

Original/Review article

Effects of Sunflower Oil Biodiesel Blends on Diesel Engine Performance and Emissions

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Abstract

The environmental impacts and limited reserves of fossil fuels have increasingly highlighted the importance of alternative fuel sources. In this study, the effects of a sunflower oil biodiesel–diesel blend on the performance, fuel consumption, and exhaust emissions of a single-cylinder diesel engine were experimentally investigated. During the tests, pure diesel fuel (B0) and a blend containing 90% diesel and 10% sunflower biodiesel (B10) were evaluated under various load conditions. After the engine reached steady-state operating temperature, power output, fuel consumption, and exhaust emissions were measured. The findings indicate that the biodiesel blend does not adversely affect engine power and provides performance comparable to pure diesel at all load levels. While fuel consumption was similar at low and medium loads, a measurable reduction was observed at high loads when using the biodiesel blend, which is attributed to the improved combustion associated with the fuel's higher oxygen content. Regarding exhaust emissions, the addition of biodiesel resulted in reductions in CO and HC emissions, whereas a slight increase in NO_x emissions was observed. This increase is attributed to higher combustion temperatures and is considered manageable through appropriate emission-control strategies. In conclusion, the sunflower biodiesel blend enhances fuel efficiency while maintaining engine performance and offering environmental benefits; however, additional measures may be required to mitigate elevated NO_x emissions.

Keywords: Energy, Biodiesel, Diesel engine, Exhaust emissions

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INTRODUCTION

The progressive depletion of fossil fuel reserves and growing concerns regarding the environmental problems caused by greenhouse gas emissions have significantly increased interest in sustainable energy sources such as biodiesel. Biodiesel, a renewable and biodegradable fuel, offers a cleaner combustion profile compared to petroleum-derived fuels and produces lower amounts of carbon monoxide (CO), sulfur oxides (SO_x), particulate matter (PM), unburned hydrocarbons (HC), and carbon dioxide (CO₂). However, a major challenge in biodiesel production is ensuring cost-effectiveness while preventing competition with food resources (Stanescu et al., 2025). In recent years, significant advancements have been achieved in diversifying feedstocks for biodiesel production and improving transesterification processes. Feedstocks used in biodiesel production are generally classified as edible vegetable oils (first generation), non-edible oils, animal fats, and waste materials (second generation), microalgae (third generation), and genetically or metabolically engineered biomass (fourth generation) (Mandari and Devaraj, 2022). Studies have shown that blending biodiesel with diesel fuel at specific ratios can have positive effects on engine performance. In particular, the higher oxygen content of biodiesel enables more complete combustion in diesel engines, leading to reduced soot accumulation in engine components, especially in the combustion chamber and exhaust system (Raheman et al., 2013; Ramaprabhu et al., 2008; Jadhav, S. S, 2009). Despite these advantages, biodiesel may cause certain performance issues when used in its pure form. These include increased carbon deposits in the fuel system, higher levels of injector tip fouling, and accelerated wear in cylinder liners (Kose et al., 2020). To minimize such adverse effects and maintain long-term engine performance, the use of biodiesel blended with conventional fossil diesel fuel is widely recommended. For these reasons, academic studies increasingly focus on the direct applicability of alternative fuels particularly those that reduce environmental impacts and fossil fuel consumption to existing diesel and gasoline engine systems (Vergel-Ortega et al., 2021; Zahan and Kano, 2018; Escobar-Yonoff, et al., 2021). Within this context, biodiesel is considered one of the promising solutions for Direct Injection (DI) engines, primarily because it can be used without requiring significant modifications to the engine structure (Dhar, and Agarwal, 2014). The physical and chemical properties of biodiesel contribute to more complete combustion, thus significantly reducing harmful emissions such as carbon monoxide (CO), carbon dioxide (CO₂), particulate matter, and unburned hydrocarbons (HC) (Kumar and Chauhan, 2013). Furthermore, numerous studies indicate that biodiesel use provides environmental benefits without negatively affecting engine performance, particularly by decreasing soot and deposit formation. These characteristics highlight biodiesel as both an environmentally friendly and engine-compatible alternative fuel.

