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EXPERIMENTAL ANALYSIS OF EXHAUST GAS TEMPERATURE DURING THE USE OF BIODIESEL FUEL

ABSTRACT: The application of biofuels in internal combustion engines is gaining increasing importance from the aspects of improving energy efficiency, reducing the consumption of fossil fuels, and decreasing greenhouse gas emissions. In the field of diesel engines, particular attention has been directed toward the use of biodiesel and its blends with conventional diesel fuel, with the aim of improving the environmental characteristics of the propulsion system while maintaining satisfactory engine performance characteristics. The aim of this paper is to determine the influence of different blending ratios of biodiesel and conventional diesel fuel on exhaust gas temperature. The laboratory testing conducted for the purposes of this study was carried out in an engine testing laboratory equipped with modern measuring and testing equipment intended for the analysis of propulsion and environmental characteristics of internal combustion engines. The applied laboratory equipment enabled precise monitoring and evaluation of relevant operating parameters during the experimental investigation. During the experimental research, exhaust gas temperature parameters were monitored using four different types of fuel, namely biodiesel–diesel fuel blends (BD7, BD15, BD20, and BD30). The obtained results indicate that increasing the concentration of biodiesel in fossil diesel fuel leads to a reduction in exhaust gas temperature. The significance of this study is reflected in the consideration of the possibilities for wider application of biodiesel fuels in modern propulsion systems, as well as in the analysis of their influence on the environmental characteristics of internal combustion engines.

KEYWORDS: diesel fuel, biodiesel, exhaust gas temperature, diesel engines

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EKSPERIMENTALNA ANALIZA TEMPERATURE IZDUVNIH GASOVA PRI UPOTREBI BIODIZEL GORIVA

REZIME: Primjena biogoriva u motorima sa unutrašnjim sagorijevanjem sve više dobija na značaju sa aspekta povećanja energetske efikasnosti, smanjenja potrošnje fosilnih energenata i redukcije emisije gasova sa efektom staklene bašte. U oblasti dizel motora posebna pažnja usmjerena je na upotrebu biodizela i njegovih mješavina sa konvencionalnim dizel gorivom, sa ciljem unapređenja ekoloških karakteristika pogonskog sistema uz zadržavanje zadovoljavajućih eksploatacionih performansi motora. Cilj rada jeste utvrđivanje uticaja različitih mješavinskih odnosa biodizela i konvencionalnog dizel goriva na temperaturu izduvnih gasova. Laboratorijsko ispitivanje za potrebe ovog rada sprovedeno je u laboratoriji za ispitivanje motora, opremljenoj savremenom mjerno-ispitnom opremom namijenjenom za analizu pogonskih ni ekoloških karakteristika motora sa unutrašnjim sagorijevanjem. Primijenjena laboratorijska oprema omogućila je precizno praćenje i evaluaciju relevantnih radnih parametara tokom eksperimentalnog istraživanja. Tokom eksperimentalnog istraživanja praćeni su parametri temperature izduvnih gasova pri upotrebi četiri različite vrste goriva, odnosno mješavina biodizela i dizel goriva (BD7, BD15, BD20 i BD30). Dobijeni rezultati ukazuju da povećanjem koncentracije biodizela u fosilnom dizel gorivu dolazi do smanjenja temperature izduvnih gasova. Značaj rada ogleda se u sagledavanju mogućnosti šire primjene biodizel goriva u savremenim pogonskim sistemima, kao i u analizi njegovog uticaja na ekološke karakteristike motora sa unutrašnjim sagorijevanjem

KLJUČNE REČI: dizel gorivo, biodizel, temperatura izduvnih gasova, dizel motori

INTRODUCTION

Biodiesel represents one of the alternative fuels for use in diesel engines and has been the subject of extensive research due to the increasing need to promote renewable energy sources and reduce dependence on fossil fuels. Its physicochemical properties differ from those of conventional diesel fuel, which may affect the combustion process, engine operating characteristics, and exhaust emissions (Wenbo & Haeng Muk Cho, 2024; Azad et al. 2023).

