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Mitigating Environmental Impact: A Study on the Performance and Emissions of a Diesel Engine Fueled with Biodiesel Blend

Anant Sidhappa Kurhade[1,2]*, P. Bhavani[3], Shital Anant Patil[4], Nilesh R. Kolhalkar[5], Kolluri Srinivasa Chalapathi[6], Prashant Ashok Patil[1] and Shital Yashwant Waware[1]

[1]Department of Mechanical Engineering, Dr. D. Y. Patil Institute of Technology, Pimpri, Pune - 411018, Maharashtra, India; a.kurhade@gmail.com

[2]School of Technology and Research, Dr. D. Y. Patil Dnyan Prasad University, Pimpri, Pune - 411018, Maharashtra, India

[3]Department of Engineering Chemistry, Sagi Rama Krishnam Raju Engineering College, Bhimavaram - 534204, Andhra Pradesh, India

[4]Department of Engineering Mathematics, PCET's Pimpri Chinchwad College of Engineering and Research, Ravet, Pune - 412101, Maharashtra, India

[5]Department of Mechanical Engineering, MKSSS's Cummins College of Engineering for Women, Karvenagar, Pune - 411052, Maharashtra, India

[6]School of Engineering, Anurag University, Venkatapur, Ghatkesar, Medchal–Malkajgiri district, Hyderabad - 500088, Telangana, India

Abstract

This research delves into the operational performance and environmental impact of a single-cylinder diesel engine fueled with a 15 % blend of Nahar biodiesel (B15), derived from non-edible oil sources. The study scrutinizes critical engine parameters such as brake thermal efficiency, specific fuel consumption, exhaust gas temperature, and emissions of harmful pollutants like carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter (smoke opacity). Experimental results indicate that while the B15 blend exhibited a minor reduction in thermal efficiency at higher engine loads compared to conventional diesel, it demonstrated substantial improvements in emission reduction. The blend significantly lowered emissions of CO, HC, NOx, and smoke, contributing to a cleaner and healthier environment. Additionally, the combustion process was optimized, as evidenced by a shortened ignition delay, leading to more efficient fuel combustion. In conclusion, the research establishes the viability and sustainability of the Nahar biodiesel blend B15 as a promising alternative to conventional diesel fuel. Its ability to significantly reduce emissions without compromising engine performance to a significant degree underscores its potential to contribute to greener energy solutions and mitigate environmental impact. The findings suggest that B15 biodiesel can play a crucial role in advancing sustainable energy initiatives while ensuring acceptable engine efficiency levels.

Major Findings: *Biodiesel blends demonstrate higher Brake Thermal Efficiency (BTE) at low to mid loads, but their performance declines at high loads due to increased fuel consumption. The Brake Specific Fuel Consumption (BSFC) of biodiesel (B15) remains consistently higher than diesel, driven by its lower calorific value and higher viscosity. Despite these drawbacks, biodiesel offers significant environmental advantages, including lower exhaust gas temperatures (6-9 °C cooler)*

**Author for correspondence*

and reduced emissions of CO, HC, and NOx, attributed to its superior combustion efficiency and higher oxygen content. Additionally, biodiesel exhibits quicker ignition with shorter delays compared to diesel, enhancing atomization and combustion quality, which positions it as a promising cleaner alternative to conventional diesel fuel.

Keywords: Alternative Fuel, Co Emissions, Combustion, Diesel Engine, Emission Reduction, Hc Emissions, Nahar Biodiesel, Nox Emissions, Performance, Thermal Efficiency

1.0 Introduction

The rising global energy demand, coupled with environmental challenges associated with fossil fuel consumption, has heightened the urgency to develop sustainable and cleaner energy alternatives. Fossil fuels such as coal, oil, and natural gas have dominated global energy systems for centuries but are major contributors to air pollution, greenhouse gas emissions, and climate change. These environmental concerns have prompted researchers to explore renewable energy sources like solar, wind, and hydropower. Despite advancements, the transportation sector remains heavily dependent on fossil fuels, particularly diesel, highlighting the need for alternative liquid fuels. Biodiesel, a renewable biofuel produced via transesterification of vegetable oils or animal fats, offers a viable substitute. Produced from both edible and non-edible feedstocks, biodiesel provides environmental advantages such as reduced CO, HC, and particulate matter emissions, with non-edible sources like Nahar oil emerging as cost-effective and sustainable options.

