Biodiesel Blends for Sustainable Transportation: Comprehensive Performance, Emission and Fuel Characteristics Analysis of Hybrid with Nanoparticles

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Abstract:- This study presents an in-depth evaluation of the performance, emission characteristics, and fuel quality of many hybrid biodiesel blends, with a focus on the leading candidate, WCO + Karanja with Nanoparticles (NP). Comprehensive engine testing reveals better braking power and thermal efficiency, as well as reduced CO, CO_2, and NO_x emissions for WCO + Karanja with NP. The fuel characteristics analysis demonstrates that this blend has a favourable density, flash point, fire point, kinematic viscosity, and a high calorific value, establishing it as a sustainable and efficient alternative fuel for internal combustion engines. The findings contribute to the current debate over environmentally acceptable transportation fuels.

Keywords*: Biodiesel blends, Engine performance, Emission characteristics, Fuel properties, Hybrid Biodiesel*.

1. Introduction

1.1. Background on Biodiesel and its Significance

Biodiesel, a sustainable and biodegradable fuel, is created from organic sources such as vegetable oils, animal fats, and waste cooking oils. As worldwide worries about environmental deterioration and the depletion of fossil fuels mount, biodiesel has emerged as a possible alternative to regular petroleum-based diesel. Its benefits are manifold: it minimises greenhouse gas emissions, lessens the dependency on non-renewable resources, and provides possible economic advantages by employing locally available materials. Moreover, biodiesel's compatibility with current diesel engines gives it a realistic and immediate answer to some of the urgent energy concerns.

1.2. The Need for Hybrid Biodiesel Blends

While biodiesel on its own offers numerous advantages, hybrid biodiesel blends—combinations of different biodiesel sources—present an opportunity to optimize fuel properties and performance. By blending different feedstocks, like waste cooking oil and Karanja oil, researchers can tailor the fuel's characteristics to specific applications or environmental conditions. Such hybrid blends can potentially offer improved combustion efficiency, reduced emissions, and enhanced fuel stability, making them a focal point of contemporary biodiesel research.

1.3. Energy scenario in India

India confronts a huge energy dilemma, with its oil reserves predicted to last just for another 25 years. This underscores the urgent need to develop and execute strategies concentrating on alternate energy sources. Recent research suggests that oil consumption and supply in India might triple from 1990 to 2020[3]. Presently, India generates just 30% of its entire petroleum requirements, importing the other 70% at an annual cost of roughly Rs. 80,000 crores. The implementation of a 5% biodiesel mix with diesel has the potential to save around INR 4000 crore. Projections predict that by 2015, India may generate 288 metric tonnes of biodiesel, meeting 42% of the nation's fuel use. In response, the Planning Commission of India began a bio-fuel initiative in approximately 200 districts across 18 states, suggesting Jatropha and Karanja for biodiesel production [4–18].

1.4. Needs of alternative energy fuel

The need for alternate energy sources is highlighted by India's expanding population, economic progress, and increased individual energy use. The dependence on imported fuel oil is producing economic imbalances, growing costs, and problems. Moreover, fossil fuel emissions are considerably contributing to climate change and atmospheric alterations [2]. Despite attempts at conservation, the need for energy continues unabated, prompting the discovery of alternate energy alternatives.

Biodiesel, a viable alternative, can be blended with fossil fuels in varying proportions to create biodiesel mixtures. It's compatible with CI engines without the need for modifications [19]. Studies show that using 100% biodiesel instead of a 20% blend could reduce air-toxics by 92%, with a 20% blend also significantly lowering emissions like hydrocarbons, carbon monoxide, and smoke [20-22].

Research is ongoing in producing biodiesel from both low and high free fatty acid (FFA) oils. The challenge lies in securing enough vegetable oils for biodiesel production, dependent on geographical and agricultural factors. This study focuses on producing biodiesel using a mix of two or more oils, both in pre-mix and post-mix conditions. The pre-mix approach involves blending raw oils with similar properties before biodiesel production, while post-mix involves blending different types of biodiesels. This strategy aims to mitigate the availability issues of biodiesels and enhance engine performance with minimal modifications. Both pre-mix and post-mix biodiesels were evaluated in terms of their characteristics, performance, and emissions, and compared with pure diesel and ASTM standards.