Exhaust gas temperature (EGT) is one of the parameters that can be used to assess the thermal behaviour of an engine. Previous studies indicate that variations in the biodiesel content of a fuel blend may have different effects on EGT, with the resulting temperature values depending on fuel properties, biodiesel blend ratio, and engine operating conditions (Azad et al. 2023; Guirong et al. 2020). The objective of this study is to experimentally investigate the effect of different biodiesel mass fractions in diesel fuel on the exhaust gas temperature of a Volkswagen 1.9 TDI PD BKC engine. The experiments were conducted at engine load levels of 50% and 100%, using BD7, BD15, and BD20 fuel blends, in order to determine variations in exhaust gas temperature as a function of fuel composition and engine load.

POSSIBILITIES FOR THE APPLICATION OF BIODIESEL IN INTERNAL COMBUSTION ENGINES

Biodiesel is a renewable alternative fuel for diesel engines, primarily produced from vegetable oils and animal fats. Its use may contribute to reductions in CO_2 emissions, particulate matter, carbon monoxide, aromatic compounds, and sulfur oxides. In addition to its environmental benefits, biodiesel is characterized by biodegradability and low toxicity, while its production from locally available renewable feedstocks may contribute to reducing dependence on fossil fuels and supporting local economic development. Biodiesel can be used in diesel engines as a neat fuel or, more commonly, in blends with fossil diesel fuel. According to standard nomenclature, B100 denotes a fuel containing 100% biodiesel, whereas B5 and B20 denote blends containing 5% and 20% biodiesel, respectively. At relatively low biodiesel blend ratios, such blends can generally be used without significant engine modifications; however, the applicability of neat biodiesel depends on engine design, manufacturer specifications, and fuel quality. Biodiesel intended for use in diesel engines should comply with the requirements of the EN 14214 standard. Biodiesel can be blended with mineral diesel fuel at different ratios, provided that an appropriate blending procedure is applied to ensure a homogeneous mixture. According to (Babić, 2013), biodiesel blending can be performed by spraying, directly in the fuel tank, or in the fuel line upstream of the tank.

In addition to the aforementioned advantages, the use of biodiesel is associated with certain limitations. A particular concern is its less favourable low-temperature performance, namely higher cloud point and pour point compared with conventional diesel fuel. As the temperature decreases, crystal formation and an increase in viscosity may occur,

impairing fuel flow and delivery and potentially causing clogging of fuel system components. Therefore, suitable additives may be used under low-temperature operating conditions to improve the low-temperature properties of the fuel. Another limitation is the higher distillation temperature of biodiesel, which may affect mixture formation and increase the potential for fuel dilution of the lubricating oil. Under such conditions, more frequent monitoring and replacement of the engine lubricating oil may be required.

REVIEW OF RELEVANT LITERATURE

Karrar & Hyder (2026.) investigated the effects of biodiesel and biodiesel–diesel blends on the operating characteristics of an internal combustion engine under different engine load conditions, with particular emphasis on variations in exhaust gas temperature (EGT). Tests conducted using neat diesel fuel (D100) and biodiesel blends with different biodiesel contents (D10, D20, D30, D40, D50) demonstrated a pronounced increase in exhaust gas temperature with increasing engine load, regardless of the fuel type used. According to the author, this trend can be attributed to the increased amount of fuel required at higher engine loads, resulting in a more intensive combustion process and, consequently, higher in-cylinder temperatures. Compared with neat diesel fuel, the use of biodiesel resulted in an increase in exhaust gas temperature of approximately 6.8%, particularly at full engine load. The author attributed this behaviour to the specific physicochemical properties of biodiesel, particularly its oxygen content, which may affect combustion characteristics and exhaust gas temperature. Similar trends were also observed for biodiesel produced from waste cooking oil (WCO), with the higher oxygen content of the fuel influencing combustion characteristics and EGT as engine load increased (Genet, et al. 2026.).

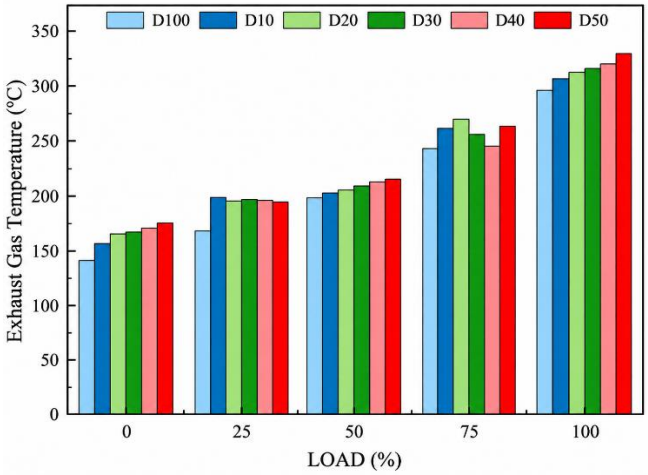


Figure 1 Variation in exhaust gas temperature as a function of engine load for diesel fuel and different biodiesel blends (Karrar & Hyder, 2026)