Strict government emission standards, such as BS-IV (equivalent to Euro 6), are driving the need for cleaner and more efficient transportation solutions to reduce air pollution and combat climate change[1]. Nations heavily reliant on petroleum face significant challenges due to fluctuating prices, supply uncertainties, and environmental concerns. India, for instance, imports a substantial portion of its petroleum needs, further exacerbating these issues[2,3]. Biomass-derived fuels, particularly biodiesel, have emerged as promising alternatives to fossil fuels. Biodiesel, produced from renewable sources like non-edible oils, offers several advantages, including reduced greenhouse gas emissions, improved engine performance, and reduced dependence on fossil fuels[4,5]. By blending biodiesel with conventional diesel fuel, it is possible to achieve significant reductions in harmful emissions without major engine modifications[6-8].

India possesses a significant potential for biodiesel production from various non-edible oil sources, such as neem, castor, and karanji[10]. Biodiesel derived from *Calophyllum inophyllum* oil, also known as the Beauty Leaf Tree, shows promise as a sustainable fuel but faces challenges related to its oxidative stability[11]. To address the increasing thermal challenges faced by high-performance electronic devices, such as smartphones, researchers are exploring innovative cooling techniques. Phase Change Materials (PCMs) have emerged as a promising solution for efficient thermal management. By strategically integrating PCMs into electronic devices, it is possible to absorb and dissipate excess heat, preventing overheating and improving overall performance. Among the various PCMs studied, N-Eicosane has demonstrated exceptional cooling performance, significantly reducing operating temperatures and enhancing device reliability[12-16]. Additionally, researchers are developing innovative solutions to address global challenges, such as water scarcity and poor sanitation. A novel faucet design has been proposed to improve hygiene and conserve water in developing countries. By incorporating advanced features and ergonomic design, this faucet can help reduce water wastage and promote better sanitation practices[17]. The manufacturing industry is continuously seeking to improve the efficiency and sustainability of production processes. Hybrid Metal Matrix Composites (HMMCs) offer superior mechanical properties and lightweight advantages, making them ideal for applications in the automotive and aerospace industries. However, machining HMMCs presents unique challenges due to their complex material composition. By optimizing machining parameters and selecting appropriate cutting tools, it is possible to improve machining efficiency and surface quality[18]. Advancements in thermal management are crucial for various industries, including energy, electronics, and transportation. Techniques such as minijet impingement and twisted tape inserts can significantly enhance heat transfer in heat exchangers. In the

renewable energy sector, optimizing biodiesel-dimethyl carbonate blends and utilizing nanofluids can improve engine performance and thermal efficiency. Aerodynamic optimizations, achieved through CFD simulations and wind tunnel testing, can lead to significant improvements in the efficiency of wind turbines and aircraft[19-29]. Future research efforts will focus on further developing advanced heat transfer techniques, such as enhanced tape inserts and optimized wind turbine designs. Integrating PCMs into electronic components and selecting suitable substrate materials can further improve thermal performance. By combining these interdisciplinary approaches, researchers aim to develop innovative solutions for a wide range of thermal management challenges[30-38]. The mechanical behavior of curved structures is a critical consideration in various engineering applications. Recent studies have explored the impact of factors such as thickness, overlapping angle, and material properties on the strength and deformation of curved structures. By understanding these factors, engineers can design more robust and efficient structures[39-41]. Biodiesel blends have emerged as promising alternatives to conventional diesel fuel. Studies have shown that biodiesel derived from sources like mango seed, castor oil, and Camelina sativa can improve engine performance and reduce emissions. By optimizing engine parameters, such as injection timing, compression ratio, and Exhaust Gas Recirculation (EGR), it is possible to further enhance the performance and environmental benefits of biodiesel-fueled engines[42-50].