While there has been substantial study on the usage of biodiesel blends in diesel engines, most studies have focussed on single biodiesel mixes. Hybrid mixes, particularly pre-mixed and post-mixed, have received scant attention. Karanja oil, commonly touted as a diesel alternative, was used for this experiment, along with waste cooking oil. The research initially studied the physio-chemical parameters of these hybrid test fuels, noticing increased kinematic viscosity and calorific value compared to separate biodiesel mixes. Subsequent testing focused on engine performance and exhaust emissions of the hybrid biodiesel mixes, comparing these findings with normal diesel fuel.

2. Materials and Methods

2.1. Description of the Biodiesel Blends Used

The biodiesel blends utilized in this study were derived from a combination of Waste Cooking Oil (WCO) and Karanja oil. These oils were mixed in a 50:50 ratio to produce a hybrid biodiesel. Following the blending, a transesterification process was employed to convert the mixed oils into biodiesel. Various blends were prepared for experimentation, including B25, B50, B75, and B100.

2.2. Experimental Setup and Conditions

The studies were done on an engine running at a constant speed of 1500 rpm. The engine's timing was continuously maintained at 23° BTDC (before top dead centre) for both diesel and biodiesel fuels. The injection pressure was changed across four levels: 160 bar, 180 bar, 200 bar, and 220 bar. Whenever there was a change in the gasoline type, the fuel lines were thoroughly cleaned, and the engine was allowed to run for 30 minutes, assuring it stabilized under the new circumstances. Emissions from the engine, comprising CO, HC, CO_2, O_2, and NO_x, were painstakingly measured using the AVL DIG AS 444 gas analyzer, fitted with a DIGAS SAMPLER at the exhaust.

3. Results and Discussions

3.1. Fuel Characteristics

Table 1: Fuel characteristics comparison of different hybrid biodiesel from other researchers

	Cotton seed + Eucalyptus	Karanja + mahua (Pre-Mix)	Karanja + mahua (Post-Mix)	WCO + Soya Bean Oil	H100*
Density (kg/m^3)	872	859.7	853.1	885.7	874.3
Flash Point (℃)	142	137	135	150	142
Fire Point (℃)	154	149	146	163	155
Kinematic Viscosity (mm^2/s)	5.2	3.43	3.22	4.411	3.67
Calorific Value (MJ/kg)	39.5	41.13	42.02	41.5	42.42

*Hybrid oil used for present work

The fuel characteristics comparison reveals distinct variations among different hybrid biodiesel formulations, each with unique properties that influence their applicability. WCO + Karanja with Nanoparticles demonstrates promising characteristics, with a density of 874.3 kg/m^3 falling within a reasonable range, contributing to its potential for efficient combustion. The flash point and fire point of 142 ℃ and 155 ℃, respectively, are comparable to other biodiesel blends, indicating good ignition properties and safety margins.

Additionally, WCO + Karanja with NP exhibits a kinematic viscosity of 3.67 mm^2/s, suggesting favourable flow characteristics for use in engines. The calorific value of 42.42 MJ/kg is relatively high, signifying a substantial energy content, which is crucial for optimal engine performance. These features collectively position WCO + Karanja with Nanoparticles as a well-balanced biodiesel blend, offering both efficient combustion properties and high energy density.

Comparatively, its fuel characteristics, combined with superior engine performance and reduced emissions, highlight the multifaceted benefits of WCO + Karanja with NP. This biodiesel blend emerges as a promising candidate for sustainable energy solutions, demonstrating a harmonious balance between physical properties and environmental performance in the pursuit of cleaner and more efficient fuels for future applications.

3.2. Engine Performance

The performance results across various hybrid biodiesels reveal significant differences in key metrics. In comparison to other biodiesel blends, WCO + Karanja with Nanoparticles stands out with a Brake Power (BP) of 3.4 kW, surpassing most counterparts. Additionally, its Brake Thermal Efficiency (BTHE) of 26.15% positions it competitively, indicating effective energy conversion. The Brake Specific Fuel Consumption (BSFC) of 0.23 kg/kW-h is noteworthy, reflecting efficient fuel utilization. This suggests that the incorporation of Karanja biodiesel with nanoparticles enhances engine performance, demonstrating higher power output, improved thermal efficiency, and lower fuel consumption compared to other hybrid biodiesel formulations. These findings underscore the potential of WCO + Karanja with Nanoparticles as a promising and efficient biodiesel blend for sustainable and high-performance engine applications.