A review of the literature on sunflower biodiesel indicates that several studies have examined the performance, combustion, and emission characteristics of single-cylinder diesel engines fueled with waste sunflower oil biodiesel blends. According to the findings, higher maximum in-cylinder pressure,

shorter ignition delay, and improved combustion were observed (Naik et al., 2022). In another study, the effects of repeatedly heating coconut, sunflower, and palm oils on the fatty acid profiles and physicochemical properties of the biodiesels produced from these oils were investigated in detail. The performance, combustion, and emission characteristics of a diesel engine fueled with 20% biodiesel blends were analyzed. Results showed a 0.28% decrease in thermal efficiency and a 65 ppm increase in NO_x emissions when using sunflower biodiesel (Niyas and Shaija, 2022). In a different study, MgO nanoparticles were added to biodiesel produced from waste sunflower and cottonseed oils via transesterification, and the performance and emission characteristics were evaluated. The findings indicated that biodiesel significantly reduced CO, HC, and soot emissions, while causing a partial increase in NO_x emissions. The nanoparticle additives were found to positively influence combustion characteristics and thermal efficiency, thereby enhancing engine performance (Uyar et al., 2024).

This study provides a comprehensive experimental evaluation of the performance and emission characteristics of a single-cylinder diesel engine fueled with sunflower oil biodiesel–diesel blends. In particular, the simultaneous measurement of fuel consumption and exhaust gas emissions at various engine load levels reveals the detailed effects of biodiesel blending on engine behavior. In this respect, the study offers innovative and up-to-date insights into the applicability of biodiesel in terms of both engine performance and environmental impact.

MATERIALS AND METHODS

In this study, the performance and emission characteristics of two different fuels were examined using a single-cylinder, four-stroke diesel engine with a power output of 11.5 kW, as shown in Figure 1. In the first phase of the experiments, the reference fuel was selected as standard diesel, which is widely used in Türkiye. In the second phase, an alternative fuel sample consisting of a blend of 90% diesel and 10% sunflower biodiesel was tested.

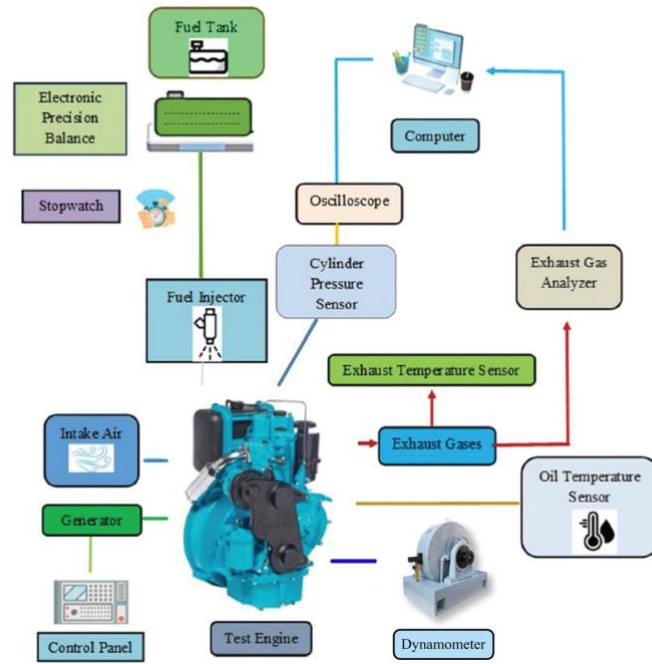


Figure 1. Experimental setup and data collection (Erturk et al.,2024).

Prior to initiating the experimental procedures, the engine was operated without load until it reached the steady-state temperature of 82°C recommended by the manufacturer, ensuring stable operating conditions. Once the target temperature was achieved, the first test sequence commenced using pure diesel fuel. Load levels of 25%, 50%, 75%, and 100% were sequentially applied to the engine, and the output power, fuel consumption, and exhaust emission values were measured. After completion of the first phase, the same experimental steps were repeated using the blended fuel containing 90% diesel and 10% sunflower oil biodiesel. The same performance and emission parameters were recorded at each load level, and all measurements were meticulously logged into the data acquisition system. Additionally, exhaust gas emissions were continuously monitored at regular intervals throughout the test period. Upon completion of all experiments, the collected data were analyzed to evaluate changes in engine power, specific fuel consumption, and exhaust emissions. The results were presented in graphical form, and detailed analyses were conducted based on these findings.

