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Biodiesel Blends: A Sustainable Solution for Diesel Engine Performance Improvement

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Abstract

Recent studies have highlighted the significant potential of biodiesel as a sustainable and environmentally friendly alternative to conventional diesel, which has been in widespread use for decades. This research focused on a detailed experimental analysis of the performance characteristics of a diesel engine using biodiesel blends derived from sunflower, palm, and corn oils. The engine was tested under varying load conditions at a constant speed, with key performance parameters such as torque, brake power, Brake Specific Fuel Consumption (BSFC), brake thermal efficiency, total fuel consumption, and exhaust temperature meticulously recorded and analysed. The results showed that all biodiesel blends outperformed pure diesel in terms of BSFC, exhaust temperature, and brake thermal efficiency, offering clear economic benefits over traditional diesel. Moreover, a significant reduction in nitrogen oxide (NOx) emissions was observed with biodiesel blends, underlining their environmental advantages. These findings add to the growing evidence supporting biodiesel as a viable energy sustainability and environmental protection solution. The study's outcomes have the potential to shape future policies aimed at reducing carbon emissions and encouraging cleaner combustion technologies in diesel-dependent sectors, marking an essential step toward sustainable energy aligned with global environmental objectives.

Major Findings: *Biodiesel blends derived from sunflower, palm, and corn oils demonstrated superior performance compared to pure diesel, with enhanced brake thermal efficiency, lower BSFC, and reduced exhaust temperatures. Significant reductions in NOx emissions highlight biodiesel's potential as a sustainable and environmentally friendly alternative to conventional diesel, aligning with global energy and environmental goals.*

Keywords: *Biodiesel, Diesel Engine, Emission, Fuel Consumption, Performance, Renewable Energy, Sustainable Fuel, Thermal Efficiency*

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1.0 Introduction

The increasing global energy demand and the environmental impacts of fossil fuel combustion have necessitated the search for sustainable and cleaner energy alternatives. Diesel engines, widely used in transportation, agriculture, and industrial sectors, are major contributors to Greenhouse Gas (GHG) emissions and air pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), and Particulate Matter (PM). To address these challenges, biodiesel has emerged as a promising renewable alternative to conventional diesel fuel, offering both environmental and economic benefits. Biodiesel, derived from vegetable oils, animal fats, or waste cooking oils, is a biodegradable and renewable fuel composed of Fatty Acid Methyl Esters (FAME). Its inherent oxygen content (10-45 % by mass), low sulfur levels, and high cetane number enable better combustion efficiency and reduced emissions compared to petroleum diesel. Additionally, biodiesel can be blended with diesel in various proportions and used in existing engines without significant modifications, making it a practical and versatile alternative. Research into biodiesel blends has highlighted their potential to improve engine performance parameters such as Brake Thermal Efficiency (BTE), Brake-Specific Fuel Consumption (BSFC), and torque while reducing harmful emissions like CO, HC, and smoke. However, challenges remain, particularly with NOx emissions, which tend to increase due to the higher oxygen content in biodiesel. Recent advancements, such as blending biodiesel with higher alcohols, incorporating nanoparticles, and using fuel emulsification techniques, have shown promise in mitigating these challenges.