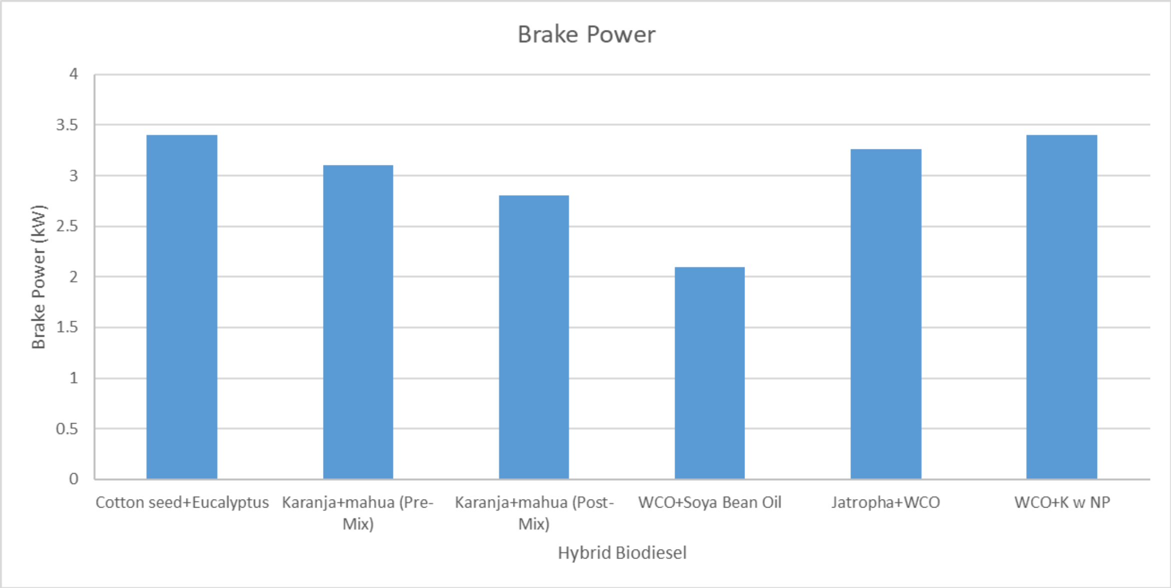

Figure 1: Graphical representation of brake power for different hybrid biodiesel

This graph illustrates the variation in Brake Power among different hybrid biodiesel blends. WCO + Karanja with Nanoparticles (3.4 kW) exhibits the highest power output, outperforming other biodiesel formulations. The vertical bars represent each biodiesel blend, emphasizing the superior performance of WCO + Karanja with Nanoparticles in terms of Brake Power.

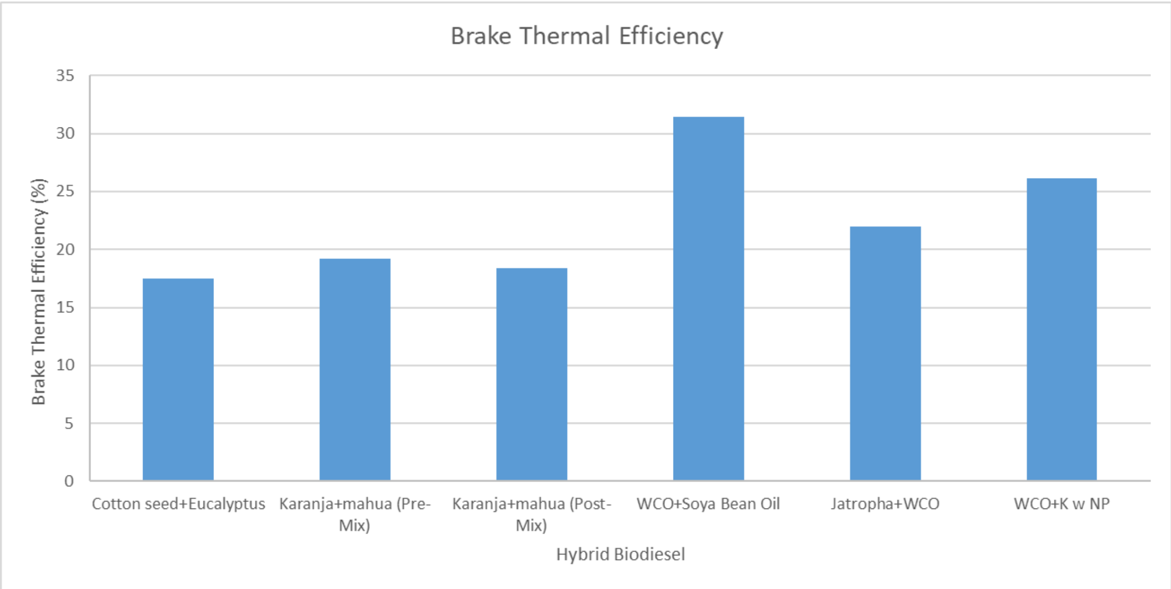

Figure 2: Graphical representation of brake thermal efficiency for different hybrid biodiesel