RESULTS AND DISCUSSION

The experimental results obtained in this study clearly demonstrate the effects of adding 10% sunflower biodiesel to diesel fuel on both engine performance and exhaust emissions. An evaluation of the power values measured during the engine tests reveals that, across all load levels, the biodiesel blend produced power outputs that closely matched those obtained with pure diesel fuel. This finding provides strong evidence that the applied blend ratio can be used as an engine fuel without difficulty and does not pose any drawbacks in terms of engine power. An assessment of the emission measurements showed that similar emission values were obtained for both fuel types at different engine load levels. The

concentrations of carbon monoxide (CO) and hydrocarbons (HC) in the exhaust gases were observed to be slightly lower when the fuel containing sunflower biodiesel was used. In contrast, a slight increase in nitrogen oxide (NO_x) emissions occurred in the biodiesel blend, particularly under high-load operating conditions. This increase is attributed to the higher combustion temperatures associated with biodiesel, which are known to promote NO_x formation; thus, the results are consistent with findings reported in the existing literature. Additionally, the measurements indicated that fuel consumption values for both fuels were remarkably similar.

As shown in Figure 2, the experiments conducted under varying load conditions clearly demonstrate that there is no significant difference in engine power output between the sunflower biodiesel-blended fuel and standard diesel. The observation of similar power values across all load levels constitutes an important technical indicator that the prepared biodiesel blend is a suitable option for engine performance and can be safely used in diesel engines.

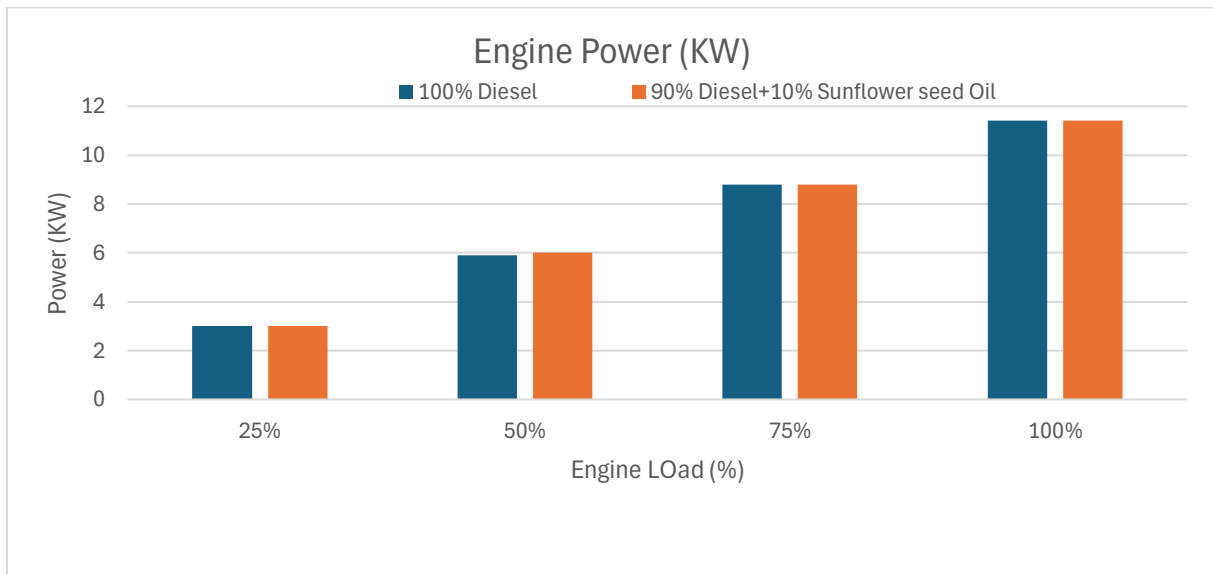


Figure 2. Engine Power Output Comparison

An examination of the results presented in Figure 3 shows that, in the experiments using the fuel containing sunflower biodiesel, similar fuel consumption values were obtained for both fuel types, particularly when the engine operated under 25% and 50% load conditions. When the engine load was increased to 75% and 100%, the biodiesel-blended fuel exhibited approximately 88–94 ml/h lower consumption. This outcome is thought to be related to the higher oxygen content of biodiesel, which contributes to a more efficient combustion process and enhances combustion quality under high-load conditions. Therefore, the increased combustion efficiency of the biodiesel blend at higher loads can be considered the primary reason for the reduction in fuel consumption observed.