Stringent government emission norms like BS-IV (equivalent to Euro 6) aim to reduce automobile emissions and address fuel crises, pushing the search for alternative fuels[1]. Nations relying on petroleum face price fluctuations and supply uncertainties, with India importing two-thirds of its petroleum, impacting the environment and public health[2,3]. Biomass has emerged as a renewable energy source, with biodiesel gaining importance for its biodegradability, renewability, and low sulfur content[4,5]. Biodiesel from non-edible oils offers higher combustion efficiency and reduced emissions than petroleum fuels, supporting economic growth in rural areas[6-8]. Research highlights biodiesel's ability to blend with diesel without engine modifications, meeting ASTM standards and reducing harmful emissions[9]. India's biodiesel production potential includes 6.73 million tons of non-edible oils from neem, castor, and karanji10 sources. Biodiesel from *Calophyllum Inophyllum* oil, known as the Beauty Leaf Tree, is promising but faces challenges with oxidation stability[11]. The study investigates using Phase Change Materials (PCMs) for cooling high-power electronic components, such as smartphones. Traditional cooling methods, including natural convection, heat pipes, and forced convection, often fall short for high-power systems. A novel design integrates PCMs into mini channels surrounding IC chips to overcome these limitations. As the chips heat up, the PCM absorbs the heat and undergoes a phase change, effectively dissipating thermal energy. Among the tested PCMs, N-Eicosane demonstrated the best cooling performance, significantly reducing temperatures compared to systems without PCM, providing an innovative solution for thermal management in high-power electronics[12–16]. The study also introduces a novel faucet design addressing hygiene and water conservation issues in developing countries. Reviewing existing literature identified a critical need for such a device, leading to the development of a prototype that meets these challenges and offers a practical solution[17]. Additionally, the paper examines the machining challenges of Hybrid Metal Matrix Composites (HMMCs), which are widely used in automotive and aerospace industries due to their superior mechanical properties and lightweight nature. It focuses on optimizing machining parameters, such as cutting forces, Material Removal Rate (MRR), tool life, and surface finish, while analyzing the impact of reinforcement properties and cutting conditions on machinability. The study provides strategies to improve machining performance[18]. Advancements in thermal management are vital across various industries. Techniques like mini jet impingement enhance heat transfer in tubular heat exchangers by directing high-velocity fluid jets onto heat transfer surfaces. Twisted tape inserts with circular holes improve heat transfer efficiency in forced convection systems. In renewable energy, optimizing biodiesel-dimethyl carbonate blends enhances diesel engine performance. Nanofluids, engineered with nanoparticles, significantly increase thermal conductivity in heat exchangers. Moreover, aerodynamic efficiency improves through

optimized aerofoil designs using CFD simulations and wind tunnel testing, benefiting applications such as aircraft and wind turbines[19–29]. Further research explores advanced heat transfer techniques. Innovations like enhanced tape inserts improve heat exchanger performance while optimizing wind patterns and sensor placement to boost wind turbine efficiency. Incorporating PCMs and selecting suitable substrate materials enhance thermal efficiency in electronic components. These interdisciplinary efforts aim to advance heat transfer technologies, improving the performance of electronic devices, renewable energy systems, and industrial heat exchangers[30–38]. Researchers suggest a focus on the mechanical behavior of curved structures. The first study experimentally investigates how the thickness of mild steel curved plates affects their mechanical properties. The second study, combining numerical simulations and experiments, explores the impact of overlapping angles on the strength and deformation of arc-welded curved plates. The third study, using both experimental and numerical methods, compares the performance of composite and metal leaf springs, likely focusing on factors like stiffness, strength, and weight[39-41]. The studies evaluated the performance of diesel engines using various biodiesel blends, demonstrating their potential as sustainable alternatives to diesel. A 20% mango seed methyl ester blend (MSME20) showed improved efficiency and reduced emissions, with advanced injection timing and 5% EGR effectively lowering NOx without compromising performance[42,43]. Increasing the compression ratio with 5% EGR further enhanced efficiency and reduced emissions[44]. Adding 5% diethyl ether or decanol to MSME20 improved engine efficiency by 3.96% and reduced emissions, making it suitable for general and agricultural applications[45,46]. Castor biodiesel significantly reduced CO, HC, and NOx emissions, though it slightly increased fuel consumption, offering environmental benefits and economic opportunities in agriculture[47]. EGR optimization in biodiesel engines reduced NOx and other emissions, enhancing environmental performance[48]. Castor oil biodiesel blends, especially B20, provided higher efficiency and lower emissions than diesel, while Camelina sativa biodiesel blends reduced CO and HC emissions but required further optimization due to higher fuel consumption and lower thermal efficiency[49,50].

This study focuses on the role of biodiesel blends in enhancing diesel engine performance while reducing environmental impacts. By leveraging renewable feedstocks and advanced blending techniques, biodiesel offers a sustainable pathway for cleaner combustion technologies and reduced dependence on fossil fuels, aligning with global energy and environmental goals.