In this graph, Brake Thermal Efficiency is compared across various hybrid biodiesels. WCO + Karanja with Nanoparticles (26.15%) stands out with a notable BTHE, showcasing its efficiency in converting fuel energy into mechanical work. Each bar corresponds to a specific biodiesel blend, highlighting the enhanced thermal efficiency of WCO + Karanja with Nanoparticles.

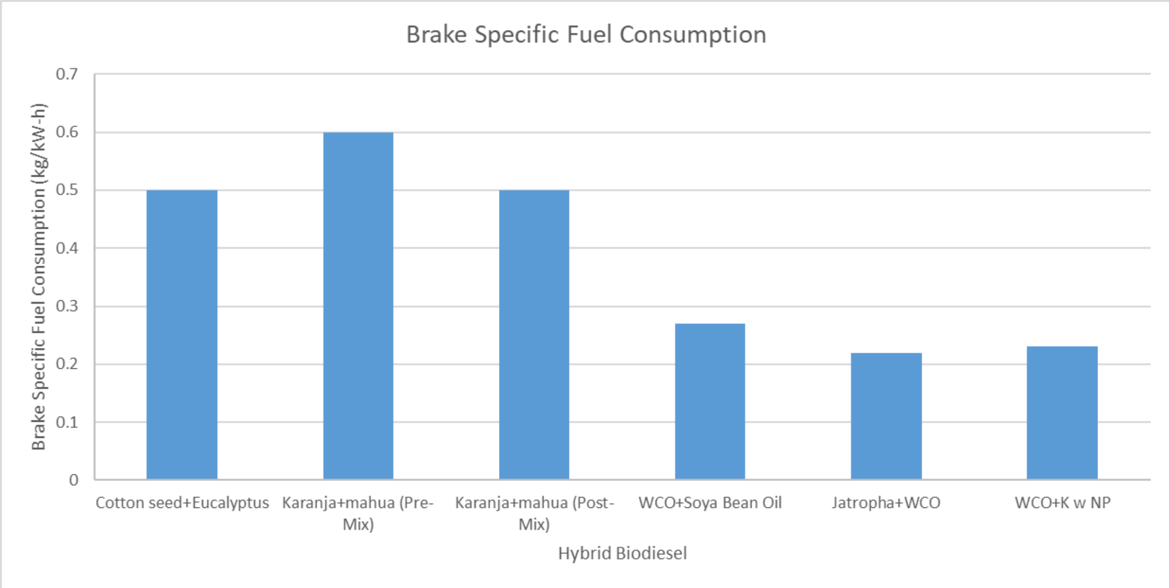

Figure 3: Graphical representation of brake specific fuel consumption for different hybrid biodiesel

The graph illustrates the Brake Specific Fuel Consumption of different biodiesel blends. WCO + Karanja with Nanoparticles (0.23 kg/kW-h) demonstrates lower fuel consumption, signifying efficient fuel utilization. The graph visually represents the comparative BSFC values, emphasizing the economic and environmental advantages of the WCO + Karanja with Nanoparticles biodiesel blend.

3.3. Emission Characteristics

The emission results underscore the environmental advantages of WCO + Karanja with Nanoparticles compared to other hybrid biodiesel formulations. With significantly lower Carbon Monoxide (CO) and Carbon Dioxide (CO_2) emissions at 0.74% Vol and 0.78% Vol, respectively, WCO + Karanja with NP demonstrates its potential for reduced air pollution. Moreover, its NO_x emissions at 320 ppm indicate a moderate impact on nitrogen oxide levels, positioning it favourably against formulations with substantially higher NO_x emissions. This suggests that WCO + Karanja with Nanoparticles not only excels in engine performance, as evidenced by higher Brake Power and Brake Thermal Efficiency, but also stands out as an environmentally conscientious choice, aligning both performance and emission efficiency in a sustainable biodiesel blend.

