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Fuel Properties and Diesel Engine Exhaust Gas Temperature of Biodiesel-*Calophyllum inophyllum*-Essential Oil mixture

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ABSTRACT

This research investigates the properties and performance of fuel blends comprising biodiesel, *Calophyllum inophyllum* oil (Nyamplung), and essential oils. Biodiesel, a renewable energy source, has gained significant attention due to its low sulfur content, high calorific value, and biodegradability. Experimental investigations involved blending biodiesel with Nyamplung oil and essential oils (clove oil, pine oil, and turpentine oil) in varying proportions. Fuel properties, including density, viscosity, and flash point, were analyzed to assess combustion characteristics. Additionally, engine performance parameters such as torque and exhaust gas temperature (EGT) were evaluated to understand combustion efficiency and engine health. The results revealed that the addition of Nyamplung oil and essential oils increased the density and viscosity of the fuel blends compared to pure biodiesel, impacting atomization and combustion processes. Despite higher viscosity potentially causing ignition delay, flash points decreased due to the presence of essential oils, enhancing safety during storage and handling. Torque measurements indicated variations in engine performance among fuel mixtures, with incomplete combustion observed in blends containing essential oils. EGT measurements further highlighted differences in combustion completeness, with lower temperatures observed in pure biodiesel due to improved atomization and complete combustion.

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INTRODUCTION

The demand for renewable energy and substitute energy from petroleum has increased in recent years. One that continues to be developed is biodiesel where currently Indonesia has implemented biodiesel levels in diesel as much as 30% (B30). The advantages of biodiesel are low sulfur content, low aromatic group, high calorific value, and biodegradable (Varma et al., 2024). Before B30 started to develop, there have been many studies on the use of biodiesel with a content of 20% (B20). One of the

studies on the performance of diesel engines using B20 has been conducted by (Wibisono et al., 2020). It was found that the performance of the Caterpillar 3196 diesel engine using B20 was still within the permissible standard. Furthermore, research on exhaust gas emissions in B20 with palm oil, bean oil, and used cooking oil has been carried out (Veza et al., 2021). In the study it was found that bean seed oil has the lowest levels of smoke, CO and HC emissions. Biodiesel made from soybean oil has been tested for exhaust emissions and combustion chamber temperature (Ariani et al., 2018). The test results explained that CO and HC exhaust emissions decreased when using B10, B20 and B30 fuel.

Nyamplung (*Calophyllum inophyllum L.*) is one of the most potential plants for biodiesel feedstock because of its high oil content (Fadhullah et al., 2015). Mechanical extraction using screw press is one method to get oil from nyamplung seed. Like other vegetable oils, Nyamplung oil can be mixed directly with diesel and tested into diesel engines. The higher the mixture of vegetable oil on diesel causes the viscosity value to be higher. This causes the atomization process to be inhomogeneous and combustion to be incomplete (Gamayel et al., 2022). High viscosity also has an impact on deposits on combustion lines, nozzles, and fuel pump lines (Cahyo et al., 2023). Based on these conditions, biodiesel needs to be added with volatile oil to be able to reduce viscosity values and help flash points occur.

Essential oils are a group of volatile oils. Essential oils are obtained from plants by extracting leaves, stems, and roots. Today, essential oils are widely used for perfume ingredients and the health industry (Sharmeen et al. 2021). Clove oil, pine oil and turpentine oil are some examples of essential oils that have been used in diesel engine performance test studies. (Mbarawa, 2010) mixed clove oil up to 75% in diesel and the test results stated that HC decreased with increasing clove oil content in diesel. The addition of clove oil as a bioadditive to diesel was investigated by (Kadarohman et al., 2012) and found that the terpene content in clove oil can be a bridge to the perfect mixing between clove oil and diesel so that combustion becomes better. Turpentine oil and diesel oil mix research were conducted by (Anand et al., 2010) and pine-diesel oil mixture was researched by (Vallinayagam et al., 2019). The results of the study stated that exhaust emissions have decreased. Based on the studies above, there has been no research on mixing biodiesel, nyamplung oil and essential oils. Therefore, it is necessary to conduct this study with the aim of obtaining fuel properties and diesel performance in mixing three types of fuel. In addition, this study is needed to explore the potential of Nyamplung oil that can be used directly in diesel engines as fuel mixtures.