Biodiesel's renewable nature makes it a near-carbon-neutral fuel, as the CO_2 released during combustion is offset by the CO_2 absorbed during crop growth. Non-edible oils like Nahar oil, which are abundant and do not compete with food crops, are particularly promising. Biodiesel blends, such as B10, B15, and B20, have been found to reduce harmful emissions without compromising engine performance. Studies reveal that higher cetane numbers in biodiesel improve ignition and combustion characteristics, contributing to lower CO and particulate emissions. However, biodiesel production faces challenges such as feedstock costs, processing technologies, and land use, especially for edible oils. Advancements in esterification and transesterification processes, along with the adoption of non-edible feedstocks, can further enhance biodiesel's viability as a sustainable fuel for mitigating environmental impacts.

To overcome these challenges, researchers have focused on optimizing the production process and developing more efficient catalysts. In the case of non-edible oils such as Nahar oil, the high FFA content often necessitates a two-step process involving esterification followed by transesterification. The use of waste oils and non-food crops further alleviates the pressure on food production and land use, contributing to the overall sustainability of biodiesel production. This study investigates the performance and emissions of a single-cylinder diesel engine fueled with a 15 % biodiesel blend (B15) derived from Nahar oil. Biodiesel production involves transesterification, where triglycerides in oils react with alcohols (typically methanol or ethanol) in the presence of a catalyst, yielding biodiesel and glycerol as byproducts. For feedstocks high in Free Fatty Acids (FFAs), a preliminary step is required. The experimental results showed that the B15 blend significantly reduced emissions of CO, HC, NOx, and smoke opacity while maintaining comparable performance to conventional diesel. The blend exhibited enhanced combustion efficiency due to higher oxygen content, leading to a shorter ignition delay, though Brake Thermal Efficiency (BTE) was slightly lower at higher engine loads.

2.0 Experimental Setup

2.1 Engine Specifications

1. Engine Type: Four-Stroke, Four-Cylinder, Diesel Engine
2. Engine Make: Kirloskar
3. Cooling System: Water-cooled
4. Bore: 87.5 mm
5. Stroke: 110 mm
6. Compression Ratio: 16:1 to 20:1
7. Displacement Volume: 2.2 to 3.0 Liters
8. Maximum Power Output: 30 kW to 50 kW
9. Maximum RPM: 1500 - 3000 RPM

Before conducting the experiments, a thorough inspection was performed to ensure safety and precision. This included verifying the water supply for cooling, checking electrical connections, confirming adequate

Table 1. Properties of fuel and blend

Properties	B15	Diesel
Calorific Value (MJ/kg)	42.542	43
Density (g/cc)	0.842	0.836
Cetane Number	49.65	49.07
Pour Point (°C)	-7.8	-9.7



Figure 1. Actual setup.

lubrication, and eliminating air from the fuel line. The engine was started and fuel flow was monitored. Once the engine reached a stable idle speed, fuel consumption was measured. Subsequently, the engine was subjected to varying loads, and engine speed, fuel consumption, and load measurements were recorded. Exhaust gas analysis was carried out to determine the levels of CO, HC, and NOx emissions. A 15% biodiesel blend (B15) was prepared and used as fuel. These meticulous preparations and controlled experimental conditions were essential for obtaining reliable data on engine performance and emissions. The results and discussions, along with supporting plots, are presented in the following sections.

3.0 Results and Discussion

3.1 Brake Thermal Efficiency (BTE)

Biodiesel blends outperform diesel at low-mid loads

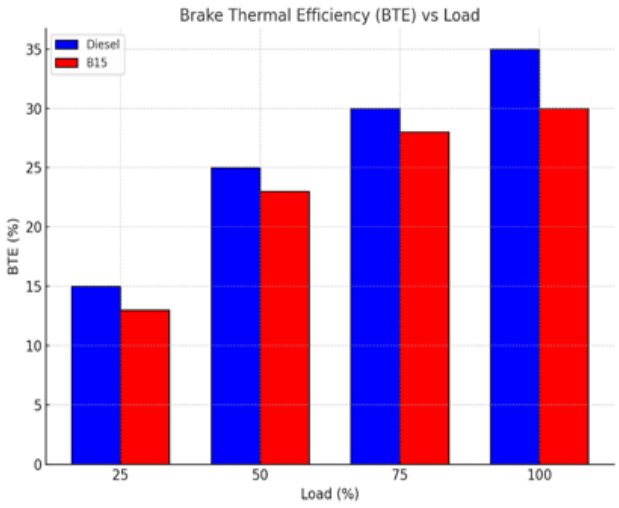


Figure 2. Load vs BTE efficiency.