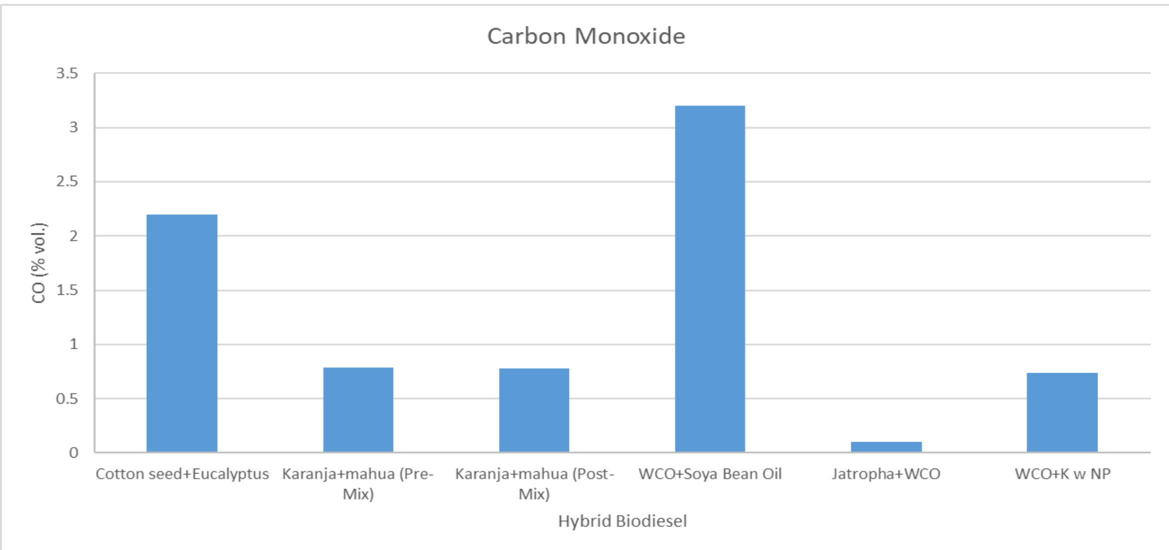

Figure 4: Graphical representation of carbon monoxide emission for different hybrid biodiesel

This graph visually represents the variation in CO emissions across different hybrid biodiesel blends. WCO + Karanja with Nanoparticles exhibits the lowest CO emissions at 0.74% Vol, emphasizing its cleaner combustion and reduced carbon monoxide impact compared to other biodiesel formulations. Each bar corresponds to a specific biodiesel blend, providing a clear visual comparison of CO emissions.

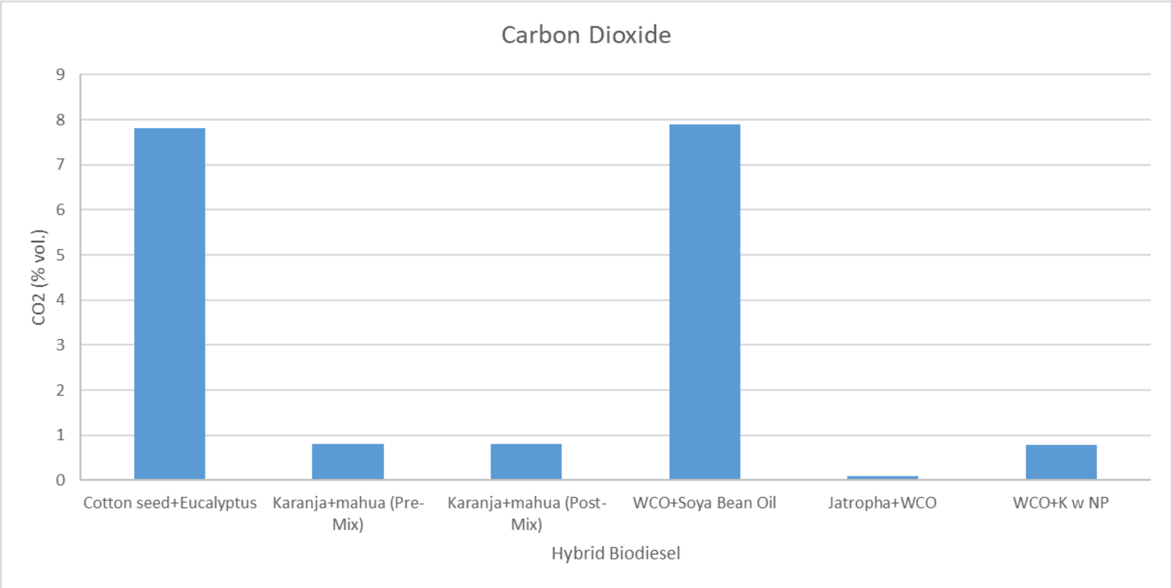

Figure 5: Graphical representation of carbon dioxide emission for different hybrid biodiesel

