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DETERMINATION OF THE EFFECTS OF SAFFLOWER BIODIESEL BLEND RATIOS ON THE PERFORMANCE AND EMISSIONS OF A SINGLE-CYLINDER INDUSTRIAL DIESEL ENGINE

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Abstract: The gradual depletion of fossil fuel reserves, combined with increasing economic constraints and growing environmental concerns, has substantially intensified the demand for alternative energy sources. Biodiesel produced from vegetable oils has emerged as a prominent renewable fuel due to its sustainable nature, low environmental impact, and high compatibility with conventional compression ignition engines. In this context, safflower oil provides significant techno-economic advantages owing to its high unsaturated fatty acid content, low viscosity, and broad agronomic adaptability. This study experimentally investigates the effects of blending safflower seed oil with conventional diesel fuel at volumetric ratios of 5 and 15% on the performance and exhaust emission characteristics of a single-cylinder diesel engine. The results indicate that the 5% safflower diesel blend maintains engine power output comparable to that of pure diesel across all load conditions, whereas the 15% blend leads to a slight reduction in brake power. Emission measurements reveal a minor decrease in carbon monoxide (CO) concentrations for both blend ratios, while nitrogen oxide (NO_x) emissions increase due to altered combustion behavior and elevated in-cylinder temperatures. Load-dependent performance analysis shows that the brake-specific fuel consumption remains nearly unchanged for the 5% blend, whereas the 15% blend results in a moderate increase. Overall, the findings suggest that blending 5% safflower seed oil with conventional diesel achieves an optimal balance between engine performance and emission characteristics, representing a technically advantageous option for diesel engine operation.

Keywords: Energy, Diesel engine, Safflower oil biodiesel, Exhaust emissions

INTRODUCTION

Rapid advancements in technology and the increasing global focus on environmental sustainability have made profound changes in the energy sector unavoidable. The limited availability of conventional energy resources, along with the escalating environmental consequences of their use, necessitates a shift toward more sustainable energy production and consumption strategies (Doğan et al., 2024). Reflecting this trend, the automotive industry has placed greater emphasis on alternative fuels aimed at reducing dependency on traditional petroleum-based fuels. Among these, innovative diesel blends incorporating various additives are considered promising solutions to address future energy demands. Despite these efforts, fossil fuels continue to dominate global energy consumption (Kesharvani et al., 2023).

Diesel engines, in particular, are widely employed in commercial transport, agriculture, and industrial sectors due to their high fuel efficiency, reliability, and long operational life. However, the environmental impact of petroleum-derived diesel and the ongoing depletion of fossil fuel reserves have prompted intensified research into sustainable and eco-friendly alternatives (Krishnamoorthi et al., 2024). Biodiesel has emerged as a notable candidate in this regard, offering renewable production routes and a comparatively lower environmental footprint (Rajak et al., 2023). It can be synthesized from diverse organic feedstocks, including vegetable oils, animal fats, microalgal oils, and waste oils. Extensive research has investigated biodiesel utilization in diesel engines, focusing on how different blend ratios affect engine performance and emissions. Findings indicate that pure biodiesel (100%) can be used without major engine modifications, highlighting its potential as a large-scale sustainable energy source (Chen et al., 2024). Additionally, biodiesel has been shown to reduce exhaust emissions, supporting its role as an environmentally compatible alternative for conventional diesel engines.

Diesel-powered internal combustion engines also play a critical role in construction and auxiliary machinery used in road and bridge projects. While their widespread adoption boosts productivity and economic growth, it simultaneously underscores the need for more efficient and cleaner technologies (Zheng et al., 2008; Kanimozhi et al., 2022). Experimental studies on safflower oil biodiesel, enhanced with CeO₂ nanoparticles and hydrogen, have demonstrated improvements in engine power, torque, and thermal efficiency, along with reductions in CO and CO₂ emissions. Minor increases in NO_x were observed, suggesting a need for careful optimization (Wang et al., 2023). Biodiesel production parameters, such as methanol-to-oil ratio, catalyst concentration, reaction temperature and time, and stirring speed, critically affect yield. Optimal conditions for safflower oil biodiesel have been reported as a 16:1 molar ratio, 4 g KOH catalyst, 60 °C reaction temperature, 4 hour reaction time, and 700 rpm stirring, achieving approximately 90% yield. Subsequent blends, including B20, B30, and B40, showed that the B20 blend achieved brake thermal efficiency comparable to conventional diesel while significantly reducing CO, HC, and smoke emissions. However, NO_x emissions were slightly elevated due to the higher cetane number of neat biodiesel (Asokan et al., 2021). High viscosity remains a challenge for biodiesel, influencing combustion, performance, and emissions.

