with a high flash point are less volatile, while fuels with a low flash point are more volatile. As a general rule for hydrocarbons, the simpler the molecule, the lower the flash point. Although several equations have been developed to calculate flash points, their usefulness is limited due to significant variations in accuracy. Stirring in the distillation process will cause molecular cracking to break large saturated chains, which produce volatile gases. Flash point research results were obtained at 120, 146, and 144 PMcc, ^{0}C which are presented in Table 2. These results show the influence of stirring on the resulting flash point. Density is a very important parameter in fuel. In a diesel engine, the injection system, pump, and injector must deliver the right amount of fuel to produce proper combustion so as to get good performance. Density is related to the type of raw material and purification steps; besides that, temperature greatly influences the density value; the higher the distillation temperature, the higher the density value [33]. Density can be calculated as an indicator of the energy content of the fuel; fuels with high density have a high energy content. In this study, the density value ranged between

847 - 858 kg/m^3. The standard shows that the density value of biodiesel fuel is between 815 - 860 kg/m^3 [34]. Therefore, taking this into account, all the DLF obtained can be used as diesel engine fuel. As a consideration, fuel density can affect fuel consumption, fuel/air ratio, fuel spray time, engine performance, and exhaust emissions.

The kinematic viscosity at WLO 500 rpm is lower; the friction between molecules caused by stirring with higher rotation causes higher intermolecular forces, therefore the viscosity is higher [12]. In this study, the viscosity values were 3.406, 3.195, and 3.107 cSt, with the lowest values at 500 rpm stirring. Viscosity is a parameter that influences pollutant emissions. In addition, viscosity will affect the quality required for lubrication because it indicates the fluid's resistance to flow, resulting in degradation. Thus, fuel with a high viscosity value is difficult to flow, causing an unstable fuel supply, which can result in the fuel not burning properly, and reducing engine performance, or causing damage to the fuel system [35]. Diesel fuel with a low viscosity rating may not provide sufficient lubrication to the plunger, barrel, and injector. The viscosity of diesel fuel is usually determined at 40 ^{0}C, with the standard for diesel fuel being 2.3–6.0 cSt [34], thus the resulting DLF viscosity can be used as diesel engine fuel. The calorific value of DLF is a very important parameter to measure in comparison with diesel fuel. The low energy content of DLF affects the performance, parameters of engine performance such as horsepower and maximum torque [36]. The calorific value of biodiesel is more influenced by the high level of unsaturation than the length of the carbon chain. The minimum calorific value of biodiesel is 35 MJ/kg, or 8359.61 kcal/kg, as set by the EN 14213 standard. The higher the calorific value, the higher the oxygen content will be, thus helping proper combustion in the engine and reducing the potential for oxidation [37]. In this research, the calorific value was produced and presented in Table 2. These results are still higher than the standard EN 14213, so it can be concluded that it is suitable to be used as diesel engine fuel.

Table 2. Fuel Characteristic

Liquid fuel	Flash point	Density	Viscosity	Calorific Value	Reference
	(PMcc,°C)	(Kg/m 3)	(cSt)	(K.cal/kg)	
WLO 0 rpm	120	847.3	3,407	10978	Test results
WLO 300 rpm	146	850	3,195	10972	Test results
WLO 500 rpm	144	858.3	3.107	10967	Test results
Fuel waste derivatives (WDF)	15	809.1	2,155	4730	[21]
Waste tire fuel	73	843	3.7	9624.28	[38]
Plastic pyrolysis waste fuel (HDPE)	231.77	920	2.57	-	[33]
Plastic pyrolysis waste fuel (LDPE)	212.74	1130	3.27	-	[33]
Transformer waste fuel	150	840	10.47	-	[39]
Biodiesel EN14214 standard	>120	872-878	3.5-5.0	10685	[40]
Biodiesel SNI 7182	>100	815-860	2.3-6.0	8359.6	[34]

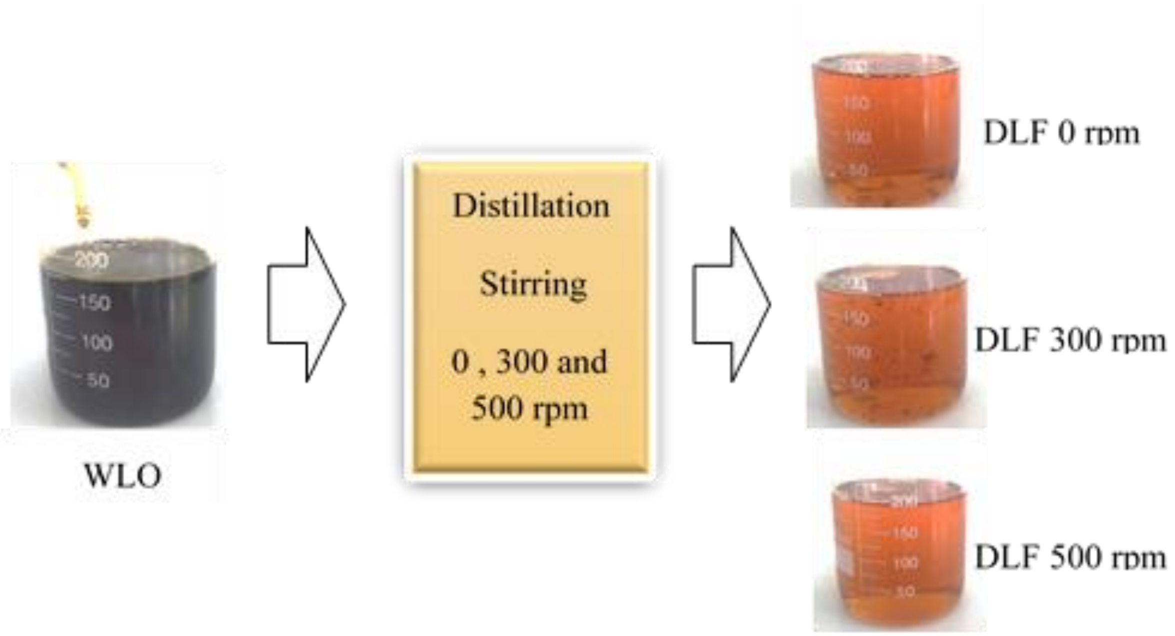


Fig. 6 Distribution of WLO to DLF conversions

Conclusion

The research results show that the use of the Shell Turbo T-46 type WLO gas turbine using the distillation method produces DLF. The effect of stirring on the distillation process was analyzed to see the distribution of heat transfer and the characteristics of the DLF. With the stirring of the raw material, the temperature is more even and the temperature increases more quickly, as well as speeding up the breaking of long-chain molecules from WLO and producing better DLF. The obtained fuel results make it possible to conclude that DLF can be used in diesel engines. However, its properties can be improved through further research. Future work could be carried out by observing the effect of produced DLF on the performance and exhaust emissions of diesel engines.

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