(BTE: biodiesel > diesel). However, at high loads (75%, 100%), the blend's lower calorific value increases fuel consumption, reducing BTE (biodiesel: 32.56%, diesel: 33.49%). Despite this, the engine maintains satisfactory performance with reduced noise levels.

3.2 Brake Specific Fuel Consumption (BSFC)

Biodiesel blends (B15) consistently exhibit higher BSFC than diesel across all engine loads. This is attributed to lower heating value and higher viscosity, leading to less efficient combustion. At full load, BSFC is 3.6% higher

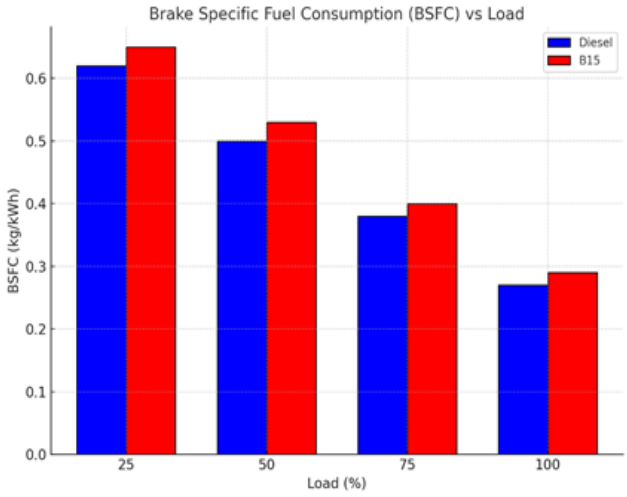


Figure 3. Load vs BSFC.

for B15, while at 25% load, it's 6.91% higher. Despite this, B15's lower friction losses due to lubricity improve BTE at low loads.

As engine load increases, the lower energy density of biodiesel blends (B15) hinders their ability to meet higher power demands. This leads to increased fuel consumption and higher BSFC. At full load, B15's BSFC is 0.267 kg/kWh, while diesel's is 0.260 kg/kWh.

3.3 Exhaust Gas Temperature (EGT)

EGT increases with engine load for both biodiesel blends and diesel. However, biodiesel consistently exhibits lower EGT. At full load, biodiesel is 6°C cooler than diesel. Overall, biodiesel is 7-9 °C cooler across all loads. This is due to lower temperature oxidation and improved combustion efficiency, reducing heat loss through the exhaust.

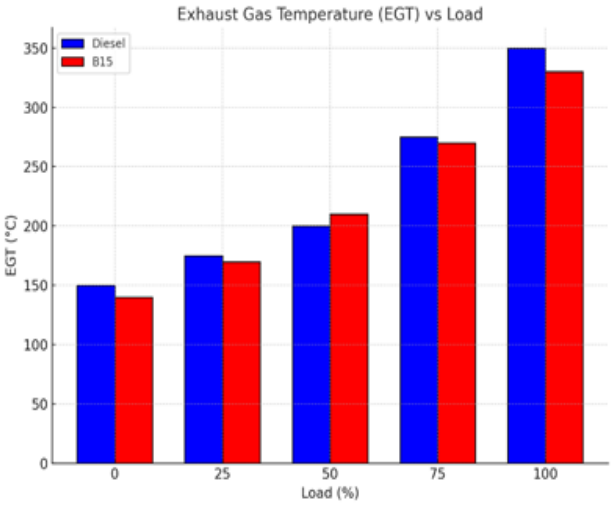


Figure 4. Load vs EGT.

