

# Analysis of thermal efficiency and exhaust emissions of diesel engines using biodiesel from used cooking oil with the Addition of Ether Additive (DEE)

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## ABSTRACT

This study aims to analyze the effect of using biodiesel from used cooking oil mixed with Diethyl Ether (DEE) additive on thermal efficiency and exhaust emissions in a single-cylinder diesel engine. Biodiesel is produced through a transesterification process, then mixed with DEE at various concentrations of 5%, 10%, and 15%. Testing was carried out at full load conditions with a constant rotation of 1500 rpm. The results showed that the B20+DEE10 mixture produced the highest thermal efficiency of 31.8% compared to pure diesel (29.4%). CO and HC emissions decreased significantly, but NO<sub>x</sub> emissions increased slightly. The use of DEE in a biodiesel mixture from used cooking oil has been shown to improve thermal performance and is environmentally friendly.

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## 1. INTRODUCTION

The use of fossil fuels as the main source of fuel has had a long-term negative impact on the environment and national energy security. The transportation and industrial sectors rely heavily on diesel fuel, which contains non-renewable hydrocarbon compounds and produces greenhouse gas emissions such as carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and unburned hydrocarbons (HC) (Alkhatat, 2023; Ayca & Dincer, 2025; Inderjeet, 2023; Masuk et al., 2021; Nimagalu et al., 2023).

On the other hand, used cooking oil or used cooking oil that is available in large quantities (Foo et al., 2022), especially from the household sector and the food industry, has great potential as an alternative raw material for biodiesel (Neupane, 2022). Used cooking oil that is not managed properly often pollutes the environment (Hosseinzadeh-Bandbafha et al., 2022). With the transesterification process, used cooking oil can be converted into biodiesel that is suitable for use as diesel engine fuel (Haq et al., 2021; Pauline et al., 2021).

However, pure biodiesel has disadvantages, including lower calorific value, high viscosity, and combustion performance that is not as good as diesel (Gebremariam, 2023; Palani et al., 2022). To overcome these disadvantages, oxygenate additives such as Diethyl Ether (DEE) can be added

(Hua, 2023; Ribun et al., 2023). DEE is known to have volatile properties and can improve the combustion characteristics of biodiesel (EL-Zohairy et al., 2024).

Several previous studies have shown that the addition of DEE to biodiesel can increase thermal efficiency and reduce exhaust emissions. However, specific research on the use of DEE in used cooking oil-based biodiesel is still limited, especially in the context of diesel engine conditions in Indonesia which are widely used in the agricultural and fisheries sectors.

This study aims to evaluate the thermal performance and exhaust emission characteristics of a single-cylinder diesel engine using a mixture of biodiesel from used cooking oil with the addition of DEE at various concentrations. The results of the study are expected to provide practical solutions in the utilization of renewable energy and sustainable domestic waste management.

## 2. METHOD

### 2.1 Biodiesel Production Process

Waste cooking oil is filtered to remove impurities, then heated and reacted with methanol (ratio 1:6) using NaOH catalyst 1% of the weight of the oil. The transesterification process takes place at a temperature of 60°C for 60 minutes. The biodiesel from the reaction is separated and washed with warm water until the pH is neutral.

### 2.2 Fuel Formulation

Fuel mixtures are made in the following variations:

- B20 (20% biodiesel + 80% diesel)
- B20 + DEE 5%
- B20 + DEE 10%
- B20 + DEE 15%

### 2.3 Test Equipment

- 4-stroke, 296 cc, air-cooled single-cylinder diesel engine
- Dynamometer for torque and power measurement
- Gas sensors (CO, HC, NO<sub>x</sub>)
- Thermocouple for exhaust gas temperature measurement

### 2.4 Tested Parameters

- Thermal efficiency.
- Specific fuel consumption (SFC)
- CO, HC and NO<sub>x</sub> emissions.

## 3. RESULTS AND DISCUSSION

### 3.1 Thermal Efficiency

**Table 1.** Thermal Performance and Flue Gas Emission Data

Fuel Type	Efficiency Thermal (%)	SFC (kg/kWh)	CO (%)	HC (ppm)	NO <sub>x</sub> (ppm)
Solar	29.4	0.32	0.15	75	385
B20	30.1	0.3	0.12	65	392
B20 + DEE 5%	30.9	0.29	0.1	58	402
B20 + DEE 10%	31.8	0.28	0.09	52	415
B20 + DEE 15%	31.0	0.29	0.11	56	410

Thermal efficiency is an important parameter in assessing diesel engine performance. The results showed that the use of B20 biodiesel blends with the addition of DEE resulted in a significant increase in thermal efficiency. The 10% B20 + DEE blend recorded the highest thermal efficiency of 31.8%, compared to pure diesel of 29.4%. This is due to the characteristics of DEE, which has a high

cetane number and good volatility, thus accelerating combustion initiation and improving overall fuel combustion.

In contrast, at 15% DEE concentration, the efficiency slightly decreased to 31.0% which is likely due to the excessive dilution of the fuel mixture and the decrease in energy density. Therefore, the additive concentration should be optimized to obtain maximum results.

### 3.2 Specific Fuel Consumption (SFC)

SFC is used to measure the efficiency of fuel consumption in producing power. The lower the SFC value, the more efficiently the fuel is used. In this study, the lowest SFC value was achieved by the B20 + DEE 10% blend at 0.28 kg/kWh, compared to pure diesel at 0.32 kg/kWh. This shows that the addition of DEE is able to increase the efficiency of fuel use.

The decrease in SFC is due to more complete combustion, where DEE helps the fuel vaporization process in the combustion chamber and reduces energy loss during combustion. The addition of 15% DEE did not provide any further significant reduction, in fact it tended to increase the SFC value to 0.29 kg/kWh due to the negative influence on the total heating value of the mixture.

### 3.3 Exhaust Gas Emissions

Exhaust emissions tested included carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO<sub>x</sub>). The results showed that the use of biodiesel and DEE blends had a positive impact on reducing CO and HC emissions. The 10% B20 + DEE blend produced CO emissions of 0.09%, which was lower than that of diesel (0.15%). HC emissions also decreased significantly from 75 ppm (diesel) to 52 ppm in the blend.

This decrease in CO and HC emissions is attributed to the increased oxygen content in the fuel mixture due to the addition of DEE. The additional oxygen aids in the complete oxidation of the fuel, thereby reducing the amount of unburned exhaust gas. However, the increase in DEE concentration was also followed by a slight increase in NO<sub>x</sub> emissions. This is due to the increase in combustion temperature due to better combustion quality. NO<sub>x</sub> emissions in B20 + 10% DEE were recorded at 415 ppm, up from 385 ppm in pure diesel.

## 4. CONCLUSION

Based on the results of the study, it can be concluded that the use of biodiesel from used cooking oil with the addition of Diethyl Ether (DEE) can increase the thermal efficiency of diesel engines and reduce exhaust emissions such as CO and HC. The 10% B20 + DEE mixture showed the best performance with a thermal efficiency of 31.8% and the lowest CO emissions. The addition of DEE has a positive effect on the combustion process. However, NO<sub>x</sub> emissions increased slightly, so further research is needed to minimize this effect.

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