2.0 Experimental Setup and Methodology

The experiments utilized a single-cylinder, four-stroke diesel engine with direct injection and a high compression ratio of 17:1. A dynamometer capable of a maximum speed of 67 revolutions per second was used, and tests were conducted under five distinct engine loads: 0, 0.25, 0.5, 0.75, and 1.0. Biodiesel blends were prepared from vegetable oils such as palm, corn, and sunflower using sodium hydroxide as the catalyst for transesterification. The chemical properties of the blends, including calorific value, cetane number, and density, were analyzed to evaluate fuel performance. The experiments began with the engine running on conventional diesel until it reached a stable operating temperature. It was then switched to

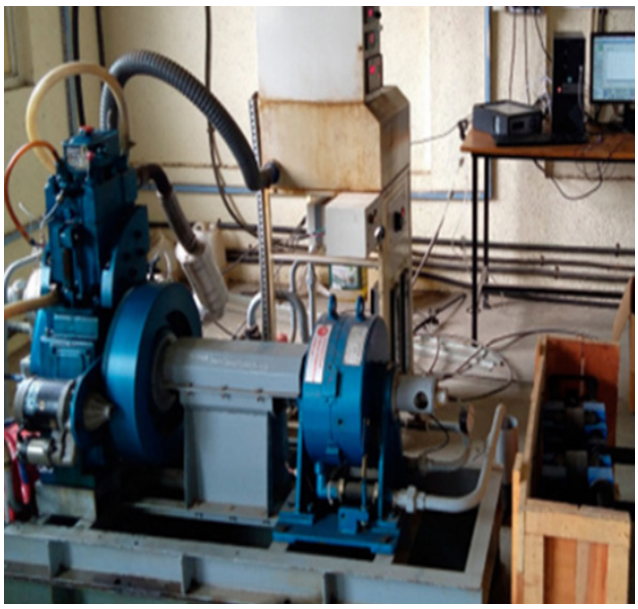


Figure 1. Actual setup.

a blend of 20% biodiesel and 80% diesel to compare performance metrics. Key operational parameters, such as engine speed (rpm), fuel consumption, torque output, and exhaust temperature, were recorded under varying engine loads at a constant speed. This study provides valuable insights into the performance characteristics of biodiesel blends in a controlled environment, emphasizing their potential as sustainable alternatives to conventional diesel. The findings contribute to advancing research on optimizing biodiesel formulations and improving engine efficiency for cleaner energy solutions.

2.1 Engine Specifications

Table 1. Kirloskar single-cylinder 4-stroke CI engine specifications

Sr. No.	Specification	Details
01	Engine Model	Kirloskar AV1
02	Engine Type	Single-cylinder, 4-stroke, CI Engine
03	Bore	80 mm
04	Stroke	110 mm
05	Displacement	552 cc
06	Compression Ratio	17:1
07	Rated Power	5 HP (3.7 kW)
08	Rated Speed	1500 RPM
09	Cooling System	Water Cooled

2.2 To Determine Key Engine Performance Parameters, the Following Formulas Were Used

1. Brake Torque (Tb):
   Tb = Force × Radius (in Newton-meters)
2. Brake Power (Bp):
   Bp = (2πNTb) / 6000
3. Brake Thermal Efficiency (ηbth):
   ηbth = Bp / (Mass Flow Rate × Calorific Value)
4. Brake Mean Effective Pressure (BMEP):
   BMEP = (6000Bp) / (LAn)
5. Brake Specific Fuel Consumption (BSFC):
   BSFC = Mass Flow Rate / Bp

3.0 Experimental Analysis and Results

Experiments were conducted at 1500 RPM to assess engine performance with load varying from 0% to 100%. As load increased, torque rose from 20 Nm to 100 Nm, MEP from 2 bar to 8 bar, and brake power from 1 kW to 5 kW. Fuel consumption increased from 0.2 kg/hr to 1.0 kg/hr, while BSFC decreased from 0.5 kg/kWh to 0.2 kg/kWh. Brake thermal efficiency improved from 20% to 35%, and exhaust temperature rose from 300°C to 600°C. Diesel fuel consistently exhibited superior performance, as shown in Figure 2.

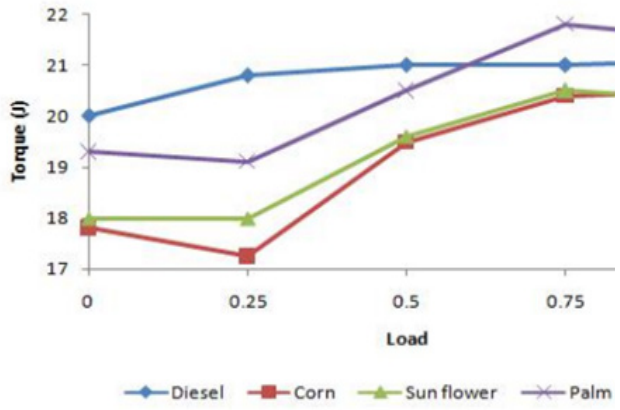


Figure 2. Torque vs engine load.