3.4 Brake Specific Co Emission

BSCO emissions decrease with increasing engine load. At 25% load, BSCO is 42.3 g/kWh (diesel) and 32.52 g/kWh (biodiesel). At full load, it's 3.41 g/kWh (diesel) and 3.21 g/kWh (biodiesel). Higher combustion temperature improves atomization, leading to more complete combustion. Biodiesel's higher oxygen content further aids in reducing BSCO emissions, making it a promising alternative for cleaner combustion.

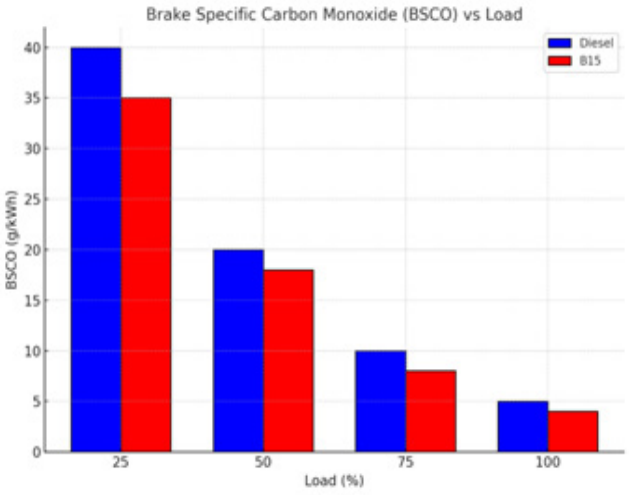


Figure 5. Load vs BSCO.

3.5 Brake Specific Hc Emission

BSHC emissions decrease with increasing load for both diesel and biodiesel (B15). Biodiesel consistently emits less BSHC. At 25 % load, BSHC is 0.1075 g/kWh (diesel) and 0.097 g/kWh (B15). At full load, it's 0.051 g/kWh (diesel) and 0.045 g/kWh (B15).

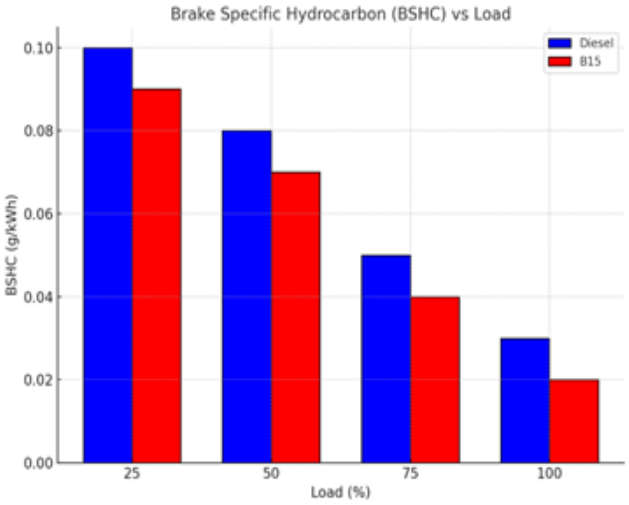


Figure 6. Load vs BSHC.

3.6 NOx Emission

Biodiesel blends (B15) consistently emit lower NOx across all loads compared to diesel. This is due to lower combustion temperatures. At full load, NOx is 964 ppm (B15) and 1035 ppm (diesel). While NOx

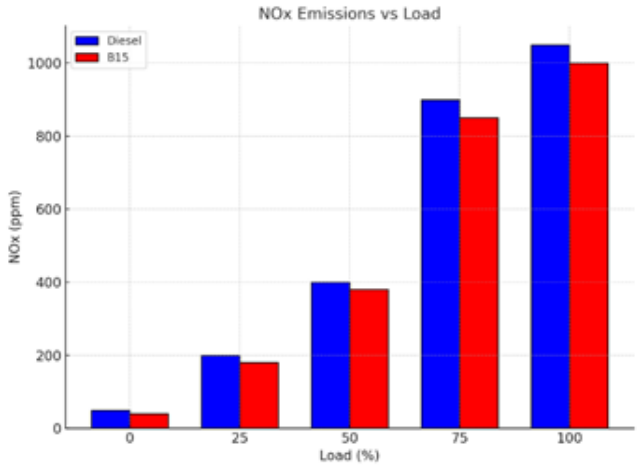


Figure 7. Load vs NOx emission.

generally increases with load due to higher combustion temperatures, biodiesel still offers lower NOx emissions.