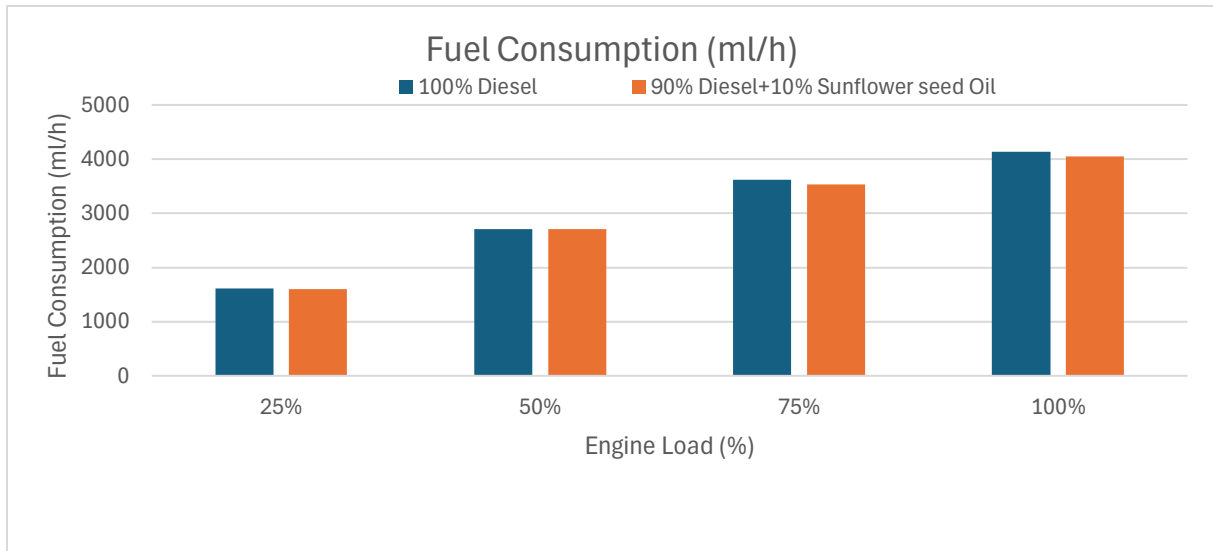


Figure 3. Comparison of Engine Fuel Consumption Across Different Fuel Types

According to the data presented in Figure 4, the use of fuel containing sunflower biodiesel results in reduced carbon monoxide (CO) emissions in the exhaust gases under all engine load conditions. This decrease is attributed to the inherently higher oxygen content of biodiesel due to its chemical structure. The oxygen present within the fuel promotes a more complete oxidation process during combustion, thereby naturally limiting CO formation. As engine load increases, the combustion process becomes more stable, and the additional oxygen supplied by the biodiesel enhances the conversion efficiency of CO to CO₂, making the reduction in emissions more pronounced. Therefore, the findings indicate that the use of biodiesel is an effective option for reducing carbon monoxide emissions, primarily due to its positive impact on combustion efficiency.