METHOD

Three stages of research were carried out, namely first: The fuel was blended in a certain percentage, second: test of fuel properties (viscosity, density, flash point), third: tested in a single-cylinder diesel engine type R175A. The diesel performance results are torque (N.m) and exhaust gas temperature (EGT). The diesel engine was operated in stationery condition with various speeds of 1000, 1250, and 1500 rpm. Details of the experimental set-up can be seen in figure 1.

The fuel used is biodiesel (B30) obtained at Pertamina public fuel sales stations (SPBU). The vegetable oil used is Nyamplung oil (*Calophyllum inophyllum L.*) then the essential oil used is clove oil, pine oil, and turpentine oil. The use of notation (table 1) is carried out on the fuel mixture to facilitate discussion, read table and graph.

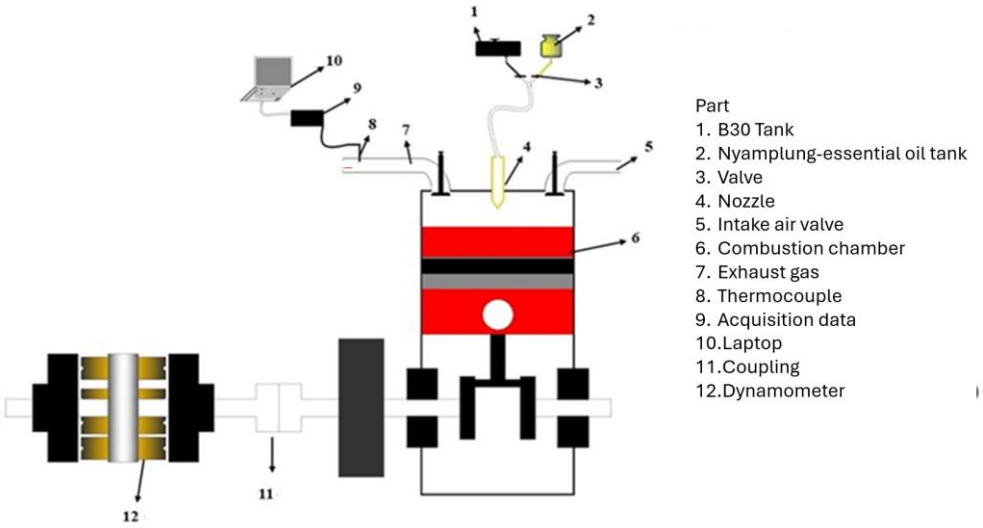

Figure 1. Experimental set-up

Table 1. Notation

Notation	Description
B30	Biodesel
B95N4P1	B30 (95%) + Nyamplung (4%) + Pine oil (1%)
B95N4T1	B30 (95%) + Nyamplung (4%) + Turpentine oil (1%)
B95N4C1	B30 (95%) + Nyamplung (4%) + Clove oil (1%)

RESULTS AND DISCUSSION

1. Fuel Properties

Fuel properties of fuel blend consist of biodiesel, Nyamplung oil, and essential oil shown in table 2. Viscosity is an indication of fluid on the stickiness and ability to flow. The density gives an indication of the ignition delay and specific energy of the fuel in a diesel engine Flash point is a flammability property of fuel. It defined as the lowest temperature at which the mixture of vapor and air above the surface of the liquid can be ignited.