Studies on injection timing in safflower methyl ester (SAME)-fueled diesel engines revealed that retarded injection reduced NO_x, CO, and smoke emissions but slightly lowered brake thermal efficiency, while advanced timing increased NO_x emissions with marginal smoke reduction. These results underscore that careful injection timing can optimize the trade-off between performance and emissions, confirming the practical potential of safflower methyl ester as an alternative fuel for transportation applications (Rajendran et al., 2023).

In contrast to the existing literature, the present study systematically investigates the effects of varying blend ratios of safflower seed oil-based biodiesel on diesel engine performance and exhaust emissions. By identifying optimal blending ratios, this work provides valuable insights that contribute to both improved engine efficiency and enhanced environmental sustainability.

MATERIAL AND METHODS

In this study, commercial diesel fuel and biodiesel blends derived from safflower seed oil were used as test fuels. Safflower seed oil was blended with diesel fuel on a volumetric basis. Within the scope of the experimental investigations, two different blends were prepared: 5% safflower seed oil 95% diesel (B5) and 15% safflower seed oil 85% diesel (B15). The homogeneity of the blends was ensured using a mechanical stirrer at ambient temperature, and no phase separation or sedimentation was observed during the experiments. Neat diesel fuel was used as the reference fuel for comparison purposes. The experiments were conducted on a single-cylinder, four-stroke, direct-injection diesel engine, as shown in Figure 1. No modifications were made to the engine, allowing the direct assessment of the effects of safflower seed oil-based biodiesel blends on engine performance.

Engine load was gradually increased using a dynamometer, and measurements were recorded once steady-state operating conditions were achieved at each load level. For each fuel type, tests were carried out at engine load levels of 25, 50, 75 and 100%, and the corresponding engine performance parameters and exhaust emissions were recorded. All tests were performed after the engine reached its normal operating temperature, with baseline measurements first obtained using neat diesel fuel. The same experimental procedure was subsequently repeated for the B5 and B15 blends. To ensure data consistency and repeatability, all measurements were conducted under constant ambient conditions. Engine performance was evaluated in terms of brake power, brake specific fuel consumption (BSFC), and load-dependent variations in power output. Fuel consumption was determined by measuring the amount of fuel consumed over a specified time interval. Using the measured data, the performance parameters for each fuel were calculated and compared with those of neat diesel fuel. Performance and emission results were analyzed as a function of engine load, enabling a systematic evaluation of the influence of safflower seed oil content on engine behavior.



Figure 1. Experimental setup of the diesel engine used for performance testing

Table 1. Technical specifications of the diesel engine used in the experimental investigation

General Characteristics	Technical Specification
Engine type	Erin motor base model
Number of valves	4
Continuous power (kw/rpm)	11.5/1500
Bore (mm)	108
Stroke (mm)	127
Combustion system	Direct injection
Compression ratio	14.6 : 1
Engine cooling	Water
Weight (kg)	157

RESULTS AND DISCUSSION

The experimental results obtained in this study comprehensively demonstrate the effects of incorporating safflower seed oil into diesel fuel at blend ratios of 5% safflower seed oil 95% diesel (B5) and 15% safflower seed oil 85% diesel (B15) on engine performance and exhaust emission characteristics. An examination of the power output data derived from the engine tests indicates that the use of both biodiesel blends at various engine load conditions yields power values that are very close to those obtained with neat diesel fuel. This finding strongly supports the feasibility of the proposed biodiesel blends as alternative engine fuels and confirms that they do not impose a significant adverse effect on engine power output. Furthermore, the comparable performance of the B5 and B15 blends to that of diesel fuel under low and medium load conditions suggests that the addition of safflower seed oil does not markedly deteriorate engine operating efficiency. These results indicate that the engine can operate reliably with these blends across a wide range of loading conditions, highlighting the practical applicability of safflower seed oil-based biodiesel blends without compromising engine performance.