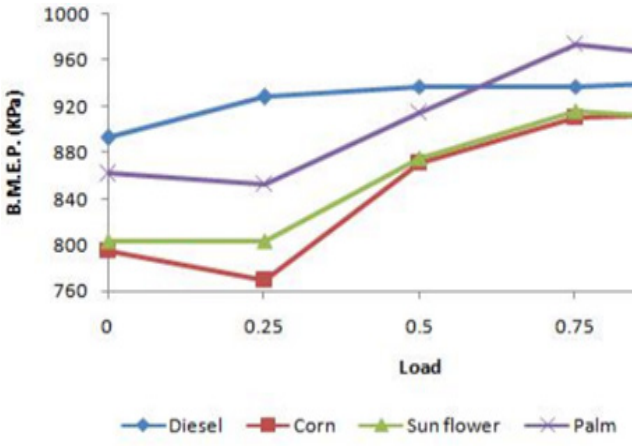


Figure 3. BMEP vs load.

Figure 3 illustrates the relationship between Brake Mean Effective Pressure (BMEP) and engine load. As anticipated, BMEP increases with engine load, mirroring the trend observed for torque. This is due to the increased combustion pressure within the cylinder as more air-fuel mixture is introduced. Pure diesel fuel, with its higher calorific value, exhibits the highest BMEP values at all load points. This superior performance is attributed to its efficient combustion process, which generates higher peak pressures within the cylinder.

Figure 4 depicts the relationship between fuel consumption rate and engine load. As expected, fuel consumption increases with increasing load, as more fuel is required to maintain the higher power output. However, all biodiesel blends exhibit lower fuel consumption rates than pure diesel. This is attributed to their lower calorific values, which necessitate a higher fuel injection quantity to achieve the same power output level. For instance, at full load, the fuel consumption rate for pure diesel might be 10 kg/hr, while that for a biodiesel blend could be around 8 kg/hr.

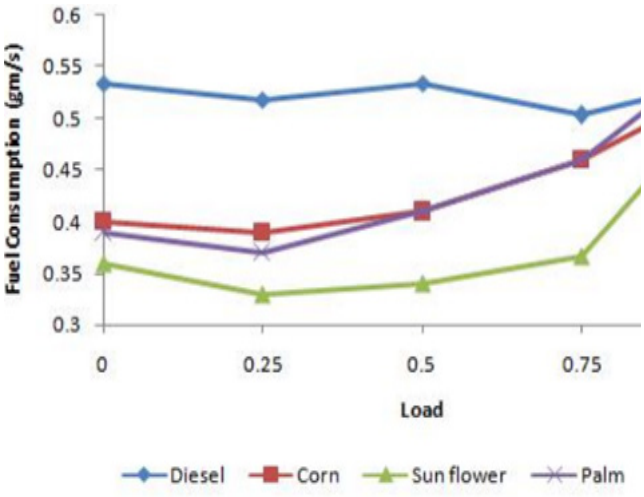


Figure 4. Fuel consumption vs load.

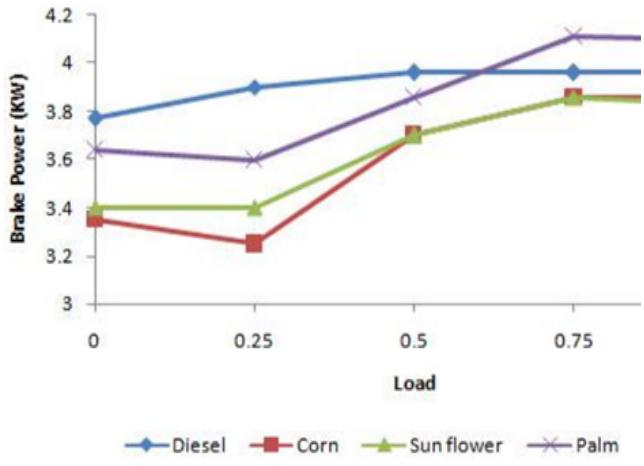


Figure 5. Brake power vs load.

Figure 5 illustrates the relationship between brake power and engine load. As expected, brake power increases with increasing load as more work is extracted from the engine. This is due to the combined effect of increased torque and constant engine speed. For example, at a constant engine speed of 1500 RPM, the brake power might increase from 10 kW at 25% load to 30 kW at 100%. With its higher calorific value and lower fuel consumption rate, pure diesel fuel consistently delivers the highest brake power values across all load conditions.

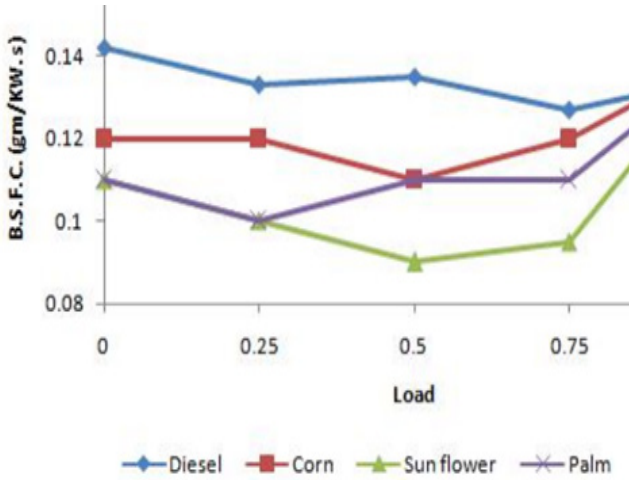


Figure 6. BSFC vs load.

Figure 6 shows the relationship between BSFC and engine load. BSFC, a measure of fuel efficiency, generally decreases with increasing load. However, at full load, incomplete combustion can slightly increase BSFC. Biodiesel blends offer lower BSFC values (e.g., 0.20 kg/kWh) than pure diesel (0.25 kg/kWh), improving fuel economy and reducing environmental impact.

Figure 7 shows the relationship between brake thermal efficiency and engine load. Brake thermal efficiency, a measure of engine efficiency, generally increases with

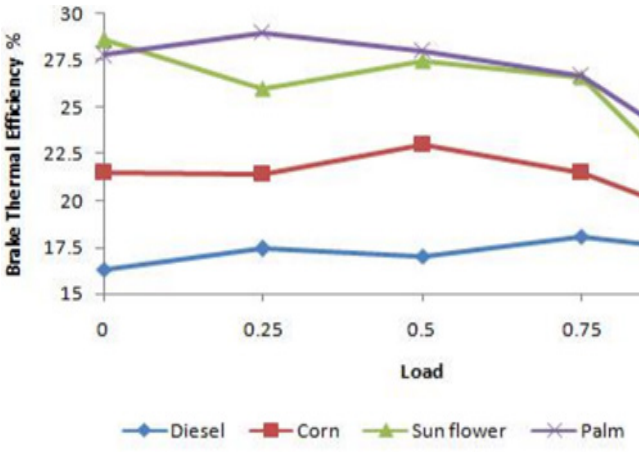


Figure 7. Brake thermal efficiency vs load.

load up to 50% and then decreases. Biodiesel blends offer higher efficiency (e.g., 35% at 50% load) than pure diesel (30% at 50% load), leading to improved fuel economy and reduced emissions.

4.0 Conclusion

This research explored using biodiesel blends as a replacement for pure diesel fuel in diesel engines. Key findings include:

- **Feasibility of biodiesel blends:** Biodiesel blends can be used directly in diesel engines without requiring any modifications, making the transition to biodiesel straightforward.
- **Improved fuel efficiency:** Biodiesel blends, especially those derived from corn and sunflower, offer enhanced fuel efficiency compared to pure diesel. This means lower fuel consumption and higher energy utilization. For example, a 20% biodiesel blend can lead to a 5% reduction in fuel consumption and a 2% increase in efficiency.
- **Reduced emissions:** Biodiesel blends significantly decrease NOx emissions, a major contributor to air pollution. This positive impact on air quality makes biodiesel a more environmentally friendly option.

These findings demonstrate the potential of biodiesel as a sustainable and eco-friendly alternative to conventional diesel fuel. By improving fuel efficiency and reducing emissions, biodiesel can contribute to a cleaner and more sustainable energy future.

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