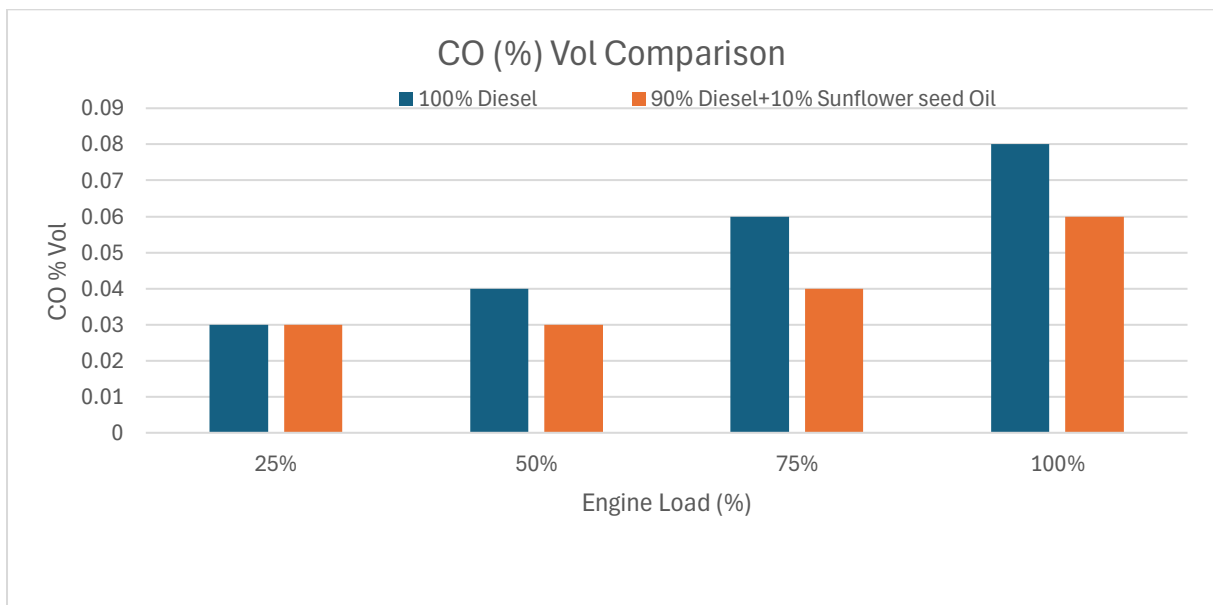


Figure 4. Comparison of Carbon Monoxide (CO) Emissions for Various Fuel Types

An examination of the data presented in Figure 5 shows that the use of biodiesel-blended fuel results in slight increases in nitrogen oxide (NO_x) emissions across all engine load levels. Although these increases remain relatively small when each load condition is evaluated individually, it can be stated that the rise in NO_x levels becomes more pronounced when the engine operates at full load (100%). The primary reason for this behavior is that the combustion characteristics of biodiesel tend to produce higher combustion temperatures compared to diesel fuel, and elevated temperature is one of the main factors directly promoting NO_x formation. As the in-cylinder temperature increases, the likelihood of oxygen and nitrogen reacting rises, thereby accelerating the rate of NO_x formation. This effect becomes even more significant under high-load conditions, where the engine operates with a denser air–fuel mixture and combustion temperature peaks intensify.

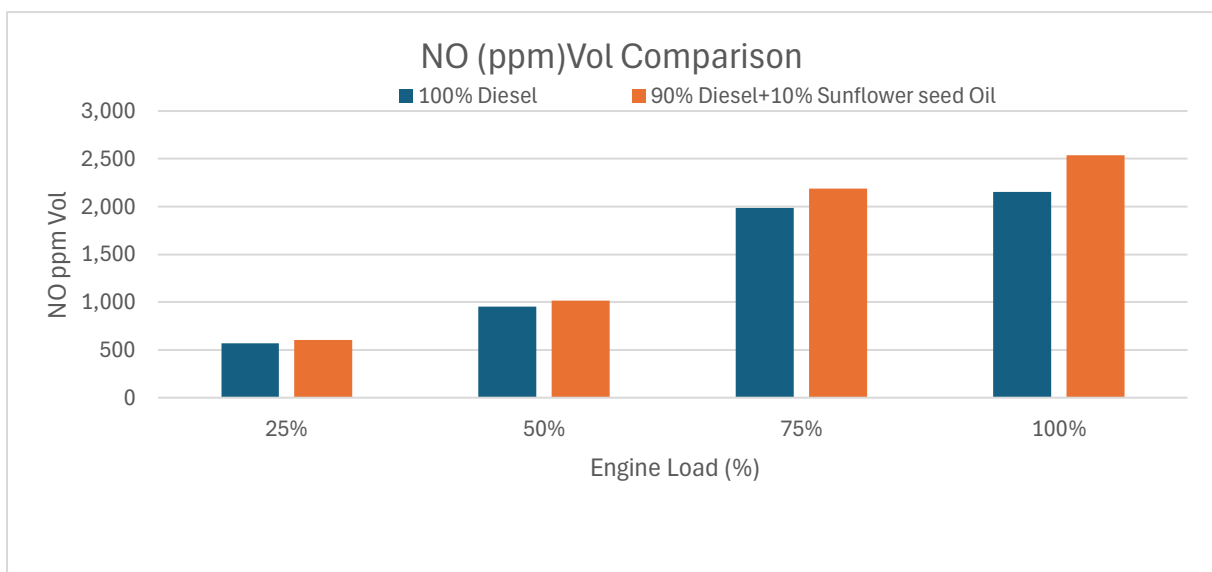


Figure 5. Comparison of Nitrogen Oxide (NO_x) Emissions Across Various Fuel Types