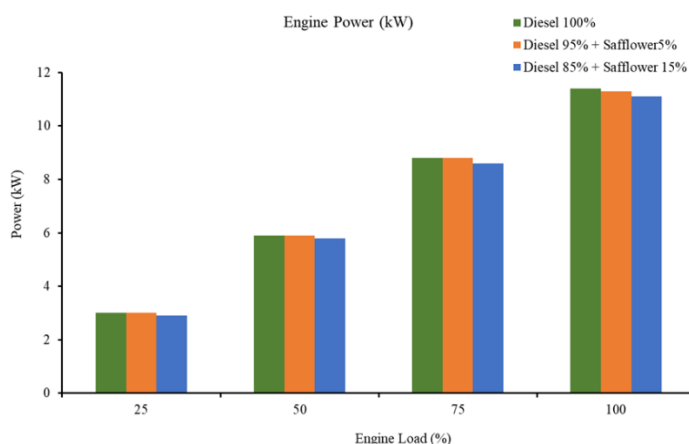


Figure 2. Comparative analysis of engine power output for different biodiesel-diesel blends

As illustrated in Figure 2, a comparison of the power outputs measured at 25, 50 and 75% engine load conditions using conventional diesel fuel and those obtained with 5% safflower seed oil-based biodiesel (B5) reveals that the engine power values are largely comparable

for both fuels. Only at full load (100%) did the B5 blend exhibit a very slight reduction in engine power of approximately 0.1 kW, indicating a negligible impact on overall performance. In contrast, when the engine was fueled with 15% safflower seed oil-based biodiesel (B15), a power reduction of about 0.2 kW was observed at 25, 50, and 75% load conditions. At 100% engine load, the decrease in power reached approximately 0.3 kW. These results suggest that although the reduction in engine performance remains limited, it becomes more noticeable with increasing biodiesel blending ratio. As also evident in Figure 2, the addition of 5% safflower seed oil to conventional diesel fuel does not result in a significant change in engine power, and the power output is largely preserved when compared with neat diesel operation.

According to the data presented in Figure 3, when the engine was fueled with 5% safflower seed oil-based biodiesel (B5), the fuel consumption values at all applied load conditions were found to be largely comparable to those obtained with conventional diesel fuel. This observation indicates that a low biodiesel blending ratio does not adversely affect the fuel efficiency of the engine. In contrast, the use of 15% safflower seed oil-based biodiesel (B15) resulted in an increase in fuel consumption depending on the engine load. The measurements revealed an increase in consumption ranging approximately from 14 mL/h to 108 mL/h.

These findings suggest that a low biodiesel blending ratio (5%) is more favorable in terms of fuel consumption, providing a more balanced trade-off between engine performance and fuel efficiency. The observed differences can primarily be attributed to the lower energy content, particularly the lower heating value, of biodiesel compared with conventional diesel fuel. In addition, the distinct physical and chemical properties of biodiesel are expected to influence in-cylinder combustion processes, air fuel mixing, and injection characteristics, thereby leading to variations in fuel consumption. Within this context, it can be concluded that low-percentage biodiesel blends can be applied without compromising engine performance and fuel efficiency, whereas higher blending ratios may lead to increased fuel consumption.

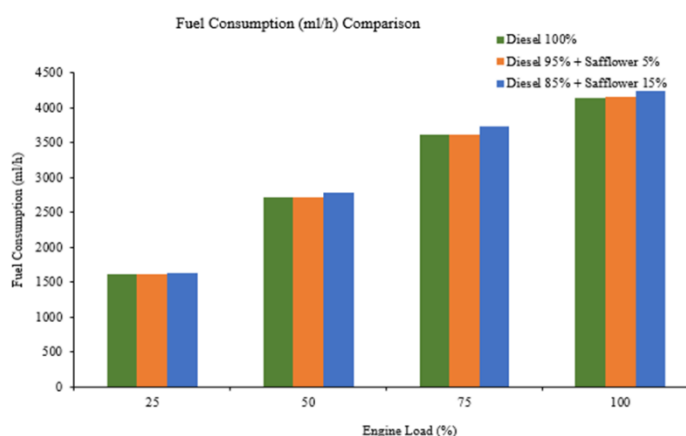


Figure 3. Comparative assessment of engine fuel consumption for various biodiesel-diesel blends

Based on the data presented in Figure 4, the influence of safflower seed oil-based biodiesel blends on carbon monoxide (CO) emissions in the exhaust gases was evaluated, and a pronounced reduction in CO emissions was observed at all engine load conditions. In

particular, the addition of 15% safflower seed oil biodiesel (B15) to conventional diesel fuel led to a substantial decrease in CO emissions, indicating that biodiesel promotes cleaner combustion processes within the engine. However, when the effects on engine power and fuel consumption are considered simultaneously, the lower safflower seed oil blending ratio (5%, B5) emerges as a more balanced option in terms of overall engine performance and fuel efficiency. In other words, although both blends demonstrate a clear potential for reducing CO emissions, the B5 blend provides a more favorable operational profile when emission reduction is evaluated together with performance and consumption parameters.