3.7 Ignition Delay

Biodiesel blends ignite more quickly than diesel fuel at all engine loads. This is because biodiesel has a higher ignition index. As the engine load increases, both fuels ignite faster due to higher temperatures inside the cylinder. At full load, biodiesel ignites 9.8 degrees Crank Angle (CA) earlier than diesel, which ignites at 10.12 degrees CA. This demonstrates biodiesel's faster ignition characteristic.

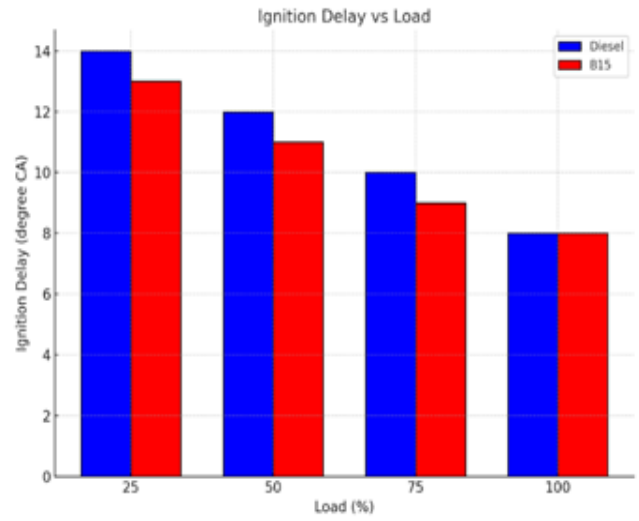


Figure 8. Load vs ignition delay.

4.0 Conclusions

Experimental tests on the performance of a 15 % Nahar biodiesel blend (B15) in an agricultural diesel engine revealed encouraging results. The blend showed promise as a cleaner and more efficient alternative to conventional diesel fuel.

4.1 Key Findings Include

Reduced Emissions: The B15 blend significantly lowered emissions of harmful pollutants, such as Carbon Monoxide (CO), Hydro-Carbons (HC), Nitrogen Oxides (NOx), and particulate matter, leading to improved air quality.

- Improved Combustion: The blend's shorter ignition delay resulted in faster and more complete combustion, enhancing engine performance and reducing fuel consumption at lower engine loads.
- Trade-offs at Higher Loads: While the blend performed well at lower to mid-range engine loads, it experienced a slight decrease in thermal efficiency and an increase in fuel consumption at higher loads.
- In conclusion, the Nahar B15 biodiesel blend offers a sustainable and environmentally friendly option for agricultural diesel engines, especially under lower to mid-load conditions. Further research and optimization efforts are necessary to address the performance trade-offs observed at higher loads and fully unlock the potential benefits of this biofuel.

5.0 Author's Contribution

Anant Sidhappa Kurhade: Conceptualization, Methodology design, Supervision, Writing – original draft, Review & Editing, Manuscript editing, Referencing, Final proofreading. P. Bhavani: Conceptualization, Methodology design, Supervision, Writing – original draft, Review & Editing, Manuscript editing, Referencing, Final proofreading. Shital Anant Patil: Experimental investigation, Data curation, Visualization, Formal analysis. Nilesh R. Kolhalkar: Literature review, Validation, Manuscript refinement, Referencing, Test setup calibration. Kolluri Srinivasa

Chalapathi: Conceptualization, Methodology design, Supervision, Test setup calibration, Data acquisition. Prashant Ashok Patil: Conceptualization, Methodology, Software, Graphical plotting, Result interpretation. Shital Yashwant Waware: Emissions analysis, Statistical evaluation, Discussion framing, Manuscript editing, Referencing, Final proofreading.

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