Table 2. Fuel blend properties

Notation	Density (gr/ml)	Viscosity (cSt)	Flash Point (°C)
B30	0.93	3.25	85
B95N4P1	0.94	3.40	78
B95N4T1	0.95	3.57	65
B95N4C1	0.94	3.67	66

Based on table 2, adding Nyamplung oil and essential oil create density and viscosity higher than biodiesel (M. Fadhlullah et al., 2015). Density and viscosity affect the atomization process where the nozzle spray fuel and mixes it with the air for combustion process. Higher density and viscosity create higher atomization and cause unperfect mixing then ignition delay take place (B. Munirathinam et al., 2023). However, the flash point of fuel blend is lower than biodiesel. The flash point is attributed for storage and handling performance. It means that the fuel has safety condition when storage in a long time or handle in transportation. The flash point of fuel blend is lower than biodiesel due to the presence of essential oil. The essential oil is a volatile oil where it has characteristics easy to volatile. For combustion process, volatile oil helps the fuel to become easy to ignition.

2. Torque in fuel mixture.

Torque measurement is carried out to see the performance of the fuel mixture with various engine speeds that shown in figure 2.

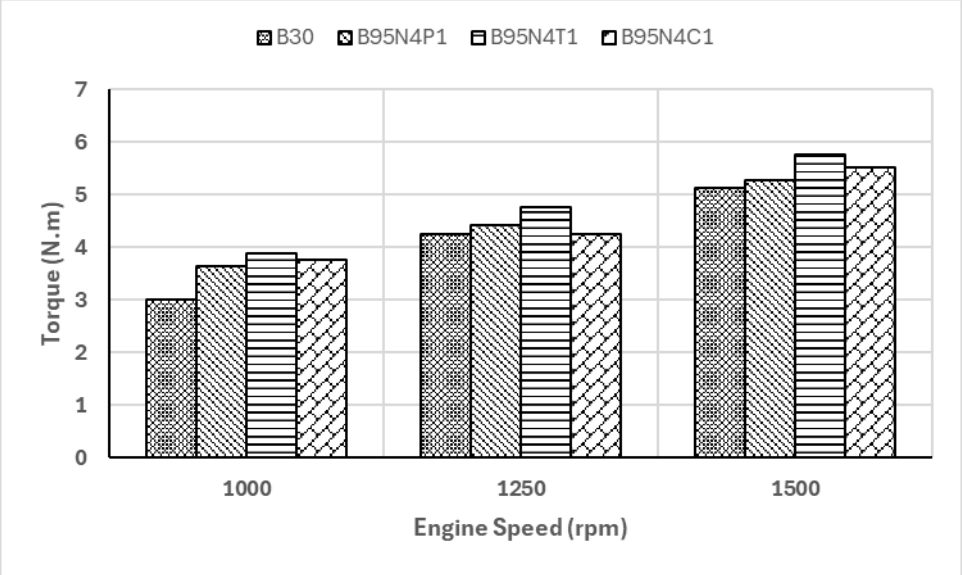

Figure 2. Torque vs RPM in fuel mixture.

Based on figure 2, engine speed increase create the torque for biodiesel and each fuel mixture increase. B30 is the lowest torque compared with the torque produced by the combustion of B95N4P1, B95N4T1, B95N4C1in every engine speed. The torque produced by essential oil is larger than biodiesel (B30) indicates the incomplete combustion. It can be seen in the density and viscosity of the fuel mixture

higher than B30. B95N4T1 is the highest torque in every engine speed variation due to presence of volatile substance like α-pinena. The volatile substance cause the ignition delay in short time, meanwhile their higher viscosity cause bad atomization then create incomplete combustion. This substance also affect in the value of flash point, where B95N4T1 is the lowest with 65 ^{o}C.

3. Exhaust gas temperature.

The objective of measuring exhaust gas temperature (EGT) is analyzing the combustion process complete or not. Beside that, EGT is used for early detection of potential damage in engine due to the incomplete combustion process.