In conclusion, the use of safflower seed oil-based biodiesel can be regarded as a viable alternative fuel for diesel engines, contributing to environmental sustainability through the reduction of carbon monoxide emissions.

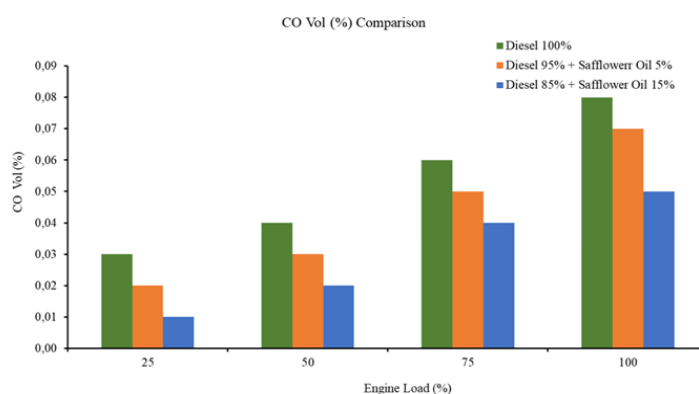


Figure 4. Comparative evaluation of carbon monoxide (CO) emissions for different biodiesel-diesel blends

These findings further support the view that biodiesel is not only a renewable energy source but also an environmentally friendly fuel option capable of mitigating exhaust emissions. According to the data presented in Figure 5, the use of biodiesel-blended fuels resulted in a limited increase in nitrogen oxides (NO_x) emissions at all engine load conditions. These increases ranged approximately between 52 and 145 ppm across different loads, and the overall emission levels were found to remain within acceptable limits.

The primary reason for the observed rise in NO_x emissions is attributed to the higher in-cylinder temperatures attained during the combustion of biodiesel compared with conventional diesel fuel, which inherently promotes NO_x formation. The more pronounced increase in NO_x emissions at higher engine loads emerges as a critical parameter that must be carefully considered when evaluating the environmental performance of biodiesel fuels. This finding suggests that the widespread application of biodiesel in diesel engines may require additional technical measures or emission mitigation strategies to effectively control NO_x emissions. In this context, the integration of appropriate combustion optimization techniques and emission control technologies is essential to enhance the environmental sustainability of biodiesel fuels while maintaining satisfactory engine performance.

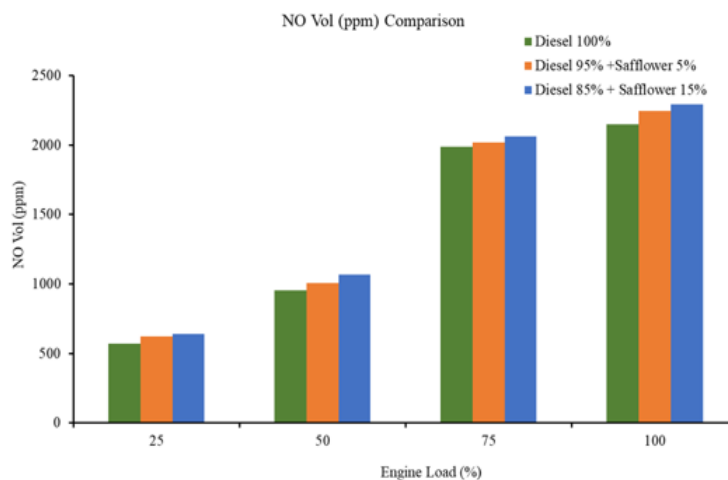


Figure 5. Comparative evaluation of nitrogen oxide (NO_x) emissions for different biodiesel-diesel blends

CONCLUSION

This study systematically evaluated the effects of safflower seed oil-based biodiesel additions (5 and 15%) on the performance and exhaust emissions of a single-cylinder diesel engine. The results showed that the 5% biodiesel blend (B5) produced engine power values nearly identical to those of neat diesel fuel at 25, 50, and 75% load conditions, with only a negligible reduction of 0.1 kW observed at full load. In contrast, the 15% biodiesel blend (B15) led to a limited but noticeable decrease in engine power as the load increased, reaching a maximum reduction of 0.3 kW at 100% load, indicating that higher biodiesel blending ratios may slightly affect engine performance.