An examination of the harmful hydrocarbon (HC) values in the exhaust emissions shows, as presented in Figure 6, that the use of fuel containing sunflower biodiesel leads to a significant reduction in HC emissions. The primary reason for this decrease is the higher oxygen content of biodiesel in comparison with diesel fuel. This inherent oxygen facilitates a more complete combustion reaction in the combustion chamber, thereby reducing the formation of unburned hydrocarbons. Furthermore, the higher cetane number of biodiesel shortens the ignition delay and contributes to a more stable and controlled combustion process, making the decrease in HC emissions even more pronounced. This finding indicates that the addition of biodiesel can enhance combustion efficiency and result in a cleaner exhaust output from an environmental standpoint.

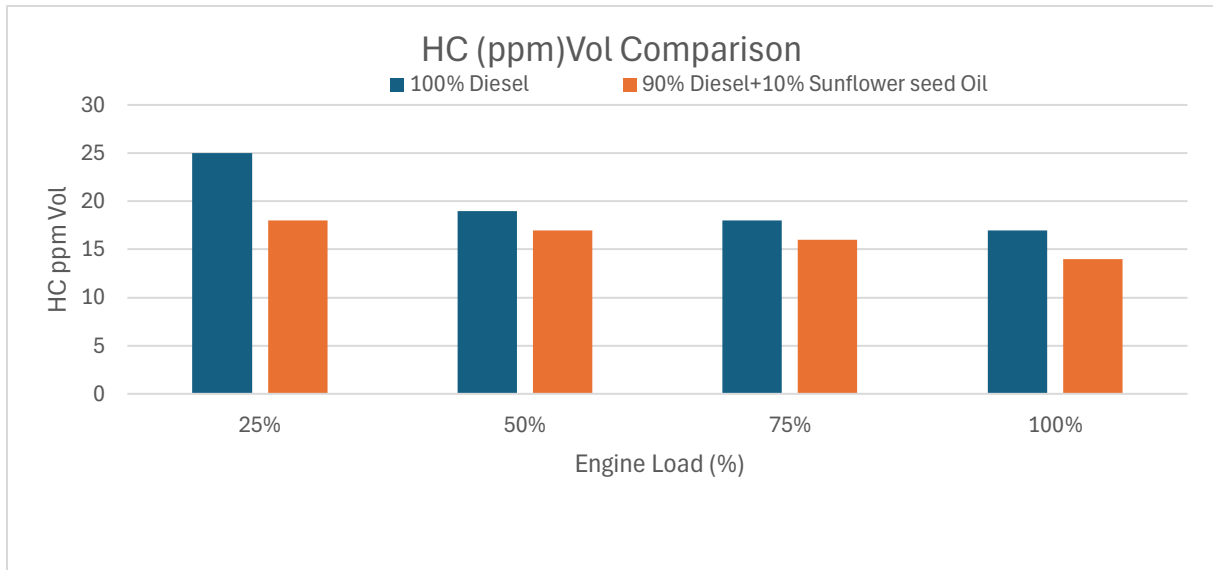


Figure 6. Comparison of Hydrocarbon (HC) Emissions by Fuel Types

CONCLUSION

In this study, the effects of a sunflower biodiesel blend on the performance and exhaust emissions of a single-cylinder diesel engine were experimentally investigated. The results demonstrated that the biodiesel blend did not adversely affect engine performance, with power outputs under various load conditions remaining largely comparable to those of conventional diesel fuel. This indicates that the tested blend ratio can be used without causing a significant loss in engine performance. Regarding fuel consumption, no notable differences were observed at low and medium load conditions, whereas a measurable reduction was achieved at high load. This improvement can be attributed to the higher oxygen content of biodiesel, which promotes more efficient and complete combustion, thereby enhancing overall fuel economy under demanding operating conditions. In terms of exhaust emissions, the biodiesel blend led to significant reductions in CO and HC emissions, primarily due to improved combustion characteristics and the higher cetane number of biodiesel. These factors contribute to a more stable combustion process and cleaner exhaust gases. However, a slight increase in NO_x emissions was observed, which is likely associated with higher in-cylinder temperatures during combustion. This effect became more pronounced at higher loads.

Overall, while the use of biodiesel presents clear environmental advantages and supports cleaner combustion, the increase in NO_x emissions suggests that additional emission control strategies may be required to fully optimize its environmental performance.

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