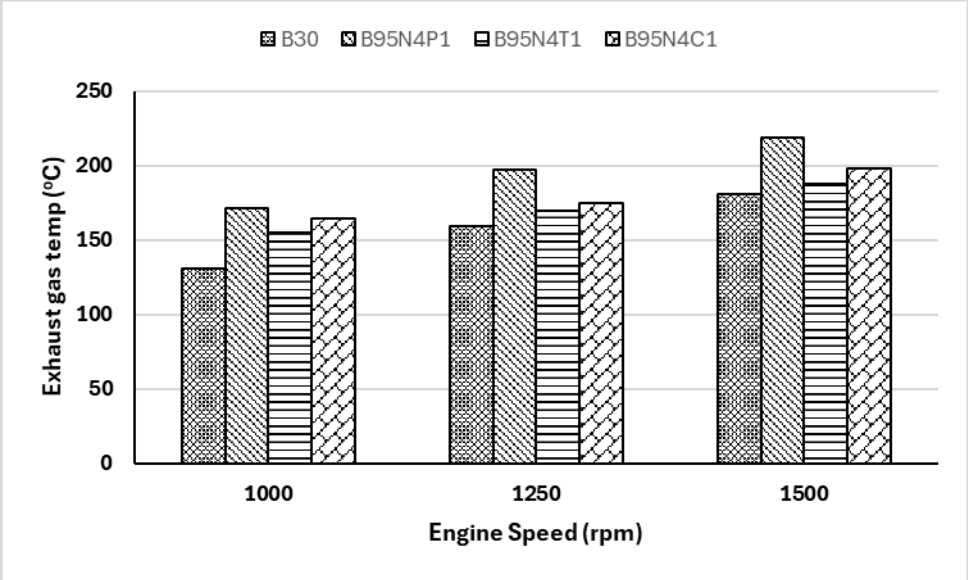

Figure 3. Exhaust gas temperature in fuel mixture.

Based on figure 3, biodiesel (B30) is the lower temperature than B95N4P1, B95N4T1, and B95N4C1. The lower exhaust temperature observed for biodiesel (B30) compared to B95N4P1, B95N4T1, and B95N4C1 can be attributed to the improved atomization and more complete combustion resulting from its lower density and viscosity. Previous studies have established that the lower density and viscosity of biodiesel fuels lead to better atomization, which enhances air-fuel mixing and combustion efficiency (Du, Enpeng et al., 2018). Beside that, the presence of benzene ring in essential oil create the high energy input to brakedown the molecule in combustion process cause the exhaust gas temperature is higher than biodiesel (B30). B95N4P1 is the highest exhaust gas temperature due to the presence of α-terpineol which the characteristic is non-toxic, antioxidant, and high boiling point.

CONCLUSION

In summary, the research underscores the complex interplay between fuel composition, combustion efficiency, and engine performance. Further investigation into optimizing blend compositions is warranted to balance viscosity, atomization, combustion completeness, and emissions for enhanced diesel engine performance and environmental sustainability.

1. The addition of Nyamplung oil and essential oil increases the density and viscosity of the fuel blend compared to pure biodiesel (B30). These properties play crucial roles in the atomization process during combustion. While higher density and viscosity may lead to imperfect mixing and ignition delay, the flash point of the fuel blend decreases compared to biodiesel alone. This decrease in flash point, attributed to the presence of essential oils, enhances safety during storage and handling.
2. Torque measurements indicate variations in engine performance among different fuel mixtures. B30 exhibits the lowest torque due to its lower viscosity, enabling better atomization and complete combustion. In contrast, fuel mixtures containing essential oils demonstrate higher torque, suggesting incomplete combustion. Notably, B95N4T1 shows the highest torque due to the presence of volatile substances like α-pinena, causing ignition delay despite higher viscosity, resulting in incomplete combustion.
3. EGT measurements provide insights into combustion completeness and engine health. B30 exhibits lower exhaust gas temperatures compared to fuel mixtures containing Nyamplung oil and essential oils. The lower density and viscosity of B30 facilitate better atomization and complete combustion. However, fuel mixtures with essential oils, containing benzene rings, contribute to higher energy inputs during combustion, elevating EGT. B95N4P1, containing α-terpineol with non-toxic and antioxidant properties, exhibits the highest EGT due to its unique characteristics.

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