Fuel consumption measurements revealed that the B5 blend achieved consumption levels comparable to conventional diesel across all load conditions. However, the B15 blend resulted in an increase in fuel consumption ranging from 14 to 108 mL/h depending on engine load, primarily due to the lower heating value and distinct physicochemical properties of biodiesel. Emission analyses demonstrated that biodiesel blending significantly reduced carbon monoxide (CO) emissions at all loads, with the B15 blend providing the greatest reduction. Nevertheless, when performance and fuel consumption were considered together, the B5 blend offered a more balanced operating profile. A moderate increase in nitrogen oxides (NO_x) emissions (52-145 ppm) was observed, particularly at higher loads, which can be attributed to the higher in-cylinder temperatures associated with biodiesel combustion. This finding highlights the need for appropriate emission control or combustion optimization strategies to mitigate NO_x emissions.

Overall, the results indicate that low-percentage (5%) safflower seed oil-based biodiesel can be utilized without compromising engine performance or fuel efficiency, while effectively reducing CO emissions and enhancing environmental sustainability. Although higher biodiesel content (15%) slightly affects power and fuel consumption, it still offers notable emission benefits. These findings support the technical feasibility and environmental potential of safflower seed oil-based biodiesel as a sustainable and eco-friendly alternative fuel for diesel engines.

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REFERENCES

- Asokan, M.A., Prabu, S.S., Prathiba, S., Mishra, S., Mittal, H., Verma, V. (2021). Emission and performance behavior of safflower oil biodiesel/diesel blends in DI diesel engine. *Materials Today: Proceedings*, 46, 8266-8270.
- Chen, Y., Zhang, J., Zhang, Z., Zhang, B., Hu, J., Zhong, W., Ye, Y. (2024). A comprehensive review of stability enhancement strategies for metal nanoparticle additions to diesel/biodiesel and their methods of reducing pollutants. *Process Safety and Environmental Protection*, 183, 1258-1282.
- Doğan, B., Yeşilyurt, M.K., Yaman, H., Korkmaz, N., Arslan, A. (2024). Comprehensive analysis of a CI engine fuelled with blends of diesel fuel/safflower seed oil biodiesel/TiO₂ or SiO₂ nanoparticles produced by green synthesis technique. *Process Safety and Environmental Protection*, 191, 417-438.
- Kanimozhi, B., Alsehli, M., Elfasakhany, A., Veeman, D., Balaji, S., Kumar, T.P., Sekar, M. (2022). Effects of oxyhydrogen on the CI engine fueled with the biodiesel blends: A performance, combustion and emission characteristics study. *International Journal of Hydrogen Energy*, 47(88), 37668-37676.
- Kesharvani, S., Dwivedi, G., Nath Verma, T., Verma, P. (2023). Sustainable alternative fuel derived from different feedstocks and its comparative life cycle assessment. *Sustain Energy Technol Assessments*, 57, 103159.
- Krishnamoorthi, T., Sampath, S., Saravanamuthu, M., Vengadesan, E., Dillikannan, D. (2024). Combined influence of thermal barrier coating and nanoparticle on performance and emissions of DI diesel engine fueled with neat palm oil biodiesel: An experimental, statistical and energy and exergy analysis. *Process Safety and Environmental Protection*, 186, 274-288.
- Rajak, U., Reddy, V.N., Ağbulut, Ü., Sarıdemir, S., Afzal, A., Verma, T.N. (2023). Modifying diesel fuel with nanoparticles of zinc oxide to investigate its influences on engine behaviors. *Fuel*, 345, 128196.
- Rajendran, S., Dhairiyasamy, R., Jaganathan, S., Murugesan, S., Muthusamy, R., Periannan, S. *et al.* (2023). Effect of injection timing on combustion, emission and performance characteristics of safflower methyl ester in CI engine. *Results in Engineering*, 20, 101599.
- Wang, J., Sun, H., Devanesan, S., Alsahi, M.S., Anderson, A., Daniel, F., Praveenkumar, T.R. (2023). Performance and emission characteristics of safflower oil biodiesel blended with nanoparticles and hydrogen on diesel engines of road and bridge machinery. *Fuel*, 352, 128946.
- Zheng, M., Mulenga, M.C., Reader, G.T., Wang, M., Ting, D.S., Tjong, J. (2008). Biodiesel engine performance and emissions in low temperature combustion. *Fuel*, 87(6), 714-722.