Karabulut et al. (2024.) investigated the effect of biodiesel content on exhaust gas temperature (EGT) and found that increasing the biodiesel fraction resulted in a decrease in EGT. At 1500 min^{-1} and full engine load, EGT values for B10, B20, B50, and B100 were 10.00%, 19.31%, 25.14%, and 32.35% lower, respectively, than that of conventional diesel fuel (B0). The reduction in EGT was primarily attributed to the lower heating value of biodiesel and its combustion characteristics, with a greater proportion of the fuel being burned before the onset of the expansion stroke. At the same time, increasing engine load and rotational speed resulted in higher EGT due to the increased amount of heat released during combustion.

Sabah et al. (2025) investigated the effects of engine load and biodiesel–diesel blend composition on exhaust gas temperature (EGT). The results showed that EGT increased with increasing engine load, which was attributed to higher fuel consumption and more intensive heat release during combustion. Most of the investigated biodiesel blends exhibited higher EGT values than conventional diesel fuel, which was associated with the oxygen content of biodiesel and more complete combustion. As an exception, the NC(CaO)B10 blend exhibited a lower exhaust gas temperature than diesel fuel and the other blends at full engine load, which was attributed to its more favourable fuel atomization and evaporation characteristics.

Mensih et al. (2025.) investigated the effect of biodiesel–ethanol blends on exhaust gas temperature (EGT). The results showed that EGT increased with increasing engine load, while all investigated blends exhibited lower EGT values compared with neat diesel fuel (D100). At full engine load and without exhaust gas recirculation, the reductions in EGT for the D80CB20, D80CB10E10, D60CB40, and D60CB20E20 blends were 4%, 11%, 8%, and 19%, respectively, compared with D100. The reduction in exhaust gas temperature was attributed to the lower heating value, higher latent heat of vaporization, and oxygen content of biodiesel and ethanol, which contributed to lower combustion temperatures.

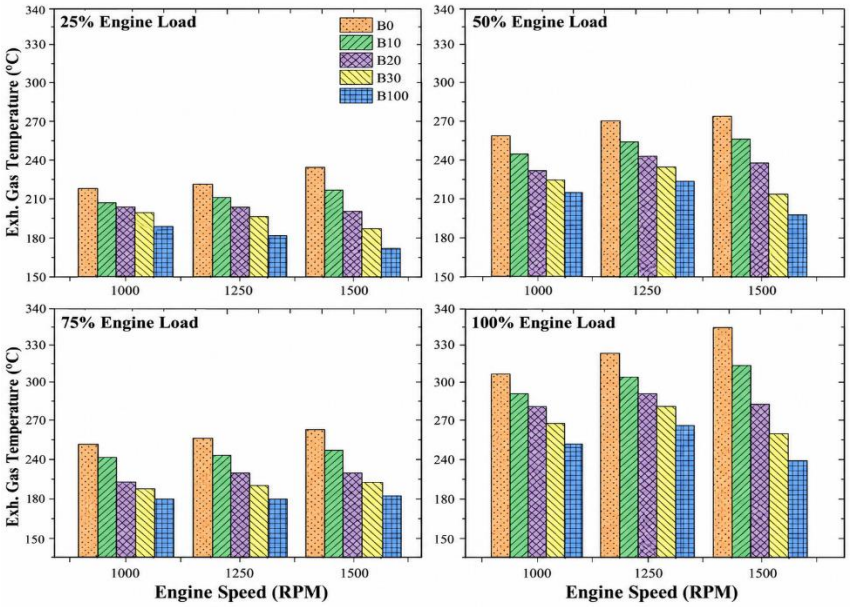


Figure 2 Variation in exhaust gas temperature (Karabulut et al. 2024)

Sudarsanam et al. (2025.) investigated the effects of fuel composition and nano-additives on exhaust gas temperature (EGT). The results showed that increasing the biodiesel content in biodiesel–alcohol blends tended to reduce EGT compared with neat diesel fuel. Ternary blends containing pentanol exhibited lower EGT values than the corresponding blends containing butanol. In contrast, the addition of 25 and 50 ppm Al_2O_3 nanoparticles increased EGT by approximately 1.5% and 5–6%, respectively, which was associated with more intensive combustion and higher in-cylinder temperatures. Furthermore, increasing engine load resulted in higher EGT values for all tested fuels due to the increased amount of injected fuel and greater heat release during the combustion process.

Figure 3 presents the effect of the investigated fuels on exhaust gas temperature (EGT) at different engine load conditions. El-Shafay et al. (2022.) reported that EGT increased with increasing engine load due to the greater amount of fuel required to meet the increased load demand. Under all investigated operating conditions, conventional diesel fuel exhibited the lowest EGT values, whereas biodiesel–diesel blends showed an increase in EGT with increasing biodiesel content. Compared with diesel fuel, the maximum EGT increases were 2% for B5, 3% for B10, 5% for B15, and 8% for B20. These variations were associated with the characteristics of the biodiesel blends and their influence on the combustion process. Similar findings have been reported by other researchers investigating the effects of biodiesel blends on exhaust gas temperature (Chen, Y. et al. 2007).

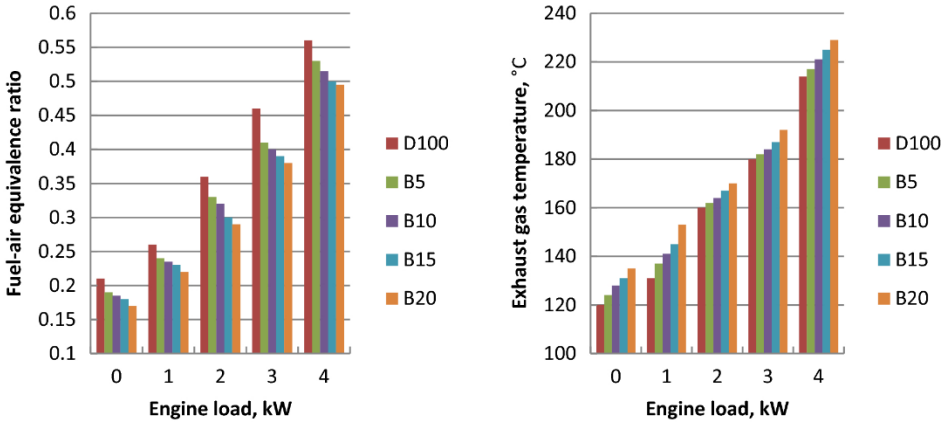


Figure 3 Variation of the fuel–air equivalence ratio and exhaust gas temperature (Text) as a function of engine load (El-Shafay et al. 2022)

The results of available studies indicate that the effect of biodiesel on exhaust gas temperature is not consistent. Some authors have reported an increase in EGT when using biodiesel, attributing this behaviour to its higher oxygen content and more intensive combustion, whereas other studies have reported a decrease in exhaust gas temperature, primarily due to the lower heating value of biodiesel and differences in combustion characteristics. The observed variations in results may also be attributed to the type of biodiesel, its proportion in the fuel blend, engine operating conditions, and engine design characteristics.

METHODOLOGY

Test Fuels and Engine Load Conditions

The experimental investigation was conducted in an engine testing laboratory equipped with advanced measurement and test instrumentation manufactured by AVL, designed for experimental studies of engine performance and combustion processes. Three fuel blends with different biodiesel mass fractions in fossil diesel fuel were investigated:

- BD7 – a blend containing 7% biodiesel and 93% fossil diesel fuel;
- BD15 – a blend containing 15% biodiesel and 85% fossil diesel fuel;
- BD20 – a blend containing 20% biodiesel and 80% fossil diesel fuel.

The specified proportions represent the mass fraction of biodiesel in the total mass of the fuel blend (m/m). This approach enabled the comparative assessment of the effect of different biodiesel contents on the investigated engine parameter. The tests were conducted at two engine load conditions. The first corresponded to a partial load of 50%, while the second represented full engine load of 100%. Exhaust gas temperature (EGT) was measured under both operating conditions. The primary parameter investigated was exhaust gas temperature, with the aim of assessing the influence of biodiesel mass fraction and engine load on EGT. The obtained experimental results were used to compare engine behaviour when operating with BD7, BD15, and BD20 fuel blends under partial and full load conditions.

Equipment for Measuring Exhaust Gas Temperature

Thermocouples are commonly employed for exhaust gas temperature measurements under experimental conditions. Their main advantages include a simple construction, compact dimensions, relatively rapid response, and a wide operating temperature range. Their operating principle is based on the Seebeck effect. When two electrical conductors made of dissimilar materials are joined and their junctions are maintained at different temperatures, a thermoelectric voltage is generated in the electrical circuit. The magnitude of this voltage depends on the temperature difference between the measuring, or hot, junction and the reference, or cold, junction. A Type K thermocouple is particularly suitable for measuring exhaust gas temperature. This thermocouple type has a wide operating temperature range and is widely used in industrial and laboratory measurement applications. Thermocouples with similar designs and characteristics have also been employed in experimental investigations of exhaust gas temperature, including the study conducted by Papaioannou et al., in which thermocouples of different diameters were used to investigate their influence on the measured exhaust gas temperature (Papaioannou et al., 2018; Son S & Kolasa A, 2006). The AVL F-FEM-AIS measurement system supports Type B, E, J, K, N, R, S, and T thermocouples. According to the technical documentation, the measuring range of a Type K thermocouple extends from −50 °C to 1372 °C, making it suitable for temperature measurements within the exhaust system of an internal combustion engine (AVL List, 2014). The following figure shows the Type K thermocouple used for exhaust gas temperature measurement in the Engine Testing Laboratory of the Faculty of Transport and Traffic Engineering in Doboj.



Figure 4 Thermocouple for exhaust gas temperature measurement

Within the scope of the present experimental investigation, the thermocouple signal was acquired using the AVL F-FEM-AIS module. The F-FEM-AIS is a Fast Front End Module designed for the acquisition of analog signals. The module enables the measurement of electrical voltage, current, electrical resistance, temperature, pressure, and other physical quantities. It is equipped with 16 analog input channels, each of which can be configured according to the connected sensor and the requirements of the specific measurement (AVL List, 2014.). During thermocouple measurements, the F-FEM-AIS performs acquisition and conditioning of the thermoelectric signal, analog-to-digital conversion, and sensor characteristic linearization. For a Type K thermocouple, the manufacturer specifies 64 linearization points for converting the hot-junction voltage into temperature. Available sampling frequencies are 1, 2, 5, 10, and 20 Hz (AVL List, 2014.). The following figure illustrates the connection of the thermocouples to the F-FEM-AIS module.



Figure 5 Connection of thermocouples to the F-FEM-AIS module

RESULTS AND DISCUSSION

The experimental results obtained for the three biodiesel–diesel blends (BD7, BD15, and BD20) indicate that, at a partial engine load of 50%, exhaust gas temperature (EGT) decreases with increasing biodiesel content in the fuel (Figure 6). The highest EGT was recorded for the BD7 blend, whereas a progressive decrease in temperature was observed with increasing biodiesel content in BD15 and BD20. This trend may primarily be associated with the lower heating value of biodiesel compared with fossil diesel, resulting in a greater quantity of the biodiesel blend being required to maintain the same engine operating condition. Increasing the biodiesel fraction also alters the physicochemical properties of the fuel, particularly its viscosity, density, and evaporation characteristics, thereby affecting mixture formation and combustion. Consequently, at 50% engine load, an increase in biodiesel content was associated with a reduction in exhaust gas temperature. The obtained result suggests that, under this operating condition, a higher biodiesel fraction may be associated with lower heat losses through the exhaust system.

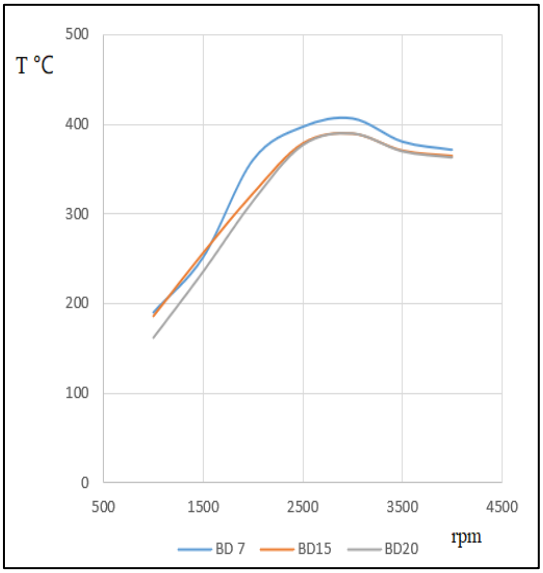


Figure 6 Exhaust gas temperature at a partial engine load of 50%

A similar trend was observed at full engine load of 100% (Figure 7). With increasing biodiesel content in the fossil diesel fuel, i.e., from BD7 to BD15 and BD20, a progressive decrease in exhaust gas temperature (EGT) was observed. The results indicate that, under the analysed operating conditions, increasing the biodiesel fraction in the

investigated blends was associated with a reduction in EGT. This behaviour may primarily be attributed to the lower heating value of biodiesel compared with fossil diesel, as well as to changes in the combustion process resulting from differences in the physicochemical properties of the fuels.

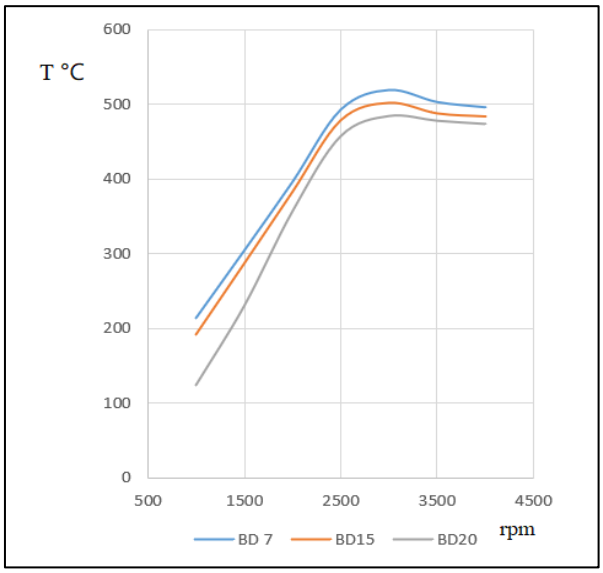


Figure 7 Exhaust gas temperature at full engine load (100% load)

Furthermore, as shown in Figures 6 and 7, exhaust gas temperature (EGT) increases with increasing engine load. Higher engine load requires greater torque output, resulting in a larger quantity of fuel being injected and combusted within the cylinder. Consequently, the amount of heat released during combustion increases, leading to higher combustion product temperatures and, consequently, higher exhaust gas temperatures. In addition, higher engine loads are associated with increased mean in-cylinder temperature, which further contributes to the rise in the temperature of the gases leaving the cylinder. The observed increase in EGT with increasing engine load is consistent with the expected behaviour of diesel engines and indicates a direct relationship between engine load, injected fuel quantity, and engine thermal loading.

CONCLUSION

Based on the experimental investigation of the BD7, BD15, and BD20 biodiesel–diesel blends, it can be concluded that increasing the biodiesel content resulted in a decrease in exhaust gas temperature (EGT) at engine loads of 50% and 100%. The observed trend may be associated with the lower heating value of biodiesel compared with conventional diesel fuel, as well as with its different physicochemical properties affecting the combustion process. Conversely, increasing engine load resulted in higher exhaust gas temperatures for all investigated blends, which can be attributed to the greater amount of injected fuel and increased heat release during combustion.

The obtained results indicate that EGT is influenced by both fuel composition and engine operating conditions. An increase in biodiesel content was associated with a progressive decrease in exhaust gas temperature, whereas increasing engine load had the opposite effect. These findings suggest that biodiesel may affect the thermal behaviour of the engine and potentially contribute to reduced thermal loading; however, its overall effect should be assessed in conjunction with other engine operating parameters.

Future research should include a larger number of biodiesel–diesel blends and a wider range of engine operating conditions to provide a more comprehensive assessment of the influence of biodiesel content on combustion and temperature characteristics. Particular attention should be given to the simultaneous analysis of exhaust gas temperature, brake-specific fuel consumption, effective power, and thermal efficiency in order to provide a more complete evaluation of the effects of biodiesel on engine performance. Further studies should also address emissions of NOx, CO, HC, and particulate matter, as well as engine behaviour at different rotational speeds and under variable load conditions. Long-term testing would additionally be valuable for assessing the effects of biodiesel on thermal stability, engine wear, and operational reliability. Integrating these parameters could contribute to a more reliable determination of the optimal biodiesel content as a balance between engine performance, fuel consumption, thermal loading, and exhaust emissions.

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