In this graph, the CO_2 emissions of various hybrid biodiesels are depicted. WCO + Karanja with Nanoparticles stands out with the lowest CO_2 emissions at 0.78% Vol, indicating its environmentally friendly nature and efficient combustion. The graph visually emphasizes the comparative CO_2 levels, highlighting the reduced carbon dioxide impact of WCO + Karanja with Nanoparticles.

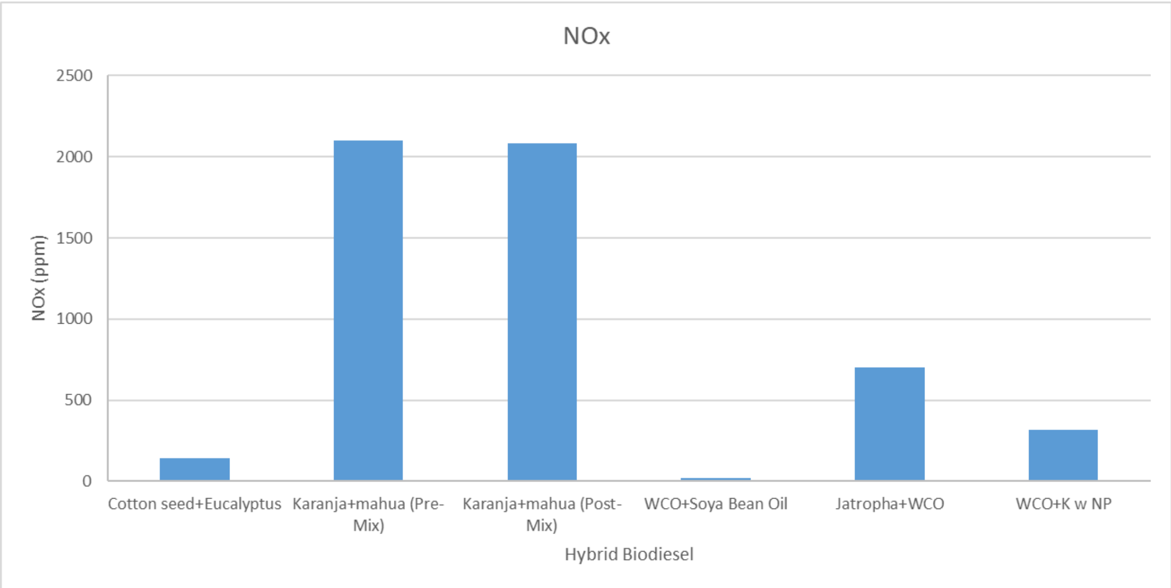

Figure 6: Graphical representation of NO_x emission for different hybrid biodiesel

The third graph illustrates NO_x emissions across different biodiesel blends. WCO + Karanja with Nanoparticles demonstrates moderate NO_x emissions at 320 ppm, positioning it favourably in terms of nitrogen oxide release. Each bar in the graph corresponds to a specific biodiesel blend, providing a visual representation of NO_x emissions for comparative analysis.

4. Conclusion

The comprehensive study and comparative analysis of various hybrid biodiesel formulations have provided valuable insights into their performance, emission characteristics, and fuel properties. Among the biodiesel blends investigated, Hybrid oil with Nanoparticles emerged as a standout candidate, exhibiting superior engine performance, notably higher Brake Power and Brake Thermal Efficiency, and reduced emissions, including lower levels of CO, CO_2, and NO_x. These findings underscore the promising potential of the Hybrid Biodiesel as an environmentally conscious and efficient alternative fuel for internal combustion engines. Furthermore, the fuel characteristics of hybrid oil, including its favourable density, flash point, fire point, kinematic viscosity, and high calorific value, contribute to its overall suitability for engine applications. The well-balanced physical and energy properties position this biodiesel blend as a promising solution for sustainable transportation and energy sectors. The study's comprehensive nature provides valuable insights for researchers, policymakers, and industries seeking environmentally friendly and high-performance biodiesel options. As the global pursuit of cleaner energy intensifies, the results presented in this study contribute significantly to the ongoing discourse on the development and utilization of biodiesel blends for a more